From: Hanks, Katie P.
To: Ohrel, Sara; Baker, Justin; Justin Baker
Sent: 11/17/2014 10:19:13 AM
Subject: RE: residues
Attachments: Wood_residuals_nonfuel_fate_v3.docx

This is the latest version I have which responds to Sara's comments.

Katie Hanks
RTI International
3040 Cornwallis Road
Research Triangle Park, NC 27709
(919) 316-3732
(919) 541-7155 (fax)

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Sunday, November 16, 2014 2:17 PM
To: Baker, Justin; Justin Baker; Hanks, Katie P.
Subject: FW: residues

This is the last version I have – thanks!

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org); Latane, Annah; Cole, Jefferson
Sent:	11/16/2014 3:26:19 PM
Subject:	app D - deliberative
Attachments:	Appendix_D_Feedstock Categories 11 16 14 DF.docx; Appendix_D_Feedstock Categories_11_13_14so.docx

For your records, tracked and clean

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Justin Baker
Sent: 11/16/2014 1:08:40 PM
Subject: FW: --Deliberate-- App K
Attachments: Appendix_K_Anticipated Baseline Construction Methods_11_13_14_aml_clean so clean.docx

Hi Justin,
Before you leave today, can you please check this one word? Then I can finalize this one.
Thanks!

From: Ohrel, Sara
Sent: Saturday, November 15, 2014 5:07 PM
To: 'Latane, Annah'; Cole, Jefferson
Cc: Baker, Justin
Subject: RE: --Deliberate-- App K

Hi all,
Here is app k; needed to update the TOC and found a few other edits. Tracked and clean attached. JB, there is one comment in the clean version, can you check to make sure the word I inserted is correct?
Thanks!

From: Latane, Annah [mailto:alatane@rti.org]
Sent: Friday, November 14, 2014 3:26 PM
To: Ohrel, Sara; Cole, Jefferson
Cc: Baker, Justin
Subject: --Deliberate-- Apps I, J,K

Sara and Jeff,

Here are I, J, and K back to you with edits made and clean versions. H is in process.

Cheers,
Annah

--this email and its content are deliberative--do not distribute or cite--
Annah M. Latané
Environmental Economist
Center for Environmental, Technology, and Energy Economics
RTI International
919.541.5976
www.rti.org
Email: alatane@rti.org

From: Ohrel, Sara
To: Baker, Justin
Sent: 11/15/2014 5:24:12 PM
Subject: RE: Checking in - deliberative
Attachments: Framework for Assessing Biogenic CO2 Emissions_11_11_14so.docx

Here is my most recent version (made a few edits since last one I sent). I recommend that for your review and comments, you clean this version so there are no tracked changes or comments so that we can easily see what you edit/comment on so we can merge your stuff back into my working version once you are done.
Sound good?

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Saturday, November 15, 2014 2:13 PM
To: Ohrel, Sara
Subject: RE: Checking in

Hi Sara,

It will be tonight at the earliest, but most likely tomorrow.

I will send you an email letting you know.

Justin

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Saturday, November 15, 2014 1:59 PM
To: Baker, Justin
Subject: Checking in

Hi JB, please let me know when you pick up the main doc. I have an idea for version control.
Thanks!

From: Ohrel, Sara
To: Justin Baker (justinbaker@rti.org); Latane, Annah; Cole, Jefferson
Sent: 11/15/2014 5:21:40 PM
Subject: Draft finals of Apps A, C, F, H, I, J and project status list - DELIBERATIVE
Attachments: Appendix_A_IPCC_Emissions Inventory 11 14 14 DF.docx; Appendix_C_Spatial Scale 11 15 14 DF.docx; Appendix_F_General Algebraic Representation 11 15 14 DF.docx; Appendix_H_RefPt LandscapeAtts 11 15 14 DF.docx; Appendix_I_Ref Pt CaseStudies 11 15 14 DF.docx; Appendix_J_Anticipated Baselines Background 11 15 14.docx

HI all,
Here is what I have so far, in terms of cleaned and draft final versions (though I may ask Jeff or Allen to review app J if time allows).

Also, here is the project status list in terms of what I know of at this point:

Ex. 5 - Deliberative

THANKS!

Sara Bushey Ohrel

Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Justin Baker (justinbaker@rti.org)
Sent: 11/15/2014 10:50:19 AM
Subject:
Attachments: NWF-SE-Carbon-Study.pdf

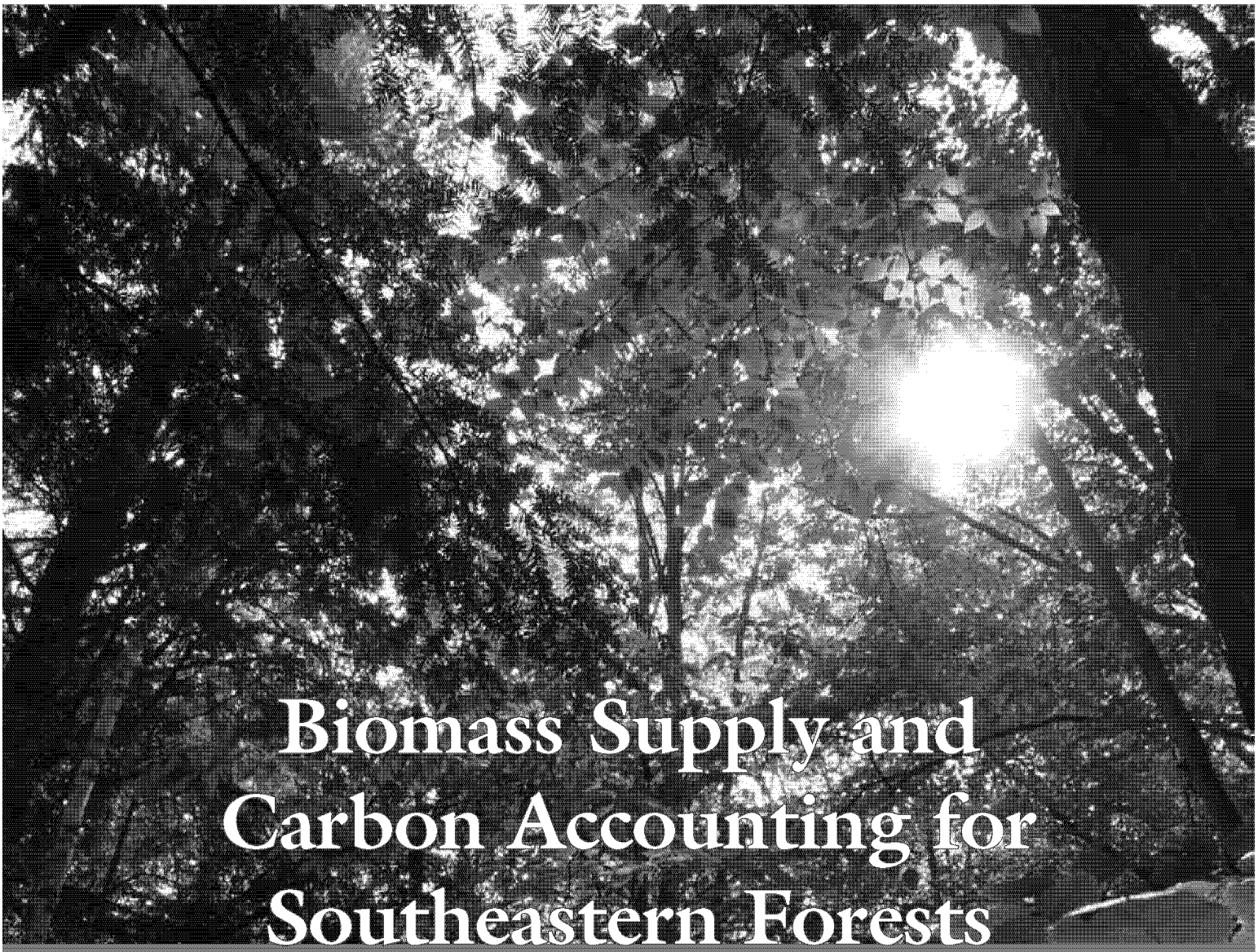
For a FABA baseline and time, maybe NWF SE study

Also for the main doc and possibly FABA apps, we should **Ex. 5 - Deliberative**

Ex. 5 - Deliberative

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--



Biomass Supply and Carbon Accounting for Southeastern Forests

February 2012

ACKNOWLEDGEMENTS

This Biomass Supply and Carbon Accounting for Southeastern Forests study was conducted by the Biomass Energy Resource Center, the Forest Guild, and Spatial Informatics Group. The members of the study team included:

Andrea Colnes
Biomass Energy Resource Center

Kamalesh Doshi
Biomass Energy Resource Center

Hillary Emick
Biomass Energy Resource Center

Dr. Alexander Evans
Forest Guild

Robert Perschel
Forest Guild

Dr. Tim Robards
Spatial Informatics Group

Dr. David Saah
Spatial Informatics Group

Adam Sherman
Biomass Energy Resource Center

The study was conducted on behalf of the National Wildlife Federation and Southern Environmental Law Center, whose project team included:

David Carr
Southern Environmental Law Center

Eric Palola
National Wildlife Federation

Frank Rambo
Southern Environmental Law Center

Julie Sibbing
National Wildlife Federation

The study was funded by the Doris Duke Charitable Foundation through a generous grant to the National Wildlife Federation and Southern Environmental Law Center. The study and project teams are grateful for their support.

We would like to thank several experts for their time, helpful input, and review comments:

Colin High
Resource Systems Group

Daniel Markowitz
Warnell School of Forestry and Natural Resources, The University of Georgia

William Schlesinger
Cary Institute

John Gunn
Manomet Center for Conservation Sciences

The views and conclusions contained in this report are those of the authors and should not be interpreted as representing the opinions or policies of the reviewers.

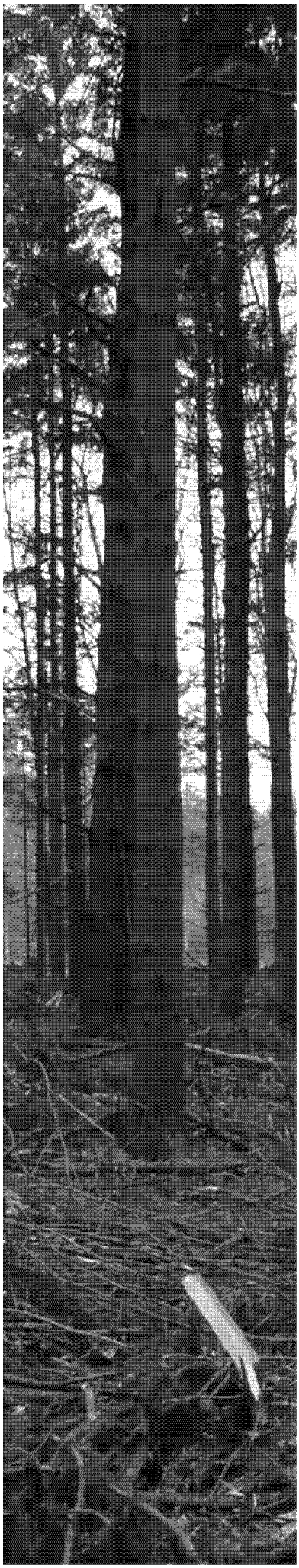
BERC
Renewable • Reliable • Resourceful
Biomass Energy Resource Center

• forest GUILD •

SIG
SPATIAL INFORMATICS GROUP

Unless otherwise noted, all pictures Biomass Energy Resource Center and used for illustrative purposes only.

© Copyright February 2012 Biomass Energy Resource Center. All rights reserved.



Biomass Supply and Carbon Accounting for Southeastern Forests • February 2012

CONTENTS

EXECUTIVE SUMMARY 4

INTRODUCTION 12

I. WOOD SUPPLY REVIEW 20

1.1.0 Introduction 20
1.2.0 Scope of Study and Methods 20
1.3.0 Annotated Bibliography 22
1.4.0 Apples-to-Apples Biomass Resource Assessment of Seven-State Region 33
1.5.0 Assessment of the Renewable Portfolio Standards 36
1.6.0 Review of Federal Renewable Fuels Standard 44
1.7.0 Conclusions 45

II. TECHNOLOGY PATHWAYS 48

2.1.0 Introduction to Technology Pathways 48
2.2.0 Summary of Pathways 54
2.3.0 Efficiency 58
2.4.0 Carbon Impacts 60
2.5.0 N_2O Impacts 64

III. ATMOSPHERIC CARBON ANALYSIS 66

3.1.0 Summary 66
3.2.0 Introduction 67
3.3.0 Methodology 68
3.4.0 Findings 89
3.5.0 Policy Challenges 107

IV. CONCLUSIONS 110

Overall 110
Wood Supply 110
Carbon Life-Cycle Analysis 112
Policy Implications 115

END NOTES 118

WORKS CITED 120

APPENDICES 123

Appendix A. Technology Pathways Database
Appendix B. Forest Growth Simulation

EXECUTIVE SUMMARY

It is important to note that due to the emphasis in the Southeast on biomass electric power production, this study examines only the use of biomass for large-scale electric power generation (and electric-led combined heat and power, or CHP).

As climate change policy develops, forest biomass is consistently recognized as an alternative fuel with the potential to replace fossil fuels and mitigate the build-up of atmospheric carbon. In response to these issues, the southeastern United States has seen recent interest in significantly expanding the biomass energy sector, including building new power plants, co-firing with coal power in existing plants, pellet manufacture for export to Europe, and producing cellulosic ethanol. While some look to these developments and see promise, others look with great concern at pressures on the region's forests, implications for forest health and sustainable wood supply, and impacts on cumulative greenhouse gas emissions.

Until recently, governmental policies have almost unanimously reflected the opinion that energy from biomass is beneficial from a greenhouse gas (GHG) perspective. Biomass typically is included in energy portfolios as a renewable energy source in the same classification as wind and solar and is eligible for the same public incentives and subsidies. Starting in the early to mid 1990s, however, a number of studies looked more closely at the net GHG benefits of burning biomass and resulted in refined calculations of benefits depending on site factors, forest growth modeling, and timing of emissions and sequestration (Manomet, 2010). In the past few years, direct challenges to the accuracy of accounting approaches spurred a rethinking of carbon accounting for biomass (Searchinger, 2009).

As part of this emerging research, the US Environmental Protection Agency (EPA) is revisiting the premise that burning biomass for energy is carbon neutral in the context of the natural carbon cycle of the earth (EPA, 2011) and is considering regulating carbon emissions from biomass combustion. This study provides an example of how the "comparative" approach can be used for a specific region. It can be further evaluated by EPA to inform its criteria for an "accounting framework for biogenic CO_2 emissions from stationary sources."

KEY QUESTIONS

To address these complex issues as relevant to southeastern forests, this study seeks to address two key questions relevant to the biomass electric power sector in this region of the country:

- How much biomass (primarily wood) is available on a sustainable basis to source the expanding southeastern biomass electric power sector? And, what is the potential of public policy to create demands that exceed sustainable supply levels?
- How will the increased use of forest biomass for electric power generation in the Southeast affect atmospheric carbon over time, and how does biomass energy compare to several fossil fuel energy alternatives in terms of cumulative GHG emissions over time?

It is important to note that due to the emphasis in the Southeast on biomass electric power production, this study examines only the use of biomass for large-scale electric power generation (and electric-led combined heat and power, or CHP). Thermal energy pathways were not examined and due to their much higher efficiencies, these thermal technologies would have significantly shorter carbon payback periods and different overall impact on atmospheric carbon levels when compared to fossil fuel technologies (Manomet, 2010).

WOOD SUPPLY REVIEW

To assess the potential for sustainably harvested biomass (primarily wood) to fuel an expanded biomass energy sector in the Southeast, the study presents a literature review of several key biomass resource assessments conducted to date, examines the current and possible future energy policies that could drive the expansion of biomass energy development, and compares the supply with this potential demand. This portion of the study has three main parts:

1. assessment of the biomass resource literature for the seven-state region
2. examination of the energy policies in the seven-state region
3. comparison of the resource supply to the potential demand

The study does not present new primary fuel-supply analysis, but is based on a review of existing information. Main findings include the following points:

- Most studies conducted in the past six years quantify the gross or total amount of woody biomass material generated on an annual basis and do not quantify how much is already being used. Most of these studies focus on residues produced from other primary activities while evidence suggests nearly all the mill and urban wood residues are already used by existing markets.
- The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).
- Whether logging slash, whole trees, or pulpwood will be used in the expansion of biomass energy in the Southeast will depend on the following:
  1. Which market the wood is going to (pellet mills need high-quality fiber from pulpwood while biomass plants are less particular about quality)
  2. How much demand increases within the pellet and power market sectors over time
  3. What happens with the pulp and paper industry in the southeast region in the future
- Prior to 2009, most fuel availability studies presented estimates of supply without any acknowledgment of the influence price has on the availability of these woody biomass resources. Since then, different studies have examined the economics using different indicators—making it difficult to compare results among the studies. For a clear assessment of the economics of woody biomass resources, the total delivered price paid by the receiving facilities is the best indicator to use.
- Various studies reviewed in this chapter used widely divergent assumptions regarding what percentage of the total amount of logging residue can be recovered from a harvested area. While the range observed in the literature was from roughly 50-100 percent, it should be noted that there is a difference between how much residue *can* be recovered and how much *should* be recovered when ecological factors are taken into account. While examining how much wood fuel could be generated if 100 percent of this material was recovered is useful for academic purposes, it is unrealistic to assume that such a high level can and should be realized. Ideally, studies would look at two critical issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered.

It should be noted that there is a difference between how much [logging] residue *can* be recovered and how much *should* be recovered when ecological factors are taken into account.

EXECUTIVE SUMMARY *(cont'd)*

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood.

- The availability of logging residues will largely depend on extraction methods. Where whole-tree harvesting systems can be used, these residues can be cost effectively accessed, however, the potential ecological effects of whole-tree logging need to be considered. Where mechanized cut-to-length and manual stem-only harvesting are used, these residues will not be easily accessible. Further analysis that determines how much whole-tree harvesting systems versus stem-only harvesting systems are used across this region would be very useful.
- Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential. In contrast, Alabama and Tennessee both had very little publicly available reports estimating biomass resources.
- Evidence suggests that there is likely enough wood to meet a 15 percent federal Renewable Energy Standard (RES) applied to each of the seven states (with the exception of Florida) when woody biomass sourced from local forests accounts for no more than 20 percent of the overall renewable electric generation target (or 3 percent of electricity supplied). It also appears, however, that adequate wood fuel resources are quite sensitive to the RES allocation. For example, if 30 percent of a 15 percent RES was allocated to forest biomass, it is likely there would not be enough wood fuel available within the region. A more aggressive RES standard for biomass leads to a higher likelihood of shortages and a greater probability of pulpwood displacement.
- Capacity to access and utilize residues is also a function of how much roundwood harvest occurs. More demand for roundwood generates more residues. The extent to which biomass power plants transition their wood procurement away from residues and toward roundwood is governed by the strength of the rest of the forest products industry. If the forest products industry strengthens as a result of greater lumber demand, it will increase its wood fiber consumption and as a result, biomass power plants would procure more residues at a lower cost and less pulpwood at a higher cost. If the forest products industry as a whole continues to contract, however, biomass power plants will likely transition toward procurement of chipped fuel from whole trees assuming they can absorb the higher cost associated with that transition.

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood. Therefore, pellet mills and biomass power plants have somewhat complementary (almost symbiotic) procurement needs. Pellet production, especially the export market to Europe, will continue to play the wild card role in future wood fuel markets.

- The supply review performed as part of this study does not directly address potential ecological impacts of biomass energy sourcing. Additional analysis will be necessary to assess these impacts on other forest resources and values.
- The potential recovery rate for harvest residue is a key variable in determining the quantity of available wood fuel. Further research is needed to assess both the current achievable residue recovery rates and reasonable future recovery rates. Projected recovery rates need to consider woody biomass retention rates to meet wildlife and biodiversity, water quality, and soil productivity needs.

While this report has identified and probed some of the issues regarding the forest resource's capacity to produce more energy in the Southeast, there are numerous areas where key information is missing. More specific research is needed in the areas of: existing forest residue utilization, use of different harvesting systems, a comprehensive wood fiber assessment for the entire seven-state region, the price elasticity of demand between fuel chips and pulpwood, and the likely impacts of federal renewable energy standards on the economic incentives that drive project development.

ATMOSPHERIC CARBON ANALYSIS

To examine the atmospheric effects of biomass electric power generation in the Southeast, this study developed a new carbon accounting framework that integrates life-cycle carbon accounting with forest carbon accounting and utilizes forest growth, forest management practices, and supply data related to the specific situation in the Southeast. The framework is based on what we will call a "landscape-woodshed approach" where actual supply zones for specific facilities across the landscape are defined and aggregated as the basis for the study. Essentially, the study framework is designed to answer policy questions related to how atmospheric carbon would be affected if certain activities were promoted. It develops a "business-as-usual" baseline and then projects the atmospheric carbon effect of different future scenarios of creating electricity from woody biomass versus creating it from fossil fuels.

The framework [for this study] is based on what we will call a "landscape-woodshed approach" where actual supply zones for specific facilities across the landscape are defined and aggregated as the basis for the study.

Given the dynamics of the southeastern forestry sector, this study assumes that most of the trees modeled would eventually be harvested for pulp or other management objectives (such as to initiate the new stand under even-aged management) versus being left untouched if not harvested for biomass energy. The study excludes all public lands and 21 percent of private lands as not available for harvesting.

This is a more dynamic approach than was recommended in EPA's accounting framework for biogenic sources released in September 2011. Although, EPA acknowledged the "comparative" approach used in this study as a more comprehensive accounting method, it chose a "reference point" approach because of the perceived difficulties and challenges in applying a more dynamic approach to actual situations in the field.

EXECUTIVE SUMMARY *(cont'd)*

This study provides an example of how more dynamic accounting can be accomplished and should be considered by EPA in its carbon accounting deliberations. The results are consistent with other studies from other states or regions using similar analytical methods (Manomet, 2010 and McKechnie, 2011). Others have recently voiced opinions over which accounting methods are most appropriate. The SAF Task Force Report, Managing Forests because Carbon Matters: Integrating Energy, Products, and Land Management Policy (Malmsheimer et al., 2011), recommends a reference-point approach to establish forest biomass as carbon neutral. The European Environment Agency's Scientific Committee on Greenhouse Gas Accounting (European Environmental Agency, 2011) recently offered an opinion championing a comparative approach to fix a serious flaw in current GHG accounting.

Carbon Modeling Results

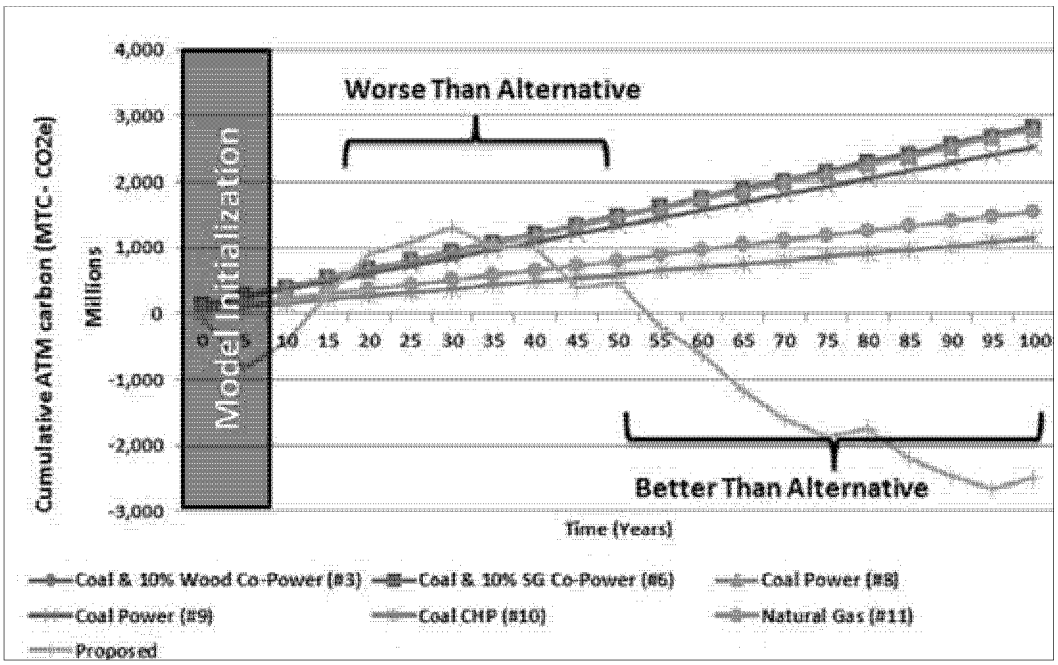
- The study modeled 22 new power plants as proposed to be developed over the next several years (1014 MW and 3.05 million tons of pellet production) added to an existing base of 17 power plants. The list of proposed plants is a snapshot compiled in May 2011 by the Southern Environmental Law Center. Additional large plants have since been proposed and are under development. As biomass demand increases with more facilities beyond the

Figure 22.

The study found that using southeastern forests for an expansion of electric power generation produced a significant long-term atmospheric benefit, but at short-term atmospheric cost.

The expanded biomass scenario creates a carbon debt that takes 35-50 years to recover before yielding ongoing carbon benefits relative to fossil fuels after this time period. (The initial apparent sequestration in the graph is a modeling artifact. It is a function of the simulation resolution and is due to the 5-year cycle with harvests mid-decade. This creates a 5-year growth period before harvest simulation.)

Figure 22. Cumulative atmospheric carbon balance over 100 years using coal and natural gas technologies to meet energy demand of proposed biomass facilities.



22 modeled, the ability of the forested landscape to provide biomass supply and store carbon may become more limited, particularly in localized areas with strong demand.

- The results indicated that the 17 existing biomass facilities were now generating and would continue to generate an improved atmospheric carbon benefit relative to fossil fuel technologies.
- The study found that using southeastern forests for the modeled expansion of power generation produced a significant long-term atmospheric benefit, but at short-term atmospheric cost. The expanded biomass scenario creates a carbon debt that takes 35-50 years to recover before yielding ongoing carbon benefits relative to fossil fuels after this time period (see Figure 22 on page 95). This outcome depends on the fossil fuel pathway used for comparison and assumes forests re-occupy the site through planting or natural regeneration, with no forest land conversion. This finding is consistent with other recent studies and naturally creates tension between climate scientists who assert that the next 20-30 years are a critical time for reducing carbon additions to the atmosphere and those who are more focused on long-term cumulative atmospheric carbon levels. This tension can only be resolved by well-informed energy and climate policy decisions.
- The efficiency of combustion technology was shown to be a critical factor influencing carbon emissions over time. The study used a mid-range value of 6,800 Bone Dry Tons (BDT) per megawatt hour per year. Using less-efficient combustion technology that requires more biomass per unit of power (e.g., using 8,000 BDT per megawatt hour per year) extends the payback period to 53 years. Using more efficient technologies would shorten this payback period. This study does not address biomass for thermal applications. While less common in the study area, strictly thermal applications or CHP applications are significantly more efficient and have much shorter carbon payback periods (in the range of 5-10 years in similar studies) than conventional combustion for base-load electrical generation that produces significant amounts of unused "waste" heat. The study also found that there is wide variability in carbon outcomes for different fuel types across different combustion systems.
- The use of logging residuals, when available from current harvests, leads to an improved carbon balance versus using standing roundwood because of the higher relative carbon storage of pulpwood versus residuals. The availability of harvest residue, however, is highly dependent on other parts of the wood products economy to generate sufficient demand for harvesting that creates residue material.
- The study did not model the use of dedicated energy crops for feedstock or crops that could be grown on fallow land and not jeopardize current sequestration and carbon stocks in existing forests. It attempted to analyze switchgrass based on information from a literature review, but this did not provide adequate or comparable information to what was available from our forest biomass modeling. Hence, a switchgrass analysis was dropped from the carbon modeling.

EXECUTIVE SUMMARY *(cont'd)*

One central issue to recognize is that [carbon] policy discussions include two competing perspectives—one long term and one short term—that will need to be assessed and weighed in the development of effective climate and energy policy.

DISCUSSION

The complex flux of forest-based carbon and the 35-50 year payback periods for the electric generation technologies modeled present both an intellectual and policy challenge. One central issue to recognize is that policy discussions include two competing perspectives—one long term and one short term—that will need to be assessed and weighed in the development of effective climate and energy policy. The long-term perspective focuses on the much lower amounts of atmopheric carbon that will eventually be realized if biomass is substituted for fossil fuels and the related beneficial effects for climate change and future generations. From this perspective, the 35-50 year payback period of biomass is less consequential. The short-term perspective, by contrast, believes near-term emission reductions are critical. This perspective is concerned with near-term "tipping points"—climate events that might be triggered by near-term increases in atmospheric carbon. From that perspective, the 35-50 year payback periods for biomass electric power are considered unacceptable climate and energy policy.

To further inform this discussion, it is useful to note that the carbon debt period shown in this study is consistent with other studies (Manomet, 2010, McKechnie, 2011) that have used life-cycle analysis, forest carbon accounting, and a business-as-usual baseline to compare biomass to other forms of energy production. As shown schematically in Figure 1 on the following page based on the Manomet study, there is an initial carbon "debt" relative to fossil fuels in the combustion of biomass for energy. Following a variable "payback" period, this debt is recovered and beyond that point biomass energy results in lower atmospheric carbon than fossil fuel alternatives.

The Manomet modeling produced a 42-year payback period for biomass- versus coal-generated electricity and the McKechnie modeling indicated 17-38 year payback periods for generating electricity with biomass instead of coal. Although these patterns are basically consistent, there are differences in debt periods, which are attributable to different forest types and harvest scenarios. In addition, our framework includes a more precise modeling of actual harvesting methods in real stands across the study region and linked to specific facilities.

Also there are significant differences between this study and the Manomet study in the time it takes to re-sequester all the emitted carbon and reach the point commonly called "carbon neutral." Our modeling indicates 53 years are required for this southeastern study region while the Manomet results for Massachusetts indicate more than 100 years are required.

Beyond the tension between this long- and short-term perspective, analyzing the climate implications of the biomass technologies modeled in this report is informed by several additional issues. First, recent climate studies indicate that whatever the ultimate peak in atmospheric carbon, it will take much longer than previously thought—hundreds or thousands of years—for the earth's systems to bring it back down to what are considered safe levels. This further complicates the understanding of how to address the short- versus long-term atmospheric carbon implications of biomass energy.

Second, it is possible to imagine future scenarios where technology leaps allow the retirement of such major sources of combustion as coal and biomass within 50 years. If realized, this would significantly shorten the payback period for biomass since facilities would be retired, biomass harvesting would stop, and re-sequestration would accelerate to shorten the payback periods. Conversely, it is possible to imagine land-use changes that would adversely affect the availability of biomass and negatively affect the payback periods. Concern over land-use change is well documented in the Southeast.

Third, it is necessary to fully consider any negative climate implications or events that could be triggered by the carbon debts created by the biomass scenarios. One should also consider whether these climate effects would eventually be triggered by continuation of the fossil fuel scenarios in the absence of biomass or other alternative fuels. Evaluating the cumulative costs and benefits to ecosystems and society of these factors over time is the task in front of policy makers in the southeastern region and at the national level.

Fourth, much of the carbon accounting debate for biomass centers on assumptions of baseline conditions. It is not uncommon to see studies that rely on generic "growth-to-removal" ratios as the key indicator of carbon accounting. The rationale is that as long as overall carbon stocks are being maintained in some specified area, then any biomass removal in that area is considered carbon neutral. This approach oversimplifies the accounting and can overlook very significant changes in forest carbon stock at the local level. They also do not accurately portray the foregone tons of new sequestration that would continue to accrue if those forests were not harvested for biomass.

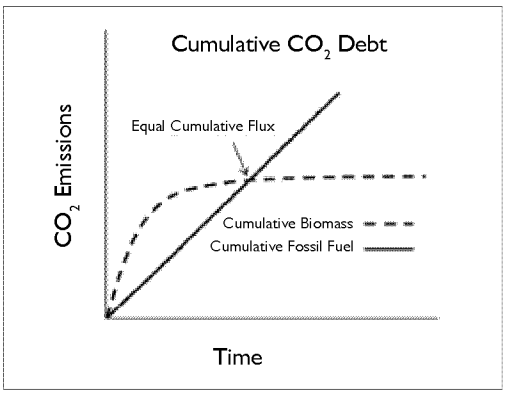


Figure 1.

Landscape-Scale Cumulative Carbon Debts and Dividends (Walker, 2012).

This study relies on a comparative approach that realistically estimates both the level of forest harvesting and the level of forest sequestration going forward in the absence of new biomass harvesting as a more accurate baseline approach. The approach used in this study can be applied to a region or an individual facility and should be useful for EPA as it develops regulations for GHG emissions.

INTRODUCTION

STUDY GOALS AND PURPOSE

Until recently, governmental policies have almost unanimously reflected the opinion that energy from biomass is beneficial from a GHG perspective.

The National Wildlife Federation (NWF) and Southern Environmental Law Center (SELC) contracted with the Biomass Energy Resource Center (BERC), in partnership with the Forest Guild and Spatial Informatics Group LLC, to provide an assessment of the greenhouse gas (GHG) impacts of an expansion of biomass electric power facilities in the southeastern United States. The study region is defined as a seven-state southeastern region including Virginia, North Carolina, South Carolina, Tennessee, Georgia, Alabama, and Florida. It is important to note that this study did not address thermal biomass energy applications, which have much higher efficiencies than electric power generation technologies and very different atmospheric carbon cycles. Nor did this study address the ecological impacts of current or increased biomass harvesting.

Energy supply and use is a national priority and a major focus of national, state, and local policy makers across the United States. The impacts of climate change, the need to increase energy efficiency, reduce reliance on foreign oil, and address related international security threats are some of the issues driving the expansion of new sources of domestic renewable energy and a new national energy policy and practice.

As climate change policy develops, forest biomass is consistently recognized as an alternative fuel with the potential to replace fossil fuels and mitigate the build up of atmospheric carbon. In response to these issues, the southeastern United States has seen recent interest in significantly expanding the biomass energy sector, including building new power plants, co-firing with coal power in existing plants, pellet manufacture for export to Europe, and cellulosic ethanol. Some of this increase in biomass utilization is driven by global demand and regulation and some by state-level renewable energy portfolios that require increased alternative energy production. To date, in the study region, North Carolina is the only state that has adopted a mandatory renewable energy portfolio standard, and Virginia has a voluntary standard. Additional state renewable portfolio standards or federal energy and climate change policies, however, will likely further increase the demand for biomass from southeast forests. According to Forisk Consulting, there are 149 announced projects in the southern United States that, in the unlikely event that they were all built, would consume more than 65 million green tons (Forisk Consulting, 2011). While some look to these developments and see promise, others look with great concern at pressures on the region's forests, implications for forest health and sustainable wood supply, and impacts on cumulative GHG emissions.

Until recently, governmental policies have almost unanimously reflected the opinion that energy from biomass is beneficial from a GHG perspective. Biomass typically is included in energy portfolios as a renewable energy source of the same classification as wind and solar and, when considered for electric power generation, is eligible for the same public incentives and subsidies. From an international perspective, policies have generally considered biomass energy to be a climate-friendly alternative to fossil fuels. In Europe for the past 10-15 years,

the International Energy Agency (IEA) has considered biomass energy to be close to carbon neutral (IEA, 2007 and 2009). The Intergovernmental Panel on Climate Change (IPCC), the primary international body focused on GHG emissions and mitigation strategies, also considers biomass energy to be an option for avoiding the GHG emissions from fossil fuels across all energy sectors (IPCC, 2000).

Starting in the early to mid 1990s, however, a number of studies looked more closely at the net GHG benefits of burning biomass and resulted in refined calculations of benefits depending on site factors, forest growth modeling, and timing of emissions and sequestration (Manomet, 2010). In the past few years, direct challenges to the accuracy of accounting approaches spurred a rethinking of carbon accounting for biomass (Searchinger, 2009).

As part of this emerging research, the US Environmental Protection Agency (EPA) is revisiting the premise that burning biomass for energy is carbon neutral in the context of the natural carbon cycle of the earth (EPA, 2011) and considering regulating carbon emissions from biomass combustion. In a 2010 rulemaking under the Clean Air Act—known as the Tailoring Rule—EPA planned to (and for a short while did) regulate carbon emissions from biomass plants as it did carbon emissions from fossil fuel burning facilities. EPA, however, also committed to studying the "carbon-neutrality" issue to determine whether the federal statute allowed carbon emissions from biomass combustion to be regulated differently than carbon emissions from the burning of fossil fuels. After extensive public and industry feedback on these new carbon emission rules as applied to biomass facilities, EPA proposed in March 2011 and finalized in July 2011 a different approach under which it instituted a three-year deferment of the regulation of biomass energy CO_2 emissions while it studied the underlying issue. During the study period, EPA said it would seek the advice of federal partners, states, a diverse group of expert scientists, and an independent scientific panel to help determine how these emissions should be treated under its air permitting program (EPA, 2011).

In September 2011, EPA released an "Accounting Framework for Biogenic CO_2 Emissions From Stationary Sources" to begin the discussion with experts and the public (EPA, 2011). EPA acknowledges several baselines that could be used in its framework, including the one used in this study, but selects a "reference-point" baseline that looks at the net change in carbon from a current reference point. Thus, if a region's stock of biomass contained more carbon after a specific point in time than the present, it would be assumed that biomass usage was not affecting atmospheric carbon. This southeastern study, by contrast, uses what EPA calls a "comparative" approach that identifies the net change that will occur in an alternative future, that is, how the carbon balance will be different if we use biomass as a source of energy versus using fossil fuels to produce that same amount of energy. The EPA framework also recognizes the carbon debt that could be incurred by land-use changes, but quantifies these emissions at a landscape scale and analyzes them on an annual basis. This southeastern study does not consider large-scale land-use change, but rather considers increased use of biomass energy harvested from forests on a sustainable basis. As this study points out, additional information is needed to determine how much additional forest biomass is available across the seven-state region to sustainably supply an expanded biomass energy sector without resulting in large-

Starting in the early to mid 1990s, however, a number of studies looked more closely at the net GHG benefits of burning biomass and resulted in refined calculations of benefits depending on site factors, forest growth modeling, and timing of emissions and sequestration.

INTRODUCTION *(cont'd)*

Overall, this literature review presents an overview of what is known about how much biomass resource is available in the region, what additional information is needed, and how closely matched current energy policy is with these available resources.

scale land-use change with related carbon and ecological effects. EPA's reasoning for selecting a less dynamic approach was the difficulty and challenges in accounting for these variables in actual situations. Others have recently voiced opinions over which accounting methods are most appropriate. The SAF Task Force report, Managing Forests because Carbon Matters: Integrating Energy, Products, and Land-Management Policy (Malmsheimer et al., 2011), recommends a reference-point approach to establish forest biomass as carbon neutral. The European Environment Agency's Scientific Committee on Greenhouse Gas Accounting (European Environment Agency, 2011) recently offered an opinion championing a comparative approach to fix a serious flaw in current GHG accounting.

This study provides an example of how the "comparative" approach can be used for a specific region. It can be further evaluated by EPA to inform its criteria for an "accounting framework for biogenic CO_2 emissions from stationary sources."

To address these complex issues as relevant to southeastern forests, this study seeks to address two key questions relevant to the biomass electric power sector in this region of the country:

1. How much biomass (primarily wood) is available on a sustainable basis to source the expanding southeastern biomass electric power sector, and, what is the potential of public policy to create demands that exceed sustainable supply levels?
2. How will the increased use of forest biomass for electric power generation in the Southeast effect atmospheric carbon over time and how does biomass energy compare to several fossil fuel energy alternatives in terms of cumulative GHG emissions over time?

It is important to note that this study examines only the use of biomass for large-scale electric power generation (and electric-led combined heat and power, or CHP). Thermal energy pathways were not examined, and due to their much higher efficiencies, these thermal technologies would have significantly shorter carbon payback periods and different overall impact on atmospheric carbon levels when compared to fossil fuel technologies (Manomet, 2010). It is also important to note that this study focuses solely on the carbon accounting of increased biomass use. There are significant ecological effects of increased removals of biomass from southeastern forests that must be evaluated and accounted for and were not within the scope of this study.

To examine fuel supply, the study conducts a literature review and critique of relevant and publicly available studies pertaining to the supply of biomass materials (primarily wood) in the seven-state region. It also examines current and future energy policies that could drive the expansion of biomass energy development and compares regional biomass supply with this potential demand. Overall, this literature review presents an overview of what is known about how much biomass resource is available in the region, what additional information is needed, and how closely matched current energy policy is with these available resources.

To examine the atmospheric effects of biomass electric power generation in the Southeast, the study develops a new carbon accounting framework that integrates life-cycle carbon accounting with forest carbon accounting and utilizes forest growth, harvest, and supply data related to the specific situation in the Southeast. The framework investigates specific landscape woodsheds associated with biomass facilities and develops business as usual baselines to compare to alternative future energy scenarios. This framework is designed to answer the following three questions:

1. What are the atmospheric carbon implications of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?
2. What are the atmospheric carbon implications of operating the existing 17 biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants? Answering this question includes a range of sensitivity analyses, including the impacts of varying the proportions of residuals versus pulpwood and natural forests versus plantations.
3. How does the atmospheric carbon balance vary when key parameters of the model are changed? The model and additional research were used to examine the sensitivity of six parameters to atmospheric carbon balance.

A NEW CARBON ACCOUNTING FRAMEWORK TAILORED TO SOUTHEAST FORESTS AND BIOMASS ENERGY

Comprehensive and specific accounting approaches are required to measure the effect of forest biomass energy systems on atmospheric carbon. Biomass systems are scientifically complex and their atmospheric carbon effects vary over time. Yet what makes them complex is also what can make them desirable for climate change mitigation—they are based on biogenic systems. A biogenic system such as a forest is part of the natural biological cycles of the planet. The carbon in a forest fluxes in and out of the atmosphere as trees grow and accumulate carbon and then die and release it. Fossil fuels, in comparison, are part of a geologic system. These fuels were stored in the earth millions of years ago and when extracted and burned for energy release additive carbon into the biogenic cycle. While the actual carbon molecules are identical, this additional carbon loading exceeds the sequestration capacity of existing forests and oceans. The resulting net increase in atmospheric carbon causes global warming and climate change.

Comprehensive and specific accounting approaches are required to measure the effect of forest biomass energy systems on atmospheric carbon.

The analysis of the atmospheric carbon impacts of biomass energy use would be straightforward and lead to the conclusion that biomass is preferable to fossil fuels in respect to reduction of GHG emissions except for three important facts. First, in most cases, the initial release of carbon into the atmosphere from burning biomass is higher than that of fossil fuels, as biomass is less energy dense than fossil fuels. This means that more biomass must be burned and more carbon released to get the same output of heat or electricity.

INTRODUCTION *(cont'd)*

Determining how biomass can contribute to a sound climate change policy hinges upon understanding this cycle of short-term costs and long-term benefits and weighing these costs and benefits relative to mitigating climate change over time.

Second, it takes time to re-sequester the carbon released from biomass combustion and to recover the foregone sequestration capacity lost when the biomass is harvested. Forests will respond differently to biomass harvests and this can result in varying and significant periods of time it takes to re-sequester the carbon. Depending on how the fuel is harvested and burned, CO_2 emissions from biomass can be re-sequestered in forests quickly or it may take many decades. Critical factors that influence the cumulative atmospheric carbon effects of burning biomass for energy include forest type, forest management, and how harvesting is distributed across the landscape and over time.

Third, the amount of CO_2 released per unit of energy produced varies significantly across different combustion technologies, with high-efficiency thermal technologies releasing far less carbon per unit of energy than electric power generation (Manomet, 2010). This is because much more usable energy value is available—as much as 70-80 percent in thermal applications—as compared to conventional combustion technologies.

Determining how biomass can contribute to a sound climate change policy hinges upon understanding this cycle of short-term costs and long-term benefits and weighing these costs and benefits relative to mitigating climate change over time. Specifically, effective energy and climate policy must consider both short-term carbon emissions and long-term atmospheric carbon accumulation and relate these factors to actual climate change tipping points and long-term mitigation goals.

These equations are complex and there is danger in blanket approaches or oversimplifications concerning the full life-cycle carbon effects of biomass energy. Research demonstrates that not all biomass energy can or should be considered a priori "carbon neutral." It is important to have a complete understanding of the three factors described above.

These concerns have led to refinements in biomass accounting protocols that now integrate life-cycle assessments and forest carbon accounting to produce a comprehensive picture of total GHG emissions over time. This study for the Southeast integrates these new accounting protocols with a "comparative" approach and a business-as-usual baseline to depict GHG emissions as a "debt-and-dividend" model as pioneered in a 2010 study, Biomass Sustainability and Carbon Policy, conducted for the Massachusetts Department of Energy Resources (Manomet, 2011). This report for Massachusetts described the flux of carbon at the forest-stand level when biomass is burned versus a fossil fuel as resulting in an initial period when biomass released more carbon into the atmosphere than an equivalent amount of fossil fuels. This difference (or "debt") gradually decreased as the harvested forest grew and sequestered carbon. If sufficient carbon is re-sequestered, the amount of carbon in the atmosphere becomes less than the fossil fuel alternative and dividends, or benefits, are accumulated over time. The study then used individual stand data to predict the results of running biomass facilities year after year, modeling carbon released into the atmosphere each year as more forest stands are harvested to supply biomass facilities.

Each year the cumulative amount of carbon in the atmosphere increased and was offset by the sequestration that occurred in the stands that were harvested and continue to grow. The cumulative debt rises until there is enough growth on the harvested stands already in the system to balance out the re-occurring debt from the yearly harvest and biomass emissions. At this point, the cumulative emissions for biomass stabilizes around an amount of carbon that, on average, has been permanently removed from the forest and will remain in the atmosphere as long as the biomass facilities are running and harvests continue. This curve can be plotted against the cumulative emissions from fossil fuel energy sources and technologies to provide a carbon flux analysis helpful for policy considerations.

The "debt/dividend" ratio and payback period will vary significantly across technology types and fossil fuel options with the shortest payback periods for biomass thermal energy and the longest for biomass electric power (Manomet, 2010). The most notable finding in the Massachusetts study was that biomass used to produce heat or heat-led CHP took only about 5-10 years to realize atmospheric carbon benefits relative to oil while biomass used to make electricity took approximately 42 years to achieve an atmospheric carbon benefit relative to coal. This is due to the significant difference in combustion efficiency between electrical-led versus thermal-led technologies.

The Manomet study was limited in scope due to available resources and time frame and reflected some peculiarities of a forestry sector that has few parallels in other states or regions, such as a lack of pulpwood markets for low-quality material, a reluctance of many landowners to conduct the sawtimber harvests that produce residues, and harvesting regimes that do not rely on clear cutting to establish new regeneration. Also, it modeled individual stands and averaged these to represent a broader landscape versus actually modeling multiple stands across a real landscape. For these reasons, there have been lingering questions as to whether the carbon flux profile would hold up under more comprehensive modeling in different regions and forest types and utilizing more accurate harvesting regimes.

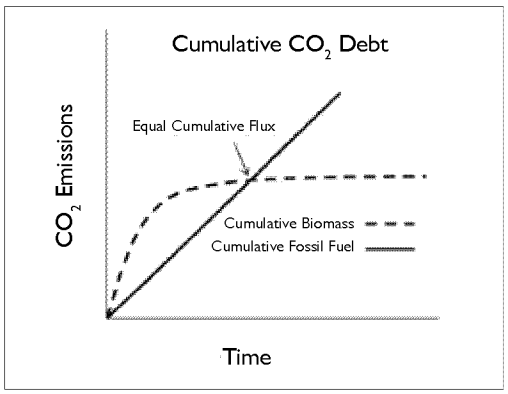


Figure 1.

Landscape-Scale Cumulative Carbon Debts and Dividends (Walker, 2012).

A related study in 2010 (McKechnie) also used an integrated approach of life-cycle analysis and forest carbon to analyze the effect of different biomass pathways compared to fossil fuels for forests in Ontario, Canada. It confirmed both the basic flux profile and significant payback periods for biomass electric power and cellulosic ethanol that were found in the Manomet study. Electrical generation using pellets in place of coal showed payback delays of 16-38 years and more than 100 years for ethanol produced from standing trees.

Enhanced modeling in this study allows a more accurate representation of GHG emissions over time and is specific to an actual forested landscape that is currently supporting 17 facilities and the expanded landscape that could be called upon to supply 22 proposed biomass facilities. The study uses life-cycle analysis and forest carbon modeling of actual forest stands across the landscape to produce a business-as-usual baseline and

INTRODUCTION *(cont'd)*

[This study] utilizes a dynamic model by predicting the role of repeated future harvests across the southeastern sourcing area for specific plants or "landscape woodsheds" as part of a business-as-usual scenario.

permit a comparison of generating energy from biomass to other ways of producing energy. The data is presented in a debt-and-benefit pattern to represent the carbon flux over time and facilitate policy development.

To further clarify several important characteristics of this study, the following issues are emphasized to facilitate comparisons to related work:

1. The GHG accounting framework used in this report represents a fresh and more realistic approach to estimate the landscape-level impacts of biomass energy expansion. In general, there are three ways to approach the modeling of GHG impacts of biomass energy:
   - Consider a *fixed landscape* and measure overall carbon stocks as an indicator of "biomass carbon neutrality" (EPA, 2011)
   - Conduct analysis at a *stand level*, multiplied upwards to estimate the landscape effect (Manomet, 2010)
   - *Consider a dynamic landscape and focus on "landscape woodsheds" to analyze the difference between emissions from the business-as-usual scenario and net changes in emissions from the increased use of biomass across different feedstock and technology pathways*

Unlike other studies that rely on variations of the first two approaches, this report uses the third method (in italics above). That is, it utilizes a dynamic model by predicting the role of repeated future harvests across the southeastern sourcing area for specific plants or "landscape woodsheds" as part of a business-as-usual scenario. It is important to note that with respect to biomass energy, the term 'landscape' approach has come to mean several different things: most often a static balance-sheet approach to carbon stocks rather than the dynamic model used here.

2. Given the dynamics of the southeastern forestry sector, this study assumes that most of the trees modeled would eventually be harvested for pulp or other management objectives (such as to initiate the new stand under even-aged management) versus being left untouched if not harvested for biomass energy. The study excludes all public lands and 21 percent of private lands as not available for harvesting.
3. This study analyzes the harvest and carbon flows for specific woodsheds and biomass facilities. It predicts and models the harvest area and harvests from the specific forest types that would feed the biomass facilities.
4. This study includes a sensitivity analysis to evaluate several variables that can be manipulated through public policy to generate different carbon payback periods. These include:
   - **Mill residuals and urban tree waste.** Biomass power plants can use sawmill waste and urban tree waste as fuel (versus in-forest residues or pulpwood). How does the carbon payback change with varying proportions of this source of woody biomass versus in-forest residuals?
   - **In-forest residues versus main stem (pulpwood).** Biomass power plants can use in-forest residues (tops and limbs) or the main stems of standing trees. How does the carbon payback change as varying percentages of residues versus main stems are used for fuel?

- **Percentage of available residue allowed in harvest.** For ecological reasons, it may be necessary to limit the total amount of residues removed from the forest. How does the carbon payback change if residue harvest is limited by management guidelines?
- **Plantations versus natural forest stands.** Forest plantations are planted and manipulated much more intensively than natural stands and often have faster growth rates. The productivity of plantations versus natural stands was considered on a stand-level basis. Since the model used real sourcing areas for existing and proposed plants, however, it was not possible to adjust the supply upward for plantations when not enough plantation supply was available. Therefore, it was not possible to study the actual change in carbon payback periods for biomass sourced from plantations versus natural stands for the study region.
- **Efficiency of biomass combustion.** The efficiency of conversion of woody biomass to energy has a significant impact on the carbon payback period for electric power production. How does varying the amount of biomass needed to produce a MW of power change the carbon payback period?
- **Pellet export percentage.** Wood pellets are manufactured in the Southeast and are used domestically or exported to Europe to produce electric power. The study examines whether varying the level of pellet export significantly changes the carbon payback period.

The study presented here seeks to address these complex issues for the forest types, energy demands, harvesting regimes, and public policy environment specific to the defined seven-state forested region of the southeastern United States.

1. WOOD SUPPLY REVIEW

1.1.0 INTRODUCTION

This literature review is focused on woody biomass resources and does not include other biomass materials such as farm manures, bio-solids, or agricultural residues.

Over the past few years, there has been a flurry of biomass energy development activities in the southeastern United States—everything from announced cellulosic ethanol plants, to pellet mills exporting product to Europe, to new power plants and retrofitting coal power plants to co-fire using biomass fuel. While the promise of cellulosic ethanol commercialization and deployment has not yet come true, there is considerable progress underway in the pellet and power production fronts. A recent announcement released by a private consulting firm that tracks biomass energy development in the United States states that there are 81 proposed electric generation projects, 51 pellet plants, and 17 liquid-fuel production plants in the southern United States with a combined biomass feedstock demand of 65 million tons (Forisk Consulting, 2011). According to the same report, however, roughly half of these projects are deemed immediately unviable by the consultant for various reasons (unproven technology, financing, permitting, wood contracts, etc.). How many of the remaining projects will eventually get built is extremely difficult to predict.

At the same time, there have been dozens of different studies quantifying the various biomass resources. Some examine resources at the national level while others hone in on the regional and state levels. Many studies examine all biomass materials from bio-solids from waste-water treatment plants to animal manures from farms. Other studies focus exclusively on woody biomass. Some are public while others are conducted by consultants for private clients and are not publicly accessible. Some use transparent data, methods, and assumptions while others are more opaque. Some focus on quantifying the total generation of biomass materials while others try to identify the net amount available after all current demands are accounted for.

Considerable information is available at the state level about the supply of biomass resources, however, biomass materials like wood tend to constantly flow across state borders to feed the markets and are not confined to use by in-state markets. For this reason looking at the regional supply and potential demand for the resource is needed.

This chapter presents a literature review of several key biomass resource assessments conducted to date, examines the current and possible future energy policies that could drive the expansion of biomass energy development, and compares the supply with this potential demand.

1.2.0 SCOPE OF STUDY AND METHODS

1.2.1 Scope of Study

The scope of this section of the study has three main parts:

1. **Assessment of the biomass resource literature for the seven-state region.** This literature review is focused on woody biomass resources and does not include other biomass materials such as farm manures, bio-solids, or agricultural residues. It covers the studies and data that are publicly available and does not address the possibly vast amount of information that is not in the public domain.

More specifically, this assessment examined resource assessment studies that addressed the supply of urban wood residues (wood pallets, tree trimmings, leftover Christmas trees, etc.), wood residues from primary wood manufacturing (sawdust, chips, and bark from sawmills), wood residues for secondary wood manufacturing (scrap wood pieces, sawdust, and wood flour from furniture, cabinet, and flooring manufactures), logging residues from the harvest of traditional timber products (primarily the top and limb wood), wood residues thinned from pre-commercial harvests, and the possible harvest of pulpwood.[1]

2. **Examination of the energy policies in the seven-state region.** This examination includes the assessment of existing state Renewable Energy Portfolio Standards (RPS), the potential for a federal Renewable Fuel Standard (RFS), and a possible future federal Renewable Portfolio Standard.
3. **Comparison of the resource supply against the potential demand.** This comparison factors the woody biomass resource, the potential pellet export market, and the possibility for dedicated energy crops to bridge a potential gap between supply and demand.

Figure 2.

Seven-state study region in the southeastern United States.

1. WOOD SUPPLY REVIEW *(cont'd)*

This literature review limited the scope to those studies published since 2005 and that squarely addressed the quantity of biomass supply within at least a portion of the seven-state region.

1.2.2 Methods

For the literature review, all biomass studies in the seven-state region were gathered, this information was reviewed and assessed, the various pieces of information were woven together to paint a more comprehensive picture, and our findings and observations were reported.

The information gathered via the literature review was incomplete and further work to assess the full picture was necessary. BERC gathered more state-specific data from the USDA Forest Service's Forest Inventory Analysis (FIA) Program, and made basic calculations to better assess the forest resource potential against the possible future demands stemming from federal energy policies.

For the assessment of the RPS for the seven-state region, the study conducted the following tasks:

1. Review the seven-states' current energy policies, identify states with an existing RPS standard, and determine whether any such standards contain a "carve out" specifically calling for a percentage of the total portfolio to come from biomass, and more specifically, woody biomass.
2. Determine the current electrical demand profile in each of the seven states.
3. Explore new possible demand scenarios if a federal RPS and RFS were implemented.
4. Compare these scenarios against the resource amounts identified in the literature review.

1.3.0 ANNOTATED BIBLIOGRAPHY

The target of this literature review was on studies that quantify the amount of biomass resource potentially available to supply future growth of biomass energy in the seven-state region. It should be noted that there are dozens and dozens of studies published in the past 10 years that touch upon the issue of biomass fuel supply. Many of these studies, however, focus on different geographic regions, on different biomass resources, on the various ecological impacts, or on the economics of biomass fuel supply. This literature review limited the scope to those studies published since 2005 and that squarely addressed the quantity of biomass supply within at least a portion of the seven-state region. Studies that did not meet these criteria were excluded from the following summary.[2]

1.3.1 National Studies

1.3.1.1 The Billion-Ton Study

In 2005, a joint report between the US Department of Energy and the US Department of Agriculture was released that quantified the amount of biomass resources potentially available to expand the use of biomass energy in the United States (Perlack, 2005). This report, commonly referred to as the "Billion-Ton Study" provided national estimates of wood residues from timber and lumber production, crop residues, fuel wood thinned from forests to reduce fire hazards, and the role of dedicated energy crops. The report concluded that there was more than 368 million dry tons per year of woody biomass from the nation's forests and another 998 million dry tons of resources from agriculture. These estimates of supply are for total generation of supply

and do not account for current demands for this resource. These estimates also include key assumptions about implementing new practices in forestry and agriculture that will generate additional volumes not currently available (such as increasing forest thinning for fire-hazard reduction and planting of dedicated energy crops).

This study's major shortcomings were that it did not make any clear effort to delineate the amount of existing demand for these materials from existing industries. The reporting was given in totals for the nation and did not provide a state-by-state breakdown of the supply in the body of the report or appendices, and therefore cannot help directly in determining the likely supply for the seven-state region being examined as part of this report. Lastly, much of the data and methods used were not made transparent, therefore making it difficult to gauge the credibility of the information being reported.

In an effort to address many of the key shortcomings of the 2005 study, the authors have recently released a detailed update that has improved the spatial resolution of the information (county level data reported for all 50 states), provided price curves for the supply of various biomass resources (indicating the supply elasticity of the various biomass resources at different price points), improved upon the data and methods used, and provided more sophisticated modeling (including land-use change) to assess future supply under different scenarios. In August 2011, the updated Billion-Ton Study was released by the lead researchers at Oak Ridge National Laboratories.

The Billion-Ton 2011 Update assumed a logging-residues recovery rate of 70 percent, leaving the remaining 30 percent onsite. Perhaps one of the most relevant conclusions emerging from the 2011 update was the following statement:

"Over the estimated price range, quantities vary from about 33 million to 119 million dry tons currently to about 35 million to 129 million dry tons in 2030. Primary forest biomass (i.e., logging and fuel treatment operations and land clearing) is the single largest source of feedstock. The resource potential does not increase much over time given the standing inventory nature of the resource and how it is managed. Results also show that very little conventional pulpwood is available for bio-energy at prices below (about) $60 per dry ton." (Perlack, 2011)

These projections of wood biomass resources represent a very large decrease compared to the estimates given in the 2005 study (from 368 down to 129 million dry tons). The reasons for this decline given by the authors are the subtraction of biomass resources already in use and the recent decline in pulpwood and sawlog markets.

1.3.1.2 A Geographic Perspective on the Current Biomass Resource Availability in the United States

In December 2005, the National Renewable Energy Laboratory issued a report by lead author A. Milbrandt entitled, A Geographic Perspective on the Current Biomass Resource Availability in the United States. Unlike the 2005 Billion-Ton Study, Milbrandt provided state-by-state estimates for crop residues, wood residues, urban wastes, methane from manure and landfills, and dedicated energy crops. Milbrandt also provided detailed information on the data and methods used to create the estimates given in the report. To estimate the amount of mill residues and forest residues, the author used 2002 data from the FIA program's Timber Products Output (TPO) for logging residues from commercial harvest and pre-commercial thinning. Table 1 on the next page presents the estimates for forest residues presented in this report.

1. WOOD SUPPLY REVIEW *(cont'd)*

Table 1. Estimates for Forest Residues

STATE	DRY TONS OF FOREST RESIDUE FROM HARVESTING
Virginia	2,403,000
North Carolina	2,995,000
South Carolina	1,733,000
Georgia	3,556,000
Florida	1,778,000
Alabama	2,555,000
Tennessee	1,319,000
TOTAL	**16,339,000**

(Milbrandt, 2005)

These estimates are based on survey data on how much wood is harvested annually and calculations based on volume ratios between the amount of traditionally merchantable roundwood harvested and the amount of tops and limbs severed and left behind. With these types of estimates, it is important to note that the methodology used does not distinguish between the total amount generated and the amount that currently goes unused by existing markets. For this study, the estimates represent the total generated. It is also important to note that not all of this residue generated could be cost-effectively gathered. In practice, only whole-tree harvesting methods allow for cost-effective collection of the top and limb wood generally left behind with either manual or mechanized stem-only harvesting. Without good data on how much whole-tree versus stem-only harvesting occurs in the Southeast (or methods to predict changes in the ratio into the future), it is difficult to accurately estimate how much of this material is/will be truly available.

1.3.1.3 Availability and Sustainability of Wood Resources for Energy Generation in the United States

In this study commissioned by the American Forest & Paper Association, the authors focused on assessing the quantity of "wood resources for energy generation that exist independently of and in excess of those needed to manufacture other forest products and can be harvested without jeopardizing the long-term sustainability of US forests" (Mendell, 2010).

This study concluded that while there was a considerable decline in wood consumed by the forest products industry between 2005 and 2010, that by 2020 the industry would recover to previous levels of timber demand. The authors concluded, however, that the pulp and paper industry's consumption of raw wood would "remain flat and decrease."

This study built upon the Billion-Ton Study and made a good effort to isolate the portion of the total supply that is "readily available." While the original Billion-Ton Study concluded there is 368 million dry tons of woody biomass (revised to 129 million in 2011) from our forests available, this study concluded there are only 50 million dry tons (roughly 100 million green tons) readily available for energy use in the United States.

This study did not provide a state-by-state breakdown of the supply in the body of the report or appendices, and therefore cannot help directly in determining the likely supply for the seven-state region being examined as part of this report.

1.3.2 Regional Studies

1.3.2.1 Eastern Hardwood Forest Region Woody Biomass Energy Opportunity

In October 2007, the US Forest Service released a study entitled, Eastern Hardwood Forest Region Woody Biomass Opportunity. Prepared by Summit Ridge Investments, it focused on the market opportunities for utilizing woody biomass within a large eastern region (nearly every state east of the Rocky Mountains). It conducted some assessment of the resource building upon work conducted in the Billion-Ton Study and concluded that at the national level, of the 368 million dry tons annually, there are only 279 million dry tons available under current practices and activities. The additional 89 million dry tons would require new practices. It also concluded that within the Eastern Hardwood Region of the United States, there are approximately 190 million dry tons annually, however, 120 million dry tons are already used for existing markets.

According to the author, the remaining 70 million dry tons available to supply additional biomass energy market expansion would represent a 50-percent increase over the current levels of wood consumption (Millard, 2007).

This study did not provide a state-by-state breakdown of the supply in the body of the report or appendices and therefore cannot help directly in determining the likely supply for the seven-state region being examined as part of this report.

1.3.2.2 Estimates of Biomass in Logging Residue and Standing Residual Inventory Following Tree-Harvest Activity on Timberland Acres in the Southern Region

The USDA Forest Service's Southern Research Station released in January, 2011 a report entitled, Estimates of Biomass in Logging Residue and Standing Residual Inventory Following Tree-harvest Activity on Timberland Acres in the Southern Region. The authors, Conner and Johnson, examined the amount of logging residues left by current harvesting and the standing trees left behind by harvesting that could be used for energy in a 13-state region of the southern United States. The authors examined all harvesting in the study area over the past 14 years and broke the harvesting into several categories—final harvest, commercial thinning, partial harvest, seed-tree/shelterwood, and Timber Stand Improvement (TSI). This study concluded there is the potential to recover an estimated 62.9 million green tons of harvest residues in their 13-state region annually.

Table 2 on the following page presents key information extracted from the Conner and Johnson study for the seven-state study region.

1. WOOD SUPPLY REVIEW *(cont'd)*

Table 2. Key Information Extracted from the Conner and Johnson Study for the Seven-State Region

	Final Harvest (Acres Harvested Annually)	Commercial Thinning (Acres Harvested Annually)	Partial Harvest (Acres Harvested Annually)	Shelter-wood (Acres Harvested Annually)	Timber Stand Improvement (Acres Harvested Annually)	Total (Acres Harvested Annually)	Logging Residue (Resulting Green Tons)
Virginia	133,600	55,100	117,900	2,600	10,400	319,600	4,863,222
North Carolina	227,500	101,800	87,100	2,100	10,600	429,200	5,936,953
South Carolina	149,800	200,000	63,900	13,200	13,000	439,800	4,773,409
Georgia	296,100	316,600	129,300	16,200	18,000	776,200	7,512,195
Florida	190,600	61,900	69,100	3,300	5,500	330,500	2,850,164
Alabama	366,400	275,200	164,600	14,900	15,600	836,700	7,951,820
Tennessee	56,600	4,400	161,500	3,900	1,200	227,600	2,905,345
TOTAL	**1,420,000**	**1,015,000**	**793,400**	**56,200**	**74,300**	**3,359,600**	**36,793,108**

Table 2 indicates that, according to the data and methods used by Conner and Johnson, there are more than 36 million green tons (or 18 million dry tons) of logging residues that could be used in the seven-state region, representing an average of 11.15 green tons per harvested acre. It is important to note that the authors chose to discount to the total amount of harvest residues calculated to account for a realistic recovery rate, using a 60 percent recovery rate for logging residues. It is unclear if this recovery rate is intended to be applied to all harvest operations where only 60 percent of the residue is gathered—factoring logistical and ecological reasons for not recovering more—or if this recovery rate applies to taking all residues from only 60 percent of the harvest operations. This is an important point because ideally, a study would look at both issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered. In addition, the extent to which these harvest residues can be cost-effectively harvested depends largely on the type of harvesting system used by the loggers: Whole-tree harvesting can cost effectively extract this material whereas stem-only harvesting systems leave these materials scattered in the woods. To better understand how much top and limb wood residues from harvesting could effectively be accessed in the seven-state region, good information about how much whole-tree harvesting versus stem-only harvesting is needed. Unfortunately, other than general anecdotal information from loggers and foresters, this information was not found.

1.3.2.3 An Interactive Assessment of Biomass Demand and Availability in the Southeastern United States

In March of 2011, The Environmental Defense Fund and the Nicholas Institute for Environmental Policy Solutions at Duke University released a model and paper entitled, An Interactive Assessment of Biomass Demand and Availability in the Southeastern United States. The paper's authors, Galik and Abt, detailed the function and general results of the modeling work.

The model currently only holds data for three southeastern states—Georgia, South Carolina, and North Carolina. The model does not specifically quantify the amount of woody biomass potentially available, but rather explores the potential impact on the forest resource of hypothetical demand scenarios stemming from the adoption of a federal RES or a federal RFS. The model utilizes previous Sub Regional Timber Supply (SRTS) modeling work and feeds these data into an Excel spreadsheet where the impacts of various demand scenarios are compared to the biomass resource under different levels of resource constraints. The framework of the model explores a wide range of percentages of biomass contribution (or biomass "carve outs") toward a possible RES (1-10 percent) or RFS (0-150 percent).

On the whole, the modeling effort indicated that it was possible to meet the resource demands of all the different policy scenarios explored when whole-trees were an allowed resource. When the model parameters were confined to only harvest residues (tops and limbs left from traditional timber harvesting), however, there was insufficient resource to meet the energy policy targets of most scenarios for the three states.

One rather interesting observation the authors made concerned the potential for the displacement of traditional pulpwood by the increased demand and price paid by emerging biomass power generation markets. The authors suggested that "where the price of biomass increases, some existing users may essentially be priced out of the market," meaning those markets that are the most price sensitive with the least capability to pass along higher raw wood costs through the supply chain will have a harder time getting the resource. Galik and Abt state "we assume that the electric sector are not price sensitive... [and] as biomass prices increase, [existing forest products industry] are the first to be priced out" (Galik, 2011).

It is important to note that these assumptions are just that—assumptions. If a federal RES were implemented without set targets for biomass, solar, and wind, and biomass proved to be the most cost effective, then there is a chance demand for biomass could drive wood prices up to a point where biomass could outcompete pulpwood. There is little evidence, however, that such a reaction would take place. In fact, there is considerable evidence of the opposite. First, all RES implemented to date contain an alternative compliance payment that sets a cap on how high renewable energy credit prices can go. Second, the electric plants using biomass have historically been the most price-sensitive and constrained portion of the wood market (operating at 25 percent efficiency tends to limit how much they can afford to pay for wood fuel). Furthermore, the pulp and paper industry is not likely as price constrained as Galik and Abt suggest. The current market price paid for delivered fuel chips by power plants in the Southeast ranges between $22-$26 per green ton whereas the current price paid for delivered residual chips at pulpmills in the Southeast ranges from $32-$38 per green ton (North American Fiber Review, June 2011).[3]

1. WOOD SUPPLY REVIEW *(cont'd)*

Pulpmills also demand significantly higher quality chips that cost more to produce than the typical woodchip fuel used by power plants. In addition, the market value of the processed pulp is more than $500 per ton and the price of bulk paper is nearly $1,000 per ton. Even with an aggressive RES creating a strong incentive for biomass energy, it would be difficult to set a high-enough rate per MWh to price out pulp for the source wood while still making biomass energy even remotely price competitive with other sources of electric generation.

In certain circumstances, pulpwood can be sent to power plants—if a biomass power plant is very close to the harvest location and the nearest pulpmill is far away, pulpwood would likely be sent to the biomass plant as demand and prices rise for biomass fuel. If a harvest operation occurs 50 miles from the nearest biomass plant and 50 miles from the nearest pulpmill, however, under today's market prices the pulpwood will clearly go to the pulpmill.

1.3.2.4 Using Southern Interface Fuels for Bioenergy

In January 2011, the USDA Forest Service's Southern Research Station released a study examining the potential to use woody biomass sourced from within the Wildland Urban Interface (WUI) for biomass energy development. This study specifically examined the amount of wood residues from timber harvesting, unmerchantable wood from pre-commercial thinnings of timber stands, urban wood recycling, and exotic plant removals. It covers a 13-state region of the southern United States but did not present any new work regarding the amounts of woody biomass potentially available (Staudhammer, 2011).

1.3.3 State Studies

Due to the fact that the national and regional supply studies reviewed here thus far present little information specific to the seven-state region in question, our review now shifts its emphasis on gathering as much pertinent information on biomass supply in each state in an effort to compile these data for the whole seven-state area.

1.3.3.1 Virginia

Parhizkar and Smith (2008) conducted an assessment of wood residues in Virginia using GIS-based spatial analysis. Their analysis focused on the woody biomass residue generation from loggers, sawmills, secondary wood manufacturers, and landfills. The authors surveyed these sources and compiled the resulting data in a GIS application. They concluded that there is 8.1 million tons annually generated by wood products manufacturers in Virginia, but more than 90 percent of this material has existing markets. The assessment estimated that there was roughly 770,000 green tons of logging residues generated in 2003 and another 1.2 million green tons is disposed and sometimes diverted at landfills. Only eight percent of the total 10 million green tons was estimated to have inadequate markets (Parhizkar, 2008).

Another regional study that covered only the three states of Virginia, North Carolina, and South Carolina (Galik, Abt, and Wu, 2009) concluded there are 1.3 million dry tons (or 2.6 million green tons) of forest residues potentially available in Virginia (Galik, 2009). Galik et al. assumed a 50-percent recovery rate for logging residues.

Table 3. Estimates of Forest Residues in Virginia from Recent Published Studies	
	Estimates of Forest Residues
Parhizkar and Smith (2008)	770,000 green tons
Galik, Abt, and Wu (2009)	2.6 million green tons
Conner and Johnson (2011)	4.8 million green tons

Table 3 above presents the wide range of estimates of forest residues in Virginia from recent published studies. When considering the 4.8 million green ton figure from the Conner and Johnson study, it is important to note that they quantified both logging residues from current harvesting activities and the amount of additional "standing residual inventory" left uncut by these harvests. Inclusion of this material is the prime reason for such high estimates.

1.3.3.2 North Carolina

Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential.

In the recently released (June 2011) La Capra report prepared for the North Carolina Energy Policy Council, the authors provided detailed estimates of biomass resources that could be used to help meet renewable energy targets in North Carolina (La Capra Associates, 2011). This analysis included estimates and projections for forest biomass, urban wood waste, and agriculture from within North Carolina and also select counties in Virginia and South Carolina (those covered within Duke Energy and Progressive Energy service territory). For this report, La Capra employed the services of Robert Abt, Christopher Galik, and Karen Abt who conducted detailed modeling using the SRTS model used in numerous other studies to forecast the supply of biomass fuel into the future under different sets of parameters.

Using this modeling method, the study team provided estimates of both the technical potential for supply and the practical potential for supply.[4] For the *technical* potential they estimated 6.73 million dry tons of logging residues and another 7.73 million dry tons of pulpwood (these recovery rates are generally considered to be on the high end of the range of what is viable).[5] It is important to note this estimate is not presented by the authors as the preferable scenario—its intent was to present an upper limit.

Accordingly, they provided a more realistic scenario of the resource capacity to expand biomass energy without the likelihood of adversely affecting the forest ecosystems and avoiding displacement of wood currently supplying the traditional forest products industry.[6] For the *practical* potential model runs, however, the supply was not modeled based on ecological constraints and layering in the demand levels of the traditional forest products industry. Instead, demand scenarios from expanded biomass energy markets were plugged into the model to see both their impact on the forest residue resource base and how much displacement of pulpwood would occur as a result after residue resources were exhausted. In other words the authors assumed that more demand for biomass would be met first by tapping into existing amounts of logging residues and then by taking some pulpwood away from current pulpwood markets with no net increase in pulpwood harvesting—rather than assuming that pulpwood for biomass fuel would result in a net increase in pulpwood harvesting.

1. WOOD SUPPLY REVIEW *(cont'd)*

Several scenarios were modeled and La Capra Associates concluded for the practical run that in the Duke /Progress service area in 2011, there are 11.6 million green tons (5.8 million dry tons) annually all from residues, or enough to support more than 1,000 MW of power plant capacity. As they modeled demand further into the future, the amount of pulpwood required by biomass energy plants increased (the threshold was estimated at about 12 million tons per year).

The La Capra report also concluded that for a biomass power plant to operate cost effectively given the capped incremental revenue of $35/MWh ($0.035 per kWh), the wood fuel cost for a 15-year period could not exceed $7.34 per green ton on a stumpage basis or $20.40 per green ton for delivered fuel. Yet evidence exists suggesting that power plants routinely pay more than $20 per green ton. Average second-quarter (2011) softwood chip prices paid by pulpmills in the southeastern United States was $35.50 per green ton. Given the incremental price cap and the current pulp value of wood fiber, there is little evidence to suggest a strong likelihood of displacement. If anything, the growth of the pellet market will have the greatest displacement potential of pulpwood because this growing market requires the fiber quality found in pulpwood and not in harvest residues.

It is important to note that many econometric studies, including the LaCapra study, present potential biomass fuel availability as a function of price and use the *stumpage* pricing paid for biomass and pulp as an indicator of the extent that biomass markets may displace pulp mill supply by turning to roundwood. While in some circumstances stumpage prices paid by the facilities directly to the landowner can dictate where the cut wood goes (and the logger is paid to merely cut and haul the wood to the given market), there are other situations where it is the *market* price paid at the wood processing facility's gate that dictates to which market cut wood flows. Such is the case with a timber sale where the logger pays the landowner stumpage and the logger decides where to take the wood based on where they can make the most profit (factoring transport costs and price paid at the gate).

Using a more conservative assumed harvest residue recovery rate of 50 percent, Galik, Abt, and Wu (2009) concluded there are only 2.8 million dry tons (5.6 million green tons) of forest residues available in North Carolina—less than half of the amount LaCapra estimates (LaCapra Associates, 2011). This lower harvest residue figure would dramatically reduce (from the LaCapra estimate of potential) the amount of electrical energy that could be generated from wood residues in North Carolina.

1.3.3.3 South Carolina

In April 2006, the South Carolina Energy Office released a report entitled, Biomass Energy Potential in South Carolina: A Conspectus of Relevant Information. This report was later revised and re-released in August 2008. This study examined the potential for direct combustion from solid biomass; methane production from various farm, municipal, and industrial wastes; and ethanol production from farm crops and residues. The study cites work previously conducted in the state that concluded there were 22 million green tons of woody biomass resources annually for biomass energy (Harris, 2004). Of these 22 million green tons, only 4.4 million were from logging residues.

Again, using the more up-to-date data, more sophisticated modeling, and a more conservative assumed rate of harvest residue recovery, Galik, Abt, and Wu concluded there are 1.8 million dry tons (3.6 million green tons) of forest residues potentially available in South Carolina.[7]

1.3.3.4 Georgia

The Georgia Forestry Commission's website reports its 2009 findings of an estimated 9.1 million dry tons more wood than what is being removed each year (Georgia Forestry Commission, 2009). A summary table presented on the commission's website provides nearly no background on the data source or methods used to come to this estimate, however, it does provide an itemized list of the various categories that add up to the 9.1 million dry tons. Figure 3 below is the summary table.

There is no clear indication where the information in the table comes from and what methods were used to make these estimates. It is also unclear whether these are intended to represent annual volumes. Furthermore, there is no clear indication whether the figures given in the "Inventory Amount" column are in units of green tons, dry tons, cubic feet, or some other unit of measure. It is assumed that the "Inventory Amount" column represents the total forest standing inventory and that the "Recovery Rate" column shows the annual rate of recovery. According to the Forestry Commission, there are 3.88 million green tons of logging residues generated annually in Georgia (assuming a 100 percent recovery rate).

Forestry Biomass Estimates for Georgia, General Statewide Assessments, 2009

Resource		Inventory Amount	Recovery Rate	Amount to Recover (oven dry ton basis)
"Non-merchantable" biomass inventory in forests	Recovery during regeneration harvests	163,300,000	1.4%	2,286,200
"Non-merchantable" biomass inventory in forests	Recovery during thinnings	163,300,000	1.0%	1,633,000
Biomass from "pre-commercial" thinning of natural forest stands of pine and pine/hardwood		46,388,654	1.0%	463,887
Logging residues produced annually in forest management operations (excluding stumps)	From growing stock	1,940,250	100.0%	1,940,250
	From non-growing stock (included in non-merchantable biomass)	1,726,920	0.0%	0
Other annual timber removals resulting from land-use change	Estimate 75% recovery	1,834,625	75.0%	1,375,969
Mill residues produced annually		7,305,000	0.0%	0
Recoverable urban wood waste annually		1,436,823	100.0%	1,436,823
			Total	9,136,128

Figure 3.

Summary table of estimated dry tons of wood removed from Georgia each year.

1. WOOD SUPPLY REVIEW *(cont'd)*

Florida's forest resources lay mostly in the northern part of the state whereas many of the other states in the region have fairly even geographic distribution of their forest resources.

1.3.3.5 Florida

In March 2010, the University of Florida released a report entitled, Woody Biomass for Electricity Generation in Florida: Bioeconomic Impacts under a Proposed Renewable Portfolio Standard (RPS) Mandate. In the report the authors, Rossi, Carter, and Abt, explore the resource supply response to the possibility of mandatory RPS of 20 percent renewables by the year 2021. The authors model various scenarios, including the use of merchantable timber, urban wood waste, and logging residues.

In this study, the authors assume that a large percentage of the 20 percent renewable energy target will come from woody biomass energy based on the assertion that other renewables like wind and solar have both technological and cost constraints. Rossi et al. found that logging residues and urban wood waste resources in Florida "do not comprise a significant amount of aggregate supply of woody biomass required under a 20 percent RPS." Furthermore, they concluded that a significant portion of the demand presented by a 20 percent RPS would need to be met using merchantable timber. It is important to note that the authors have assumed that 100 percent of the RPS would be met from woody biomass energy and nothing would come from other renewable sources.

The authors state in the executive summary, "It is widely assumed that Florida's abundant wood resources would be relied upon in order to meet much of the RPS-imposed demands for electricity, given that factors such as technological constraints and cost considerations will combine to limit the amount of renewable energy that will come from solar, wind, and other sources of renewable energy" (Rossi, 2010). There is no clear evidence to support or dispute this statement by Rossi, et al. Certainly, representatives from the wind, solar, and biogas energy industries would dispute the validity of this assertion.

Anecdotally, it is important to keep in mind that Florida's forest resources lay mostly in the northern part of the state whereas many of the other states in the region have fairly even geographic distribution of their forest resources.

1.3.3.6 Alabama

In June 2009, the Alabama Forestry commission released a report entitled, Woody Biomass Energy Opportunities in Alabama. Only very basic information regarding potential supply and demand of biomass resources is provided in this report.

1.3.3.7 Tennessee

No further studies were found for Tennessee.

1.4.0 APPLES-TO-APPLES BIOMASS RESOURCE ASSESSMENT OF SEVEN-STATE REGION

1.4.1 Summary of Wood Residues

Due to the fact that each of the studies detailed on the previous pages looked at different groups of biomass resources, quantified the resource with and without also quantifying the current use, used different data sources and different methodologies, and studied different geographic regions, there is no rational way to weave together all the various disparate studies and bits of information. To supplement the bits and pieces of state-specific information from all the various sources and studies presented earlier, the Table 4 below was created by BERC to present a consistent set of information for the biomass resource for each of the seven states.[8] It presents information assembled into fact sheets for numerous southern states by the SUN Grant initiative (Southern Forest Research Partnership, 2011).

The information presented in Table 4 is useful, yet must be put into the proper context. While nearly 50 million dry tons of annual woody biomass generation in the seven-state region may seem like a lot of biomass, without knowing how much of that amount is already being used by existing markets, it is somewhat meaningless. A large majority of recent fuel supply studies have concluded that nearly all primary and secondary wood processing mill residue (chips, sawdust, wood flour, shavings, and bark) and urban wood waste are already being utilized by wide-ranging existing markets. Pulpmills have long utilized paper-grade chips from sawmills. Many wood processors also use their own wood residues to fuel their kiln drying of lumber. Also some sawmills in the region have added pellet mills to their operations, thereby further utilizing their own residues. Agricultural markets have long been a steady outlet for sawdust and shavings for animal bedding. The landscaping and horti-

A large majority of recent fuel supply studies have concluded that nearly all primary and secondary wood processing mill residue (chips, sawdust, wood flour, shavings, and bark) and urban wood waste are already being utilized by wide-ranging existing markets.

Table 4. Biomass Resource for Each of the Seven States

	Urban Wood (DT/yr)	Mill Residues (DT/yr)	Harvest Residue (DT/yr)	Total (DT/yr)
Virginia	813,000	800,926	1,700,000	3,313,926
North Carolina	833,000	5,000,000	2,300,000	8,133,000
South Carolina	467,000	2,400,000	1,600,000	4,467,000
Georgia	1,440,000	8,000,000	3,500,000	12,940,000
Florida	4,600,000	2,600,000	1,300,000	8,500,000
Alabama	100,000	6,800,000	2,700,000	9,600,000
Tennessee	614,000	577,000	760,000	1,951,000
TOTAL	**8,867,000**	**26,177,926**	**13,860,000**	**48,904,926**

1. WOOD SUPPLY REVIEW *(cont'd)*

To give an accurate picture of whether the broader forest resource could support the potential increased demand from biomass energy beyond just the use of harvest residues, a detailed analysis for the seven-state region is needed.

culture markets have been a consistent outlet for bark (especially softwood species). Composting operations also rely on wood residues as a feedstock for mixing with sewage sludge, farm manure, and food wastes. Composite wood products industries such as particle board and oriented-strand board use various wood residues. Food flavoring industries like meat smoking use wood wastes as well. Unfortunately, little data exist on the exact consumption from each of these markets for the seven-state region.

Of the three categories listed in Table 4, it can be generally assumed that harvest residues (13.86 million dry tons per year for the seven states) are the untapped resource. It should be noted again, however, that to cost effectively extract these residues, whole-tree harvesting systems are essential. Therefore, the portion of the harvest residues generated by mechanical cut-to-length and manual stem-only harvesting are not accessible. None of the studies assessed in the literature review directly mention this point.

1.4.2 Summary of Forest Capacity for Harvested Wood Fuel Beyond "Residues"

While harvest residues have a certain potential to supply future growth of biomass energy in the southeastern United States, there is a limit to how far these resources can go in light of the gradual decline in timber harvesting over the past decade. Less wood cut for traditional markets equals fewer residues for biomass energy. At some point, biomass markets may prefer a more reliable source of fuel coming from wood harvested for the purpose of energy. Few of the studies examined in the literature review explore this potential.

To give an accurate picture of whether the broader forest resource could support the potential increased demand from biomass energy beyond just the use of harvest residues, a detailed analysis for the seven-state region is needed. This was not feasible given the scope, timeline, and budget of this study. The following section provides an extremely basic and overly simplified assessment of the forest resource to supply wood above and beyond the current demands. *This information is not intended to present accurate estimations; these numbers are for conversational purposes only.* It should be noted that forests are extremely complex and dynamic systems and any effort to quantify their inventory, growth, and capacity to supply additional amounts of wood fuel should be interpreted as being an oversimplification with a wide margin of error.

In an effort to examine the potential capacity for expanded use of forest biomass evenly across the seven-state region using consistent data and methods that are "apples to apples," we used an approach that would provide a quick-glimpse sense of the resource capacity. This approach makes numerous assumptions and takes several basic steps:

1. Assume that all the urban wood, and primary and secondary wood residues all have existing markets and that any new market growth for biomass energy will be met with harvested wood
2. Identify the total forestland land area in the seven-state region
3. Identify the total amount of standing forest inventory on that forestland footprint
4. Identify the amount of net annual growth[9] of new wood

Table 5. USDA Forest Service FIA Data for Seven-State Region[10,11]

	Forestland Area (Acres)	Total Inventory[12] (GT)	Net Growth (GT)	Removals (GT)	Net (GT)
Virginia	15,900,000	1,009,323,529	30,117,647	19,173,235	**10,944,412**
North Carolina	18,600,000	1,052,941,176	43,000,000	33,764,706	**9,235,294**
South Carolina	12,900,000	632,352,941	35,294,118	19,676,471	**15,617,647**
Georgia	24,800,000	1,102,941,176	58,823,529	47,058,824	**11,764,706**
Florida	16,900,000	567,647,059	23,823,529	17,617,647	**6,205,882**
Alabama	22,900,000	835,294,118	49,676,471	37,705,882	**11,970,588**
Tennessee	13,800,000	761,764,706	24,941,176	17,647,059	**7,294,118**
TOTAL	**125,800,000**	**5,962,264,706**	**265,676,471**	**192,643,824**	**73,032,647**

5. Identify and subtract the rate of annual removals for the seven-state region
6. Calculate the net supply of annual growth beyond current removals
7. Make more assumptions regarding the percentage of this amount that is available

Table 5 above presents this approach in detail for each state.

Knowing how much the forests are growing and what level of harvest can be sustained over time gives a basic picture of wood fuel availability and the viability of woody biomass energy.

When forests are examined from a broad perspective, wood inventory can be compared to money invested in a bank account that earns interest annually. The total annual growth of trees in a forest is analogous to the interest earned on capital invested. A wise financial investor strives to spend only the annual interest earned each year and not dip into the principal. Forests are the same: Sound forest management policy within a state or region limits harvesting to within a range that approximates the amount of annual growth so that growth-to-removal ratios are maintained in rough equilibrium.

For the purpose of this assessment, the net annual growth of new amounts of wood was chosen as the indicator of how much wood the forests of these states can provide on a sustained-yield basis.

On the surface, the data presented above indicates that there is more than 73 million green tons of annual growth of new wood beyond the current demands for timber products in the seven-state region. It should be noted, however, that the FIA data above is focused on the growing stock portion of the total forest inventory and does not account for the amount of top and limb wood. Thus, in theory there is more than that. While 73 million green tons of new wood annually seems like a lot, the reality is that it is dramatically less. Forest management and periodic harvesting occurs only on a portion of the forested footprint and therefore, physical, ecological, and social constraints on the land area

1. WOOD SUPPLY REVIEW *(cont'd)*

on which supply is estimated must be taken into account. Normally, detailed modeling would be conducted to factor such constraints (steep slopes, stream buffers, critical wildlife habitat, landowner attitudes, parcel size, etc.), but as that was beyond the scope of this study, we applied an overly simplistic assumption of 50 percent reduction to crudely account for these factors. This yields an estimated 36.5 million green tons of un-utilized annual growth beyond current market demands. This assumes that all of this annual growth beyond current removals would be available exclusively to energy markets and would not simultaneously feed other traditional timber markets. This is an unlikely scenario even though some forecasts indicate that no other wood market is poised to grow as significantly in the future as biomass energy.

If all this wood was utilized for biomass energy in the future, it translates to an average increase in harvesting of 0.58 green tons per acre per year (spread over the total forested footprint of each state). This 36.5 million green ton amount will be revisited in greater detail in Section 1.5.2. Again, it must be emphasized that these numbers are for discussion purposes only and do not represent any estimates (implied or otherwise) by the authors of how much wood could actually be available in the future.

1.5.0 ASSESSMENT OF THE RENEWABLE PORTFOLIO STANDARDS

This section explores both the existing state RPS (mandatory and voluntary) and the potential for a federal Renewable Energy Standard.

1.5.1 Current State Renewable Energy Portfolio Standards

At the present time, only three of the seven states in this study area have Renewable Energy Standards—Virginia, North Carolina, and Florida. Of these three states, only North Carolina's standard is mandatory—Virginia and Florida's are voluntary. The following section provides further details of these current standards.

1.5.1.1 Virginia

Virginia enacted a *voluntary* renewable energy portfolio goal in 2007 and further legislation was passed in 2009 to expand the goal—encouraging investor-owned utilities to purchase a percentage of the power sold from renewable energy sources. In addition, the Commonwealth of Virginia offers a performance incentive to participating utilities in the form of an increased rate of return (profit) for each "RPS Goal" attained. Electricity must be generated or purchased in Virginia or in the interconnection area of the regional transmission entity.

The voluntary targets set out in the standard are defined as percentages of the amount of electricity sold in 2007 (the "base year"), minus the average annual percentage of power supplied from nuclear generators between 2004 and 2006.

Table 6. Virginia RPS Schedule	
	Target
RPS Goal I:	4% of base year sales in 2010
RPS Goal II	Average of 4% of base year sales in 2011 through 2015, and 7% of base year sales in 2016
RPS Goal III	Average of 7% of base year sales in 2017 through 2021, and 12% of base year sales in 2022
RPS Goal IV	Average of 12% of base year sales in 2023 and 2024, and 15% of base year sales in 2025

Investor-owned electric utilities can gain approval to participate in the voluntary RPS program from the Virginia State Corporation Commission, the entity that oversees utilities, if the utility demonstrates that it has a reasonable expectation of achieving the 12 percent target in 2022.

Eligible energy resources include solar, wind, geothermal, hydropower, wave, tidal, and biomass[13] energy.

- Onshore wind and solar power receive a double credit toward RPS goals
- Offshore wind receives triple credit toward RPS goals
- Existing renewable energy generators like older hydro are eligible for RPS compliance

1.5.1.2 North Carolina

North Carolina's Renewable Energy and Energy Efficiency Portfolio Standard (REEPS) was established by Senate Bill 3 in August 2007. It requires all investor-owned utilities in the state to supply 12.5 percent of 2020 retail electricity sales (in North Carolina) from eligible energy resources by 2021. Municipal utilities and electric cooperatives must meet a target of 10 percent renewables by 2018.

Under this standard, eligible energy resources include solar-electric, solar-thermal, wind, small hydropower, ocean wave energy, biomass, landfill gas, CHP using waste heat from renewables, hydrogen derived from renewables, and electricity-demand reduction. Up to 25 percent of the requirement may be met through energy efficiency technologies, including CHP systems powered by non-renewable fuels. After 2021, up to 40 percent of the standard may be met through energy efficiency.

The overall target for renewable energy includes technology-specific targets "carve outs" or "set asides" of 0.2 percent solar by 2018, 0.2 percent energy recovery from swine waste by 2018, and 900,000 megawatt-hours (MWh) of electricity derived from poultry waste by 2014.

The compliance schedule for investor-owned utilities appears in Table 7 on the following page.[14]

1. WOOD SUPPLY REVIEW *(cont'd)*

A typical biomass power generation plant of 20 MW per hour capacity would require approximately 250,000 green tons of woody biomass fuel annually.

Table 7. Compliance Schedule for Investor-Owned Utilities

Year	Percent Target from Eligible Renewable Energy	"Set Asides" for Specific Sources
2010	0.02%	From solar
2012	3%	0.07% from solar 0.07% from swine waste 170,000 MWh from poultry waste
2013	3%	0.07% from solar 0.07% from swine waste 700,000 MWh from poultry waste
2014	3%	0.07% from solar 0.07% from swine waste 900,000 MWh from poultry waste
2015	6%	0.14% from solar 0.14% from swine waste 900,000 MWh from poultry waste
2018	10%	0.20% from solar 0.20% from swine waste 900,000 MWh from poultry waste
2021	12.5%	including 0.20% from solar + 0.20% from swine waste + 900,000 MWh from poultry waste

Utilities must demonstrate compliance by purchasing renewable energy credits (RECs) and a REC is equivalent to 1 MWh of electricity derived from a renewable energy source, or an equivalent amount of thermal energy in the case of CHP and solar water heating, or 1 MWh of electricity avoided through an efficiency measure. Any excess RECs accumulated by a utility may be applied to the next year's compliance target. Utilities may use unbundled RECs from out-of-state renewable energy facilities to meet up to 25 percent of the portfolio standard.

It is important to note that there is no minimum target for biomass energy from woody biomass sources, however, the commission will provide triple credit for every one REC generated by the first 20 MW of a biomass facility located at a "cleanfields renewable energy demonstration park." A typical biomass power generation plant of 20 MW per hour capacity would require approximately 250,000 green tons of woody biomass fuel annually.

1.5.1.3 Florida

Florida does not have a state-wide RES, however, in November 1999, JEA, a municipal utility servicing the greater Jacksonville area, signed a Memorandum of Understanding with the Sierra Club and the American Lung Association of Florida to formalize the municipal utility's commitment to generate at least 7.5 percent of its electric capacity from green energy sources by 2015. Eligible renewable energy resources include solar, biomass, biogas (methane from landfills and sewage treatment plants), and wind as well as specific efficiency projects.

1.5.1.4 Discussion of Current State Standards

It is unclear how much, if any, new woody biomass electric generation capacity will occur as a direct result of the voluntary standards set in Florida or Virginia. Although North Carolina has a mandatory standard for specific levels of renewable energy by specific dates, it is also unclear how much, if any, new biomass power generation capacity will be developed as a direct result of this policy. Certainly the triple credit applied to the first 20 MW of capacity of a biomass plant in North Carolina is a strong incentive that could result in an additional demand of 250,000 green tons of woody biomass. Given the emphasis on both poultry and swine manure in the North Carolina standard, it is also feasible that the first 20 MW that receives this triple REC credit could be fired with farm manure rather than wood.

Without any "set aside" specifically for woody biomass, it is unclear how much, if any, biomass energy development will result directly from these policies. Will other renewables (wind, solar, hydro, swine or poultry manure) be developed first and meet the targets? Will a REC price go high enough to make electric generation using woody biomass more attractive to developers? Any effort to predict the cause-and-effect relationship between a voluntary or mandatory RPS and the resulting demand from forests is highly speculative at best.

Yet, numerous new biomass power plants are being proposed as well as proposals to convert existing coal plants to burn biomass fuel. Given the flurry of biomass project proposals prior to the existence of any meaningful RPS, the question becomes what is currently driving this development activity? There are several modest incentives available to biomass power plants that improve the economics beyond market wholesale rates for sale of electricity. Interviews with plant managers and experts in the field of electric power regulation and development and further analyses of federal subsidies indicate that, generally, the most important current federal incentive is the Production Tax Credit, or PTC ($10 per MWh). Select states in the United States such as Massachusetts have adopted aggressive RPS policies that have created RECs ranging $0.02-$0.03 per kWh. While the value of a REC is higher, the price varies significantly in the marketplace with the cycling of RPS requirements, emergence of new technologies, construction of new renewable energy facilities, the state of the economy, and demand for electric power. While less valuable at only $10/MWh, the federal PTC is a more stable source of income for biomass plants over time.

Without, a clear economic incentive like a REC or the PTC for the biomass plants, many utilities in the Southeast proposing to build biomass power plants would likely be forced to request a rate increase from the state regulatory agencies to absorb the higher costs of electricity from biomass. While dozens of proposals to build biomass power plants are under development, historically only a very small percentage of the total proposals ever get built.

While dozens of proposals to build biomass power plants are under development, historically only a very small percentage of the total proposals ever get built.

1. WOOD SUPPLY REVIEW *(cont'd)*

1.5.2 Potential for a National Renewable Energy Portfolio Standard

For the purpose of this study, we were asked to explore the impact of the passage of a federal RES. There are currently 36 states in the United States with some form of a RES and these state standards vary widely in their target percentages and due dates. The resulting patchwork of energy policies is often confusing and chaotic. In 2010, a group of six US senators introduced a bill to adopt a federal RES. While the bill did not pass, it has raised the energy sector's awareness of what impact such a federal standard could have on our energy portfolio in the future.

At this time, it is unclear that if a federal standard were passed, what the overall target percentage, the target dates, and what specific "set asides" for various allowable technologies would be. Furthermore, the extent that each state had to meet these federal targets on their own or whether the targets could be met when averaged for all 50 states, is also unknown. There is no reliable way to predict how much woody biomass demand would be created by the passage of a federal RES at this time.

Given the numerous variables and uncertainties mentioned, and in an effort to explore the impacts of a federal RES, we must make some assumptions to form a series of "what if" scenarios. Let's start with the assumption that a federal RES is applied evenly to each state and requires compliance at the state level, not averaged up to the national level. Let's also assume that the federal RES contains a specific "set aside" for biomass and more specifically for woody biomass as a subset to the biomass category.

Table 8. US Energy Information Administration State Energy Data System – 2009 Electric Consumption

	Total Electric Consumption (trillions of Btu)
Virginia	370.1
North Carolina	435.6
South Carolina	260.7
Georgia	446.2
Florida	766.8
Alabama	282.7
Tennessee	322.9
TOTAL	**2,885.0**

Tables 9 and 10 below examine a scenario where a federal 15 percent RES target is achieved using forest biomass as fuel to achieve 20 percent of that overall target (or 3 percent of the total).

Table 9. Calculated Target Amount of Energy to Be Met from Biomass

	RPS Target	Resulting Amount of Energy (trillions of Btu)	Assumed % for Biomass	Amount of Energy from Biomass (trillions of Btu)
Virginia	15%	55.5	20%	11.1
North Carolina	15%	65.3	20%	13.1
South Carolina	15%	39.1	20%	7.8
Georgia	15%	66.9	20%	13.4
Florida	15%	115.0	20%	23.0
Alabama	15%	42.4	20%	8.5
Tennessee	15%	48.4	20%	9.7
TOTAL		**432.8**		**86.6**

Assuming 1.22 green tons per MWh (e). Numbers may not sum due to rounding.

Table 10. Comparison of Wood Needed to Meet Target and Estimated Supply

	50% of Annual Growth beyond Annual Harvest (as calculated in Section 1.4.2)	Green Tons Required to Meet 15% RES with 20% from Forest Biomass	Difference
Virginia	5,472,206	3,977,237	1,494,969
North Carolina	4,617,647	4,681,125	-63,478
South Carolina	7,808,824	2,801,583	5,007,241
Georgia	5,882,353	4,795,037	1,087,316
Florida	3,102,941	8,240,328	-5,137,387
Alabama	5,985,294	3,038,003	2,947,291
Tennessee	3,647,059	3,470,008	177,051
TOTAL	36,516,324	**31,003,322**	1,494,969

Numbers may not sum due to rounding.

1. WOOD SUPPLY REVIEW *(cont'd)*

In Section 1.4.2, we calculated (in grossly oversimplified terms) that there is 36.5 million green tons of forest capacity (new annual forest growth in excess of current removals), and that to meet a 15 percent federal RES with 20 percent coming from woody biomass, approximately 31 million green tons would be needed. While the total number of tons needed to meet the federal RES targets are less than the calculated values representing the total potential resource, on the state level, both Florida and North Carolina indicate a greater demand for woody biomass than the supply from forest biomass.

Sensitivity analysis indicates that when the percentage of the 15 percent RES that comes from woody biomass is decreased from 20 percent to 15 percent, all states with the exception of Florida have sufficient resources to meet the potential demand from that policy scenario. In Florida, even when the percentage is further lowered to 10 percent coming from woody biomass, our calculations indicate insufficient woody biomass resources. Florida has considerable forest resources in the northern half of the state, but this result is due to the extremely high levels of electric demand in Florida—nearly twice that of the second largest consumer of electricity, Georgia.

Table 11. Comparison of Wood Needed to Meet Target and Estimated Supply

	50% of Annual Growth beyond Annual Harvest (as calculated in Section 1.4.2)	Green Tons Required to Meet 15% RES with 30% from Forest Biomass	Difference
Virginia	5,472,206	5,965,856	-493,650
North Carolina	4,617,647	7,021,688	-2,404,041
South Carolina	7,808,824	4,202,374	3,606,450
Georgia	5,882,353	7,192,556	-1,310,203
Florida	3,102,941	12,360,492	-9,257,551
Alabama	5,985,294	4,557,005	1,428,289
Tennessee	3,647,059	5,205,012	-1,557,953
TOTAL	**36,516,324**	**46,504,982**	**-9,988,658**

Numbers may not sum due to rounding.

On the contrary, when the sensitivity analysis increased the amount of woody biomass contributing toward a 15 percent RES from 20 to 30 percent, more than 46 million green tons were required—leaving nearly all the states (with the exception of South Carolina and Alabama) in a woody biomass deficit. Table 11 on the previous page illustrates the conceptual outcome of meeting a 15 percent federal RES with 30 percent coming from forest biomass in the seven-state region. Under this scenario only South Carolina and Alabama have sufficient in-state forest resources to meet the state-level energy targets.

It is important to note that our calculations do not closely match with the model runs conducted by Galik and Abt because our crude calculations were static projections of growth over removals and do not directly account for any displacement of pulpwood. The Galik and Abt study used sophisticated models that accounted for some levels of displacement of pulpwood harvest over time. Any number of further scenarios of different federal RES levels and different woody biomass targets could be calculated but that did not fall within the scope of this study.

Because there was no significant shortfall in woody biomass resources when a 15 percent RES using 20 percent woody biomass was examined, no further assessment of agricultural residues or dedicated energy crops were required to meet this particular demand scenario. With a 30 percent biomass component for a 15 percent RES, however, there is a significant woody biomass deficit in most of the study states. Furthermore, if the pellet market continues to expand and increases its wood sourcing throughout the southeastern United States, further constraints would be placed on the resource and a 15 percent RES using 20 percent woody biomass may have difficulty achieving its target. Of course, conversely, if several pulpmills in the southeastern region shut down in the near future, that would free up a considerable amount of wood supply.

1. WOOD SUPPLY REVIEW *(cont'd)*

1.6.0 REVIEW OF FEDERAL RENEWABLE FUELS STANDARD

The federal Renewable Fuels Standard (RFS) program was established under the Energy Policy Act of 2005 and created the first renewable fuel mandate of 7.5 billion gallons of renewable fuel to be blended into gasoline by 2012. A proposed update is under development by EPA with a planned release date of November 2011 for the compliance year of 2013. The proposed targets call for a mixture of cellulosic biofuel, biomass-based diesel, advanced biofuel, and renewable fuel adding up to 15.2 billion gallons of equivalent ethanol (EPA, 2011).

A federal RFS could have an impact on woody biomass resources and several years ago there was strong evidence to suggest that cellulosic ethanol would have a major role in the future demand put on our forests. Over the past two or three years, however, less emphasis has been given to this use due to the continuing struggles to achieve commercialized production of cellulosic ethanol from wood fibers.

"One potential driver of demand for forest biomass is the federal Renewable Fuel Standard (RFS), which sets minimum standards for how much gasoline and diesel fuel must be produced from renewable sources each year. However, the initial announced targets have been steadily lowered in the face of shortfalls in production, and it is expected that energy crops and other sources would likely be preferred over wood feedstock for producing cellulosic ethanol. Our model runs therefore assume no forest biomass is used to meet RFS-driven demand for biofuels." (La Capra Associates, 2011)

Because all evidence clearly suggests that woody biomass will play only a minor role in producing liquid transportation fuels and that the technology development to implement such a demand is still years away, we have chosen to not explore the implications further.

For hypothetical purposes, let's explore the 36.5 million green tons of conceptual annual supply from the seven-state region, and see how many gallons of cellulosic ethanol that would yield (assuming fully commercialized plants get built). Assuming a yield of 40 gallons per green ton, nearly 1.5 billion gallons of ethanol could be produced, leaving no further woody biomass resources for expansion of any other market. This would account for slightly less than 10 percent of the national RFS2 target (US Department of Energy EERE, 2011). If cellulosic ethanol production expands in the near future, however, there is a high likelihood that agricultural biomass resources will contribute significantly.

1.7.0 CONCLUSIONS

Most studies conducted in the past six years quantify the gross or total amount of woody biomass material generated on an annual basis and do not quantify how much is already being used. Most of these studies focus on residues produced from other primary activities while evidence suggests nearly all the mill and urban wood residues are already used by existing markets.

The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).

Whether logging slash, whole trees, or pulpwood will be used by the expansion of biomass energy in the future will depend on:

1. Which market the wood is going to (pellet mills need high-quality fiber from pulpwood and biomass plants are less particular about quality)
2. How much demand increases within the pellet and power market sectors over time
3. What happens with the pulp and paper industry in the southeast region in the future

Prior to 2009, most fuel availability studies presented estimates of supply without any acknowledgment of the influence price has on the availability of these woody biomass resources. Since then, most fuel supply assessments have begun factoring the economics and present the availability of the resources as supply curves depicting the amount of material potentially available at different price points. The original and the updated Billion-Ton Study are good examples.

It is important to point out that different studies have examined the economics using different indicators, making it difficult to compare results among the studies. Several studies only examined stumpage prices paid to landowners (Galik and Abt, 2011) for wood fuel, which do not reflect any cost to harvest, extract, process, or transport, while other studies focus exclusively on prices paid "roadside" for yarded wood (Perlack and Stokes, 2011), which do not reflect the cost of transport. Still other studies focus on the total delivered prices paid at processing facilities (mills or power plants). For a clear assessment of the economics of woody biomass resources, the total delivered price paid by the receiving facilities is the best indicator to use.

Various studies reviewed in this chapter used widely divergent assumptions regarding what percentage of the total amount of logging residue can be recovered from a harvested area. The range observed in the studies was from roughly 50-100 percent. While examining how much wood fuel could be generated if 100 percent of this material was recovered may be useful for academic purposes, it is unrealistic to assume that such a high level can and should be realized. It is unclear from these studies whether these recovery rates are intended to be applied to all harvest operations where only a percentage of the residue is gathered—factoring logistical and ecological reasons for not recovering more—or if this recovery rate applies to taking all residues from only a percentage of the harvest operations. This is an important point because ideally, a study would look at both issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered.

The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).

1. WOOD SUPPLY REVIEW *(cont'd)*

Logging residue amounts will be difficult to access due to extraction methods. Where whole-tree harvesting systems can be used, these residues can be cost-effectively accessed. Where mechanized cut-to-length and manual stem-only harvesting are used, these residues will not be easily accessible. Further analysis determining how much whole-tree harvesting systems versus stem-only-harvesting systems are used in this region would be very useful.

Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential. Alabama and Tennessee both had very little publicly available reports estimating biomass resources.

Our quick supply estimate exercise suggests that there is likely enough wood supply in the forests to meet a 15 percent federal RES standard applied to each of the seven states (with the exception of Florida and possibly North Carolina) when woody biomass sourced from local forests accounts for no more than 20 percent of the overall renewable generation target. It also appears, however, that adequate wood resources are quite sensitive to the RES allocation; if for example 30 percent of a 15 percent RES was allocated to forest biomass, it is likely there would not be enough wood fuel available within the region. A more aggressive RES standard for biomass leads to a higher likelihood of shortages and a greater probability of pulpwood displacement.

Capacity to access and utilize residues is also a function of how much roundwood harvest occurs. More demand for roundwood generates more residues. The extent to which biomass power plants transition their wood procurement away from residues and toward roundwood is governed by the strength of the rest of the forest products industry. If the forest products industry strengthens as a result of greater lumber demand, they will increase their wood fiber consumption and as a result, biomass power plants will be able to procure more residues at a lower cost and less pulpwood at a higher cost. If the forest products industry as a whole continues to contract, however, biomass power plants will likely transition toward procurement of chipped fuel from whole-trees *assuming* they can absorb the higher cost associated with that transition. Future demand for roundwood from the pulp and pellet industries will play a role in determining how much roundwood is used for power production.

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood. In fact, this is already happening. If pellet demand continues to grow and results in increased levels of roundwood harvest, then pellets may well determine the future level of harvest residue available for the power plants to utilize.

Therefore, pellet mills and biomass power plants have somewhat complementary (almost symbiotic) procurement needs. Pellet production, especially the export market to Europe, will continue to play the wildcard role.

While this report has identified and probed some of the issues regarding the forest resource's capacity to produce more energy in the Southeast, there are numerous areas where key information is missing. More specific research is needed in the areas of: existing forest residue utilization, use of different harvesting systems, a comprehensive wood fiber assessment for the entire seven state region, the price elasticity of demand between fuel chips and pulpwood, and the likely impacts of federal renewable energy standards on the economic incentives that drive project development. In addition, further study is needed to explore the relation biomass sourcing has on harvest intensity and the potential impacts on forest biodiversity, wildlife habitat, water quality, and soil health and productivity.

2. TECHNOLOGY PATHWAYS

2.1.0 INTRODUCTION TO TECHNOLOGY PATHWAYS

This discussion focuses on those technologies and applications—electricty generation and CHP—that are already well established, or are technologically achievable in the immediate future should policies wish to guide additional biomass in these directions.

Biomass in various forms can be used for a range of energy options, through a variety of technologies, to achieve various end purposes. In this chapter, several pathways are examined to give the reader an understanding of this range, but also to inform and model potential demand for fuel supply in the future and understand the carbon implications for these choices. This assessment looks at the use of existing low-grade forest resources in the seven-state study region as well as switchgrass, an agricultural crop that can also be pelletized and used directly for biomass energy. Other sources of nonforest-based biomass—such as wood waste from construction debris or other sources sometimes considered as biomass, such as municipal waste—were also considered. The analysis of switchgrass was based on information from a literature review that did not provide adequate or comparable information to what was available from our forest biomass modeling. The switchgrass analyses in this report are incomplete and are included for information and comparative purposes only.

With respect to the forest's low-grade wood resource potentially used for energy, the end products can be solid (cordwood, woodchips, or wood pellets), liquid (pyrolysis oil or cellulosic ethanol), or gas (synthetic or producer gas made through "gasification" and "bio-char" technologies). The end uses can also range from residential to industrial applications, and fall into three general categories: electricity power production, thermal applications for heating or using thermal heat for space cooling in vapor absorption chillers, or emerging technologies such as cellulosic ethanol or gasification. Between the first two end-use categories is combined heat and power (CHP), which can be thermal-led (optimizing heat production with some electricity produced) or electricity-led (sizing the plant for optimal electricity production and using some of the heat).

Some of these technologies and applications are well established and have been in place for years. Others are pre-commercial or still under development. In the sections that follow, we describe two main currently available applications for electricity and CHP. This discussion focuses on those technologies and applications that are already well established, or are technologically achievable in the immediate future should policies wish to guide additional biomass in these directions. These are the applications most likely to place demands on southeastern forest resources in the short term.

Among these application areas, 12 technology pathways were selected to describe how biomass might be used. These pathways are used to evaluate and compare different scenarios for forest management and carbon impacts if policies are directing biomass use toward stand-alone electrical generation, and to enable comparison to the most likely fossil fuel alternatives (out of which four fossil fuel pathways were chosen). The pathways and full data assumptions are displayed in Appendix A.

2.1.1 ELECTRICITY GENERATION

2.1.1.2 Current Sources of Electrical Supply

The seven-state region produced a total of 858,238,084 megawatt hours (MWH) of electricity in 2009, the most recent year for which full data is available (EIA, 2011). Of the total electrical generation in the region, 38 percent is generated by coal power plants (345,882,814 MWH). The second largest electrical source for the region is nuclear power, comprising 29 percent of the total regional generation (248,688,358 MWH). Although natural gas is the largest fuel source for electrical generation in Florida, for the seven-state study region it is the third largest fuel source for electrical generation with 197,687,923 MWH (28 percent of total regional generation). Renewable energy accounts for only 6 percent of electrical generation in the seven-state area, with hydroelectric plants producing 4 percent of the regional electrical generation. The state energy profiles produced by the EIA do not tabulate statistics for biomass electrical generation, which is included in the category of "other renewables" and which accounts for 2 percent of the regional electrical generation.

Tables 12-18 below and on the following pages summarize the state electrical generation profiles for 2009.

Table 12. Virginia Electrical Generation Profile

Total Electric Industry	**70,082,066**
Coal	25,599,288
Petroleum	1,087,660
Natural Gas	12,201,384
Other gases[15]	-
Nuclear	28,212,252
Hydroelectric	1,478,630
Other renewables[16]	2,417,519
Pumped Storage	-1,334,709
Other[17]	420,042

2. TECHNOLOGY PATHWAYS *(cont'd)*

Table 13. North Carolina Electrical Generation Profile	
Total Electric Industry	**118,407,403**
Coal	65,082,782
Petroleum	296,859
Natural Gas	4,851,885
Other gases[15]	-
Nuclear	40,847,711
Hydroelectric	5,171,257
Other renewables[16]	1,893,404
Pumped Storage	43,077
Other[17]	220,428

Table 14. South Carolina Electrical Generation Profile	
Total Electric Industry	**100,125,486**
Coal	34,477,512
Petroleum	523,484
Natural Gas	9,780,193
Other gases[15]	-
Nuclear	52,149,734
Hydroelectric	2,332,005
Other renewables[16]	1,747,971
Pumped Storage	-976,443
Other[17]	91,029

Table 15. Florida Electrical Generation Profile	
Total Electric Industry	**217,952,308**
Coal	54,003,072
Petroleum	9,221,017
Natural Gas	118,322,308
Other gases[15]	6,800
Nuclear	29,117,877
Hydroelectric	208,202
Other renewables[16]	4,340,332
Other[17]	2,732,701

Table 16. Georgia Electrical Generation Profile	
Total Electric Industry	**128,698,376**
Coal	69,478,196
Petroleum	649,674
Natural Gas	20,505,749
Other gases[15]	-
Nuclear	31,682,579
Hydroelectric	3,259,683
Other renewables[16]	2,825,170
Pumped Storage	271,988
Other[17]	25,337

2. TECHNOLOGY PATHWAYS *(cont'd)*

Table 17. Alabama Electrical Generation Profile	
Total Electric Industry	**143,255,556**
Coal	55,608,724
Petroleum	219,274
Natural Gas	31,617,083
Other Gases[15]	134,728
Nuclear	39,716,204
Hydroelectric	12,535,373
Other Renewables[16]	3,049,857
Other[17]	374,314

Table 18. Tennessee Electrical Generation Profile	
Total Electric Industry	**79,716,889**
Coal	41,633,240
Petroleum	186,930
Natural Gas	409,321
Other gases[15]	12,010
Nuclear	26,962,001
Hydroelectric	10,211,962
Other renewables[16]	950,468
Pumped Storage	-649,832
Other[17]	788

2.1.2 CURRENT BIOMASS POWER PLANTS

The region is home to 17 biomass electrical plants. Detailed information is available for 12 of these plants, with a total capacity of 246 megawatts (Oak Ridge National Laboratory, 2011).

Table 19. Current Biomass Power Plants

Plant Name	State Name	Capacity MW	Online Year
Bryant Sugar House	Florida	6.63	1962
Stone Container Florence Mill	South Carolina	7.63	1963
DG Telogia Power	Florida	12.50	1986
Stone Container Hopewell Mill	Virginia	20.35	1980
Jefferson Power LLC	Florida	7.50	1990
Craven County Wood Energy LP	North Carolina	45.00	1990
Port Wentworth	Georgia	21.60	1991
Ridge Generating Station	Florida	47.10	1994
Multitrade of Pittsylvania LP*	Virginia	26.55	1994
Okeelanta Cogeneration	Florida	24.97	1996
Scott Wood	Virginia	0.80	2003
Buckeye Florida	Florida	25.00	2006
	Average Capacity	**20.47**	
	Total Capacity	**245.63**	

** This plant is now owned by Dominion and has a 79 MW capacity. Dominion has announced it will increase its wood requirement to 850,000 green tons/year.*

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.2.0 SUMMARY OF PATHWAYS

Pathways #1-4 describe using woodchip fuel for electrical generation.

Pathway #1 describes the average existing biomass electrical generating facility, with a typical size of 20 MW and a typical efficiency of 26 percent.

Pathway #2 describes a typical new biomass plant as proposed in the region, with a larger plant capacity of 50 MW and a higher efficiency of 28 percent.

Pathway #3 considers co-firing woodchips with coal in existing coal power plants at a balance of 10 percent woodchips and 90 percent coal. Biomass co-firing in existing coal plants would utilize biomass fuels with much lower capital investment than constructing new electrical generating stations designed to burn woodchips.

Pathway #4 considers a CHP application in a 5 MW facility with 75 percent total efficiency.

Pathways #5-7 consider using switchgrass pellets for electrical generation. The pelletization of switchgrass for use in boilers and other combustion systems is still under development. While switchgrass pellets are used in some thermal applications and have been test fired in electrical generating plants, no switchgrass electrical generation exists. Since this option is hypothetical and for the purpose of comparing the carbon implications of different types of biomass fuels, the switchgrass pathways were assumed to have the same capacities as the woodchip-fueled plants with which they are being compared.

Pathway #5 considers a 50 MW plant comparable to the new woodchip electrical generating plants considered in pathway #2.

Pathway #6 considers co-firing 10 percent switchgrass in existing coal plants.

Pathway #7 considers a CHP plant of 5 MW.

The analysis of switchgrass was based on information from a literature review that did not provide adequate or comparable information to what was available from our forest biomass modeling. The switchgrass analyses included in this report are incomplete and are included for information and comparative purposes only.

Pathways #8-10 explore electrical generation with coal.

Pathway #8 considers an average coal plant existing in the region with a capacity of 450 MW (rounded from regional average to nearest 50 MW) and an efficiency of 33 percent.

Pathway #9 considers a larger (600 MW), slightly more efficient (36 percent) coal plant typical of the size and type proposed for new coal plants in the region.

Pathway #10 is a theoretical option considering a coal CHP project similar to the proposed biomass CHP projects in pathways #4 and #7.

Pathway #11 considers a large natural gas electrical plant with an 800 MW capacity and 42 percent efficiency as representative of new natural gas plants proposed for the region.

A 12th scenario, **Pathway 2A**, was also considered as an alternative energy end use for woody biomass. Woody biomass pelletization was considered versus combustion of biomass for power generation. The pellets would most likely be exported to Europe for combustion for either heating or power generation. This scenario considers the additional carbon emissions if the biomass from the southeast region is used to make pellets, and those pellets are exported across the Atlantic to Europe and used to generate power there. Wherever they are burned, the pellets produce 765.9 pounds of CO_2 per MMBtu when combusted for electrical generation. Additional emissions result from the energy consumed in making pellets and for transportation across the Atlantic. 26.74 pounds of CO_2 would be released in the Southeast in the process of pellet production per MMBtu of pellets produced. Another 11.55 pounds of CO_2 would be released in transport from production facility to US ports and from European ports to electrical generation plants. An additional 25.87 pounds of CO_2 per MMBtu of pellets would be emitted in cross-Atlantic transport. In this scenario, some of the carbon emissions involved in pelletization would occur in the Southeast, but a good deal of the carbon emissions would occur in transportation and in Europe when the pellets are combusted.

The carbon emissions from pellet production and transport to the final end use were compared to the emissions from production and transport of woodchips (16.5 pounds per MMBtu of output), switchgrass (16.5 pounds per MMBtu of output), coal (21.3 pounds per MMBtu output), and natural gas (80.4 pounds per MMBtu of output) (Manomet, 2010). These emissions include harvesting or mining, refining and/or other fuel processing, and transport from the site of harvest or collection to processing sites, then to southeastern power plants. The carbon emissions from each fuel source for production and transportation are displayed in Table 24 on page 62.

2.2.1 Electrical Generation Pathways

Table 20 below presents the CO_2 emissions from electrical generation from the nine electrical technology pathways.

Table 20. Electrical Generation Pathway CO_2 Emissions

Electrical Generation Pathway	CO_2 Emissions (lbs/MMBtu output)
Wood (existing plants)	859
Wood (new plants)	783
Wood (exported pellets)	1,010
Coal/wood Co-firing	677
Switchgrass	829
Coal/switchgrass co-firing	669
Coal (existing plants)	643
Coal (new plants)	587
Natural gas	359

Of all the fuels considered, natural gas is the cleanest and the lowest carbon emitting due to its ability to generate power using a direct combustion turbine at higher efficiency than traditional steam turbine technologies, and the fact that it has less carbon per unit of energy.

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.2.2 CHP Options

All electrical production from combustion of fuels creates excess heat that is often wasted. In the case of power plants, excess heat is often simply released as steam from the turbine, condensed, and returned to the boiler. CHP systems seek to utilize some or all of this excess heat. As this excess heat is made into useful energy, the efficiency of the generating system increases with the proportion of heat it uses.

Electricity-led CHP is an option where power production is near a thermal demand. A 20 MW power plant produces enough heat to heat approximately 1,100 homes.[18] To date, however, the economics, incentives, and siting preferences have not resulted in power plants choosing CHP. As a result, regardless of the fuel source producing the electricity, approximately 65-75 percent of the energy value of the fuel in conventional combustion systems has been wasted as lost heat. Taking advantage of this energy value requires planning, intentional siting, and either financial or regulatory incentives that promote power producers deciding to increase the complexity of their systems by the addition of steam or hot water as a salable output. This is not the business model that has been pursued to date. Recently, with the increased appreciation of efficiency and concern about efficient use of resources, biomass power developers are beginning to incorporate some CHP in their proposals, though because of the large amount of heat available relative to potential nearby uses, these projects often make use of only a small percentage of the available heat (10-15 percent).

In contrast, thermally led CHP maximizes the demand for heat, but produces relatively little electricity. At the community scale, a typical CHP facility might produce 1-5 MW of electricity while providing enough steam for process heat and/or cooling for a small industrial park.

An important point to note is that the cost-effective scale of producing electricity alone leads to plants in the 20-50 MW size range. At this scale, it is most cost effective to produce the power, and any CHP component is a complicating factor that tends to reduce the overall cost effectiveness of the project under current policies that subsidize electrical production but do not subsidize or reward thermal energy production. At smaller-scale thermal-led CHP systems of 1-5 MW, the opposite is true—production of heat alone maximizes cost effectiveness of the project, and adding an electrical component reduces the overall economics of the project, i.e., the savings in heat help subsidize the electrical generation components.

Conventional technology requires the production of steam to produce electricity, but European commercial technologies produce electricity without steam production. These technologies include gasification where the produced gas is combusted directly in a combustion turbine, and Organic Rankine Cycle (ORC) thermal-oil technology that uses a thermal oil to gain temperature gradients necessary to produce electricity without steam so that the thermal system can be designed around low-pressure hot water. The ORC system, while more easily incorporated into a hot water-based thermal application and therefore of greater potential in smaller CHP systems (see below), is

still only approximately 20 percent efficient on its own in the production of electricity, but would be expected to be between 75-85 percent efficient in heat-led applications. Heat-led gasification can be expected to be approximately 75 percent efficient.

Pathways #4, #7, and #10 describe moderate-sized CHP systems capable of producing 5.0 MW of electricity. The first uses conventional technology, producing steam to run a turbine, and fully utilizes the 34 MMBtu/hour of heat generated to heat facilities on the order of magnitude of a college campus, a hospital, or small community. As such, the overall efficiency is rated at 75 percent, which is typical for such units. The second pathway uses gasification technology, which is just an emerging technology here in the United States. Still, there is an example of a commercial system operating since 2000 in the Town of Harboøre, Jutland, Denmark that produces 1.6 MW of electricity and heats 900 homes (BERC, 2010). The efficiency rating for this system is also 75 percent.

Table 21 below presents CO_2 emissions from energy conversion for the three CHP pathways considered.

Table 21. CHP Pathway CO_2 Emissions

CHP Pathway	CO_2 Emissions (lbs/MMBtu)
Wood	296
Switchgrass	314
Coal	295

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.3.0 EFFICIENCY

As has been discussed throughout, the efficiency with which energy value is extracted from biomass—or fossil fuel—varies according to the energy product sought and the technology pathway used to make that product. Figure 4 and Table 22 on the following pages show the range of efficiencies for the different applications and pathways selected, from most efficient to least efficient on a gross heat efficiency basis. The electrical efficiency for each option shows the percent of total energy in the fuel source that is converted into electricity. The gross thermal efficiency is the total efficiency for each option, including both the electrical efficiency and any energy captured and used as thermal energy.

It is important to recognize that what is presented is just the efficiency of the process to produce energy or fuel or product from the biomass. This does not include any losses incurred through the use of the end product. For example, for electricity, these efficiencies do not include line losses or the efficiency of a given appliance to turn remaining electricity into useful work. Similarly, for the transportation fuels, this does not include the relative inefficient (18 percent) ability of your car to take the energy value of the fuel and convert it into the work of moving you down the road. Finally, for the thermal applications, it does not include the loss of heat exchange from the thermal system to a home, or the efficiency of a home to retain heat. These examples show that further down the process more losses of the energy value of the original biomass will be incurred. They may be smaller or they may be quite large, depending on the end uses.

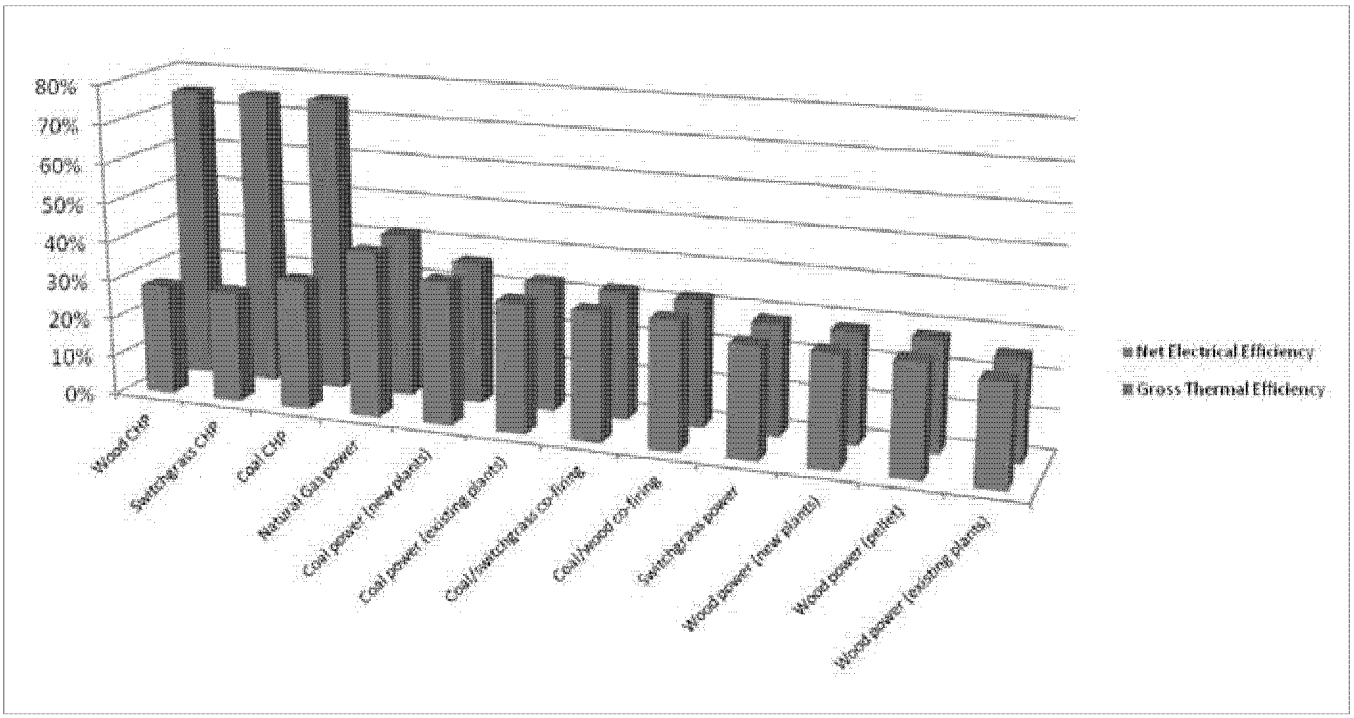


Figure 4.

Graph of Efficiency of 12 Technology Pathway Options.[19]

Table 22. Efficiency of 12 Technology Pathway Options[20]

Technology Pathway	Net Electrical Efficiency	Gross Thermal Efficiency
Wood CHP	28.2%	75.0%
Switchgrass CHP	28.2%	75.0%
Coal CHP	33.0%	75.0%
Natural Gas power	42.0%	42.0%
Coal power (new plants)	36.3%	36.3%
Coal power (existing plants)	33.0%	33.0%
Coal/switchgrass co-firing	32.5%	32.5%
Coal/wood co-firing	32.3%	32.3%
Switchgrass power	28.2%	28.2%
Wood power (new plants)	28.2%	28.2%
Wood power (pellet)	28.2%	28.2%
Wood power (existing plants)	25.6%	25.6%

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.4.0 CARBON IMPACTS

The CO_2 emissions from each of the pathways vary depending on the fuel and the efficiency of the product made. The CO_2 emissions expressed as "input" energy and the CO_2 emissions based on "output" energy reflect the efficiency of the biomass energy conversion. The carbon content on an input basis reflects only the carbon content of the fuel on a pounds per MMBtu of energy content basis before the fuel is combusted. The carbon emissions on an output basis also reflect the efficiency of the energy generation process, and reflect how much carbon has been emitted into the atmosphere after the fuel has been combusted. The input CO_2 emissions are a measure only of the pre-combustion carbon content of the fuel, while the output emissions calculate the total CO_2 emissions once the fuel has been combusted and utilized in a particular manner.

The tables and figures on the following pages reflect the different pathways. The CO_2 emissions from fuel to energy conversion are presented first on an input and output basis, followed by the CO_2 emissions from production and transportation of fuel associated with each pathway on an input and output basis, then the total CO_2 emissions for each pathway on an output basis are compared.

The emissions from production and transportation for the pellet scenario exceed the emissions due to production and transportation from any other fuel type. This is due to the assumption that the pellets will be transported to European markets for final consumption, adding 25.87 pounds of CO_2 per MMBtu of pellets. With very low-heating demands in the climate of the Southeast, however, exporting the pellets would indeed be the most likely scenario unless used for power production domestically.

As with the efficiency discussion, it is very important to note that the following tables and figures do not reflect a life-cycle analysis of these technology pathways, merely the carbon emissions resulting from the fuel-to-energy conversion and the emissions from production and transportation. While full carbon life-cycle accounting for all pathways is beyond the scope of this report, life-cycle estimates of carbon emissions for the technological options considered in Chapter 3 are provided there.

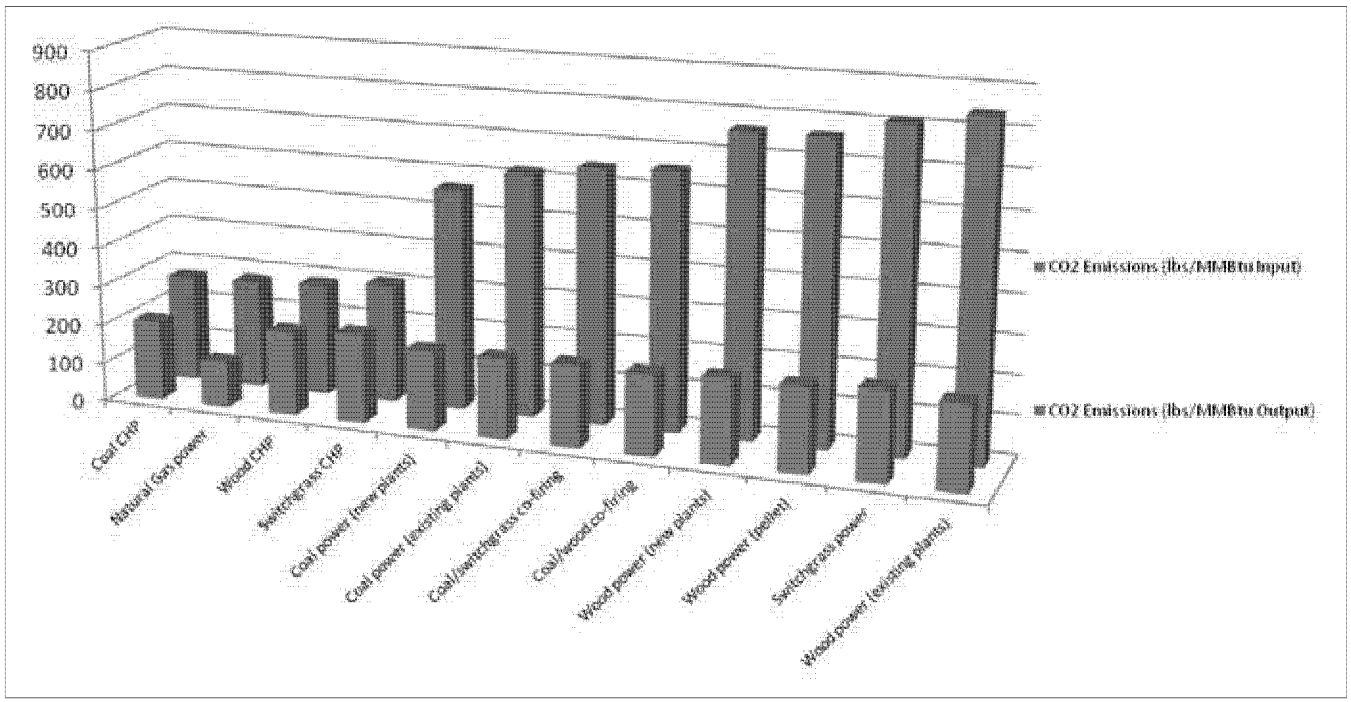


Figure 5.

Graph of CO_2 Emissions from Energy Conversion of 12 Technology Pathways.[21]

Table 23. CO_2 Emissions from Energy Conversion of 12 Technology Pathways[22]

Technology Pathway	CO_2 Emissions (lbs/MMBtu Input)	CO_2 Emissions (lbs/MMBtu Output)
Coal CHP	205.3	273.7
Natural Gas power	117.0	278.6
Wood CHP	215.7	287.6
Switchgrass CHP	229.2	305.6
Coal power (new plants)	205.3	565.6
Coal power (existing plants)	205.3	622.1
Coal/switchgrass co-firing	207.7	648.4
Coal/wood co-firing	206.3	656.3
Wood power (new plants)	215.7	765.9
Wood power (pellet)	215.7	765.9
Switchgrass power	229.2	812.6
Wood power (existing plants)	215.7	842.5

2. TECHNOLOGY PATHWAYS *(cont'd)*

Figure 6.

Graph of CO_2 Emissions from Fuel Production and Transportation of 12 Technology Pathways[23]

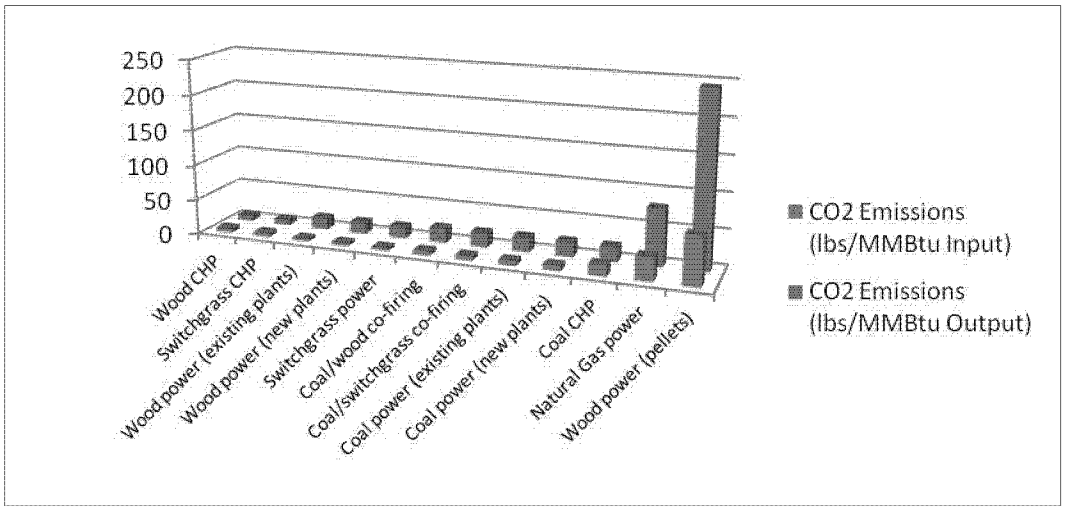


Table 24. CO_2 Emissions from Fuel Production and Transportation of 12 Technology Pathways[2]

Technology Pathway	CO_2 Emissions (lbs/MMBtu Input)	CO_2 Emissions (lbs/MMBtu Output)
Wood CHP	6.1	8.1
Switchgrass CHP	6.1	8.1
Wood power (existing plants)	4.2	16.5
Wood power (new plants)	4.7	16.5
Switchgrass power	4.7	16.5
Coal/wood co-firing	6.6	20.8
Coal/switchgrass co-firing	6.7	20.8
Coal power (existing plants)	7.0	21.3
Coal power (new plants)	7.7	21.3
Coal CHP	16.0	21.3
Natural Gas power	33.8	80.4
Wood power (pellets)	68.8	244.4

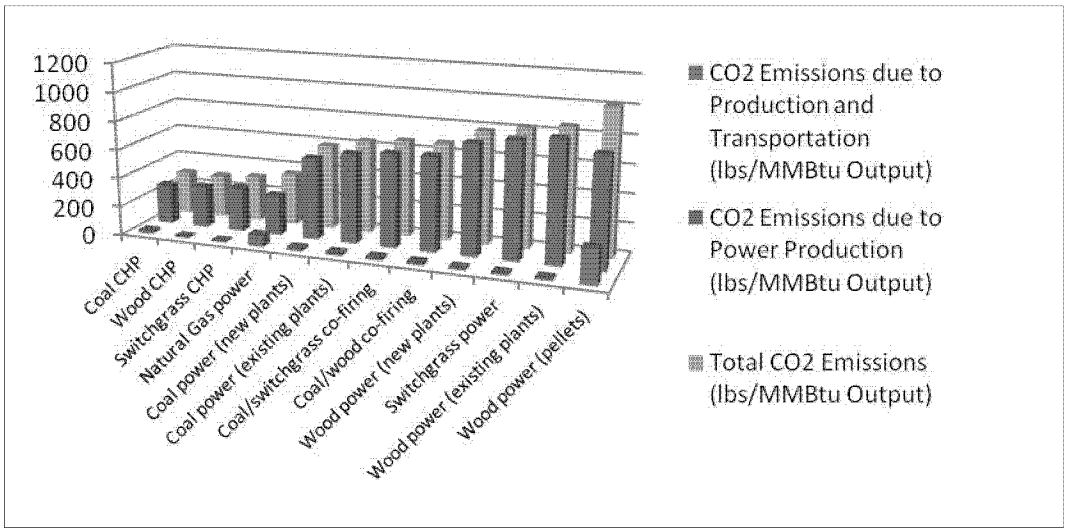


Figure 7.

Graph of Total CO_2 Emissions on Energy Output Basis of 12 Technology Pathways[25]

Table 25 . Total CO_2 Emissions on Energy Output Basis of 12 Technology Pathways[26]

Technology Pathway	CO_2 Emissions due to Production and Transportation (lbs/MMBtu Output)	CO_2 Emissions due to Power Production (lbs/MMBtu Output)	Total CO_2 Emissions (lbs/MMBtu Output)
Coal CHP	21.3	273.7	295.0
Wood CHP	8.1	287.6	295.6
Switchgrass CHP	8.1	305.6	313.6
Natural Gas power	80.4	278.6	359.0
Coal power (new plants)	21.3	565.6	586.8
Coal power (existing plants)	21.3	622.1	643.4
Coal/switchgrass co-firing	20.8	648.4	669.2
Coal/wood co-firing	20.8	656.3	677.1
Wood power (new plants)	16.5	765.9	782.5
Switchgrass power	16.5	812.6	829.2
Wood power (existing plants)	16.5	842.5	859.1
Wood power (pellets)	244.4	765.9	1010.3

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.5.0 N_2O IMPACTS

Nitrous oxide (N_2O) is a greenhouse gas with an atmospheric lifetime of approximately 120 years. Nitrous oxide is about 310 times more effective in trapping heat in the atmosphere than CO_2 over a 100-year period (EPA, 2011). EPA also reports that in 2009, 25 percent of total N_2O emissions in the United States came from fossil fuel combustion. There are currently no state or federal regulations regarding N_2O emissions. For the fuel types and energy conversion processes studies, the N_2O emissions, even on a CO_2 -equivalent basis, were insignificant compared to the CO_2 emissions.

Like the carbon emissions just mentioned, the N_2O emissions from each of the pathways vary depending on the fuel and the efficiency of the product made. Generally, the N_2O emissions expressed as "input" energy reflect the fuel the process is based on, and the N_2O emissions based on "output" energy reflect the efficiency of the product conversion, be that electricity, thermal, or fuel. Unlike the carbon accounting, the N_2O emissions calculations do not include the additional N_2O emissions from production and transport of fuels, only the energy conversion of each fuel in each pathway.

As with the efficiency and carbon discussions, it is very important to note this is not a life-cycle analysis of these technology pathways.

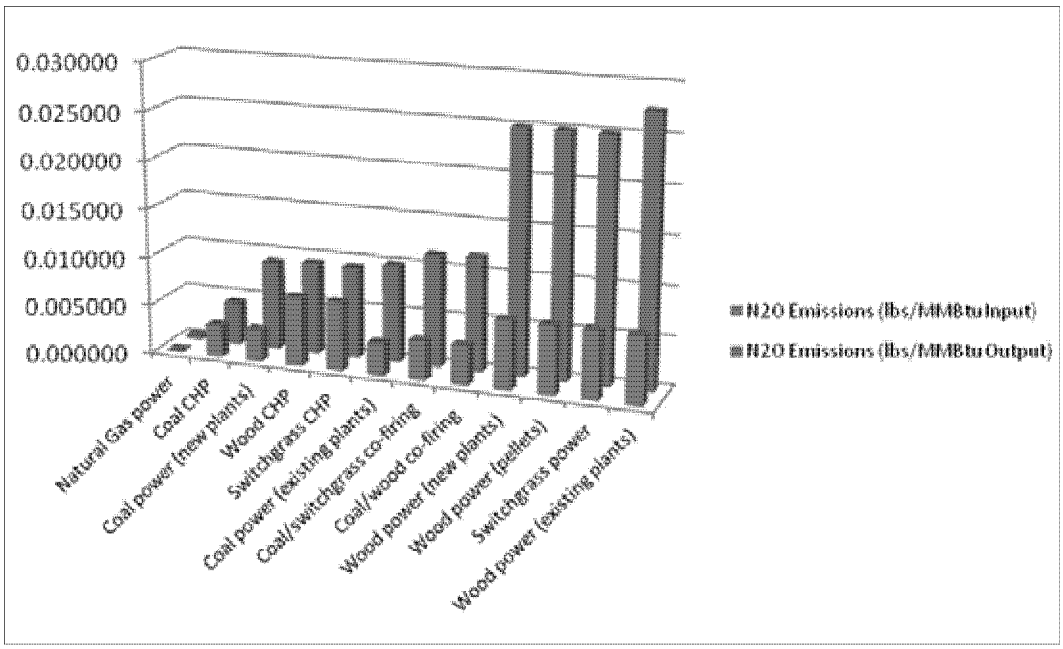


Figure 8.

Graph of N_2O Emissions of 12 Technology Pathways.[27]

Table 26. N_2O Emissions of 12 Technology Pathways[28]

Technology Pathway	N2O Emissions (lbs/MMBtu Input)	N2O Emissions (lbs/MMBtu Output)	Output N2O Emissions as Tons of CO2 Equivalent
Natural Gas power	0.000220	0.00052	0.0001
Coal CHP	0.003306	0.00441	0.001
Coal power (new plants)	0.003306	0.00911	0.001
Wood CHP	0.007054	0.00941	0.001
Switchgrass CHP	0.007054	0.00941	0.001
Coal power (existing plants)	0.003306	0.01002	0.002
Coal/switchgrass co-firing	0.004056	0.01150	0.002
Coal/wood co-firing	0.004056	0.01171	0.003
Wood power (new plants)	0.007054	0.02505	0.003
Wood power (pellets)	0.007054	0.02505	0.003
Switchgrass power	0.007054	0.02505	0.003
Wood power (existing plants)	0.007054	0.02755	0.004

3. ATMOSPHERIC CARBON ANALYSIS

3.1.0 SUMMARY

Spatial Informatics Group has provided an atmospheric carbon-balance analysis of biomass feedstock for this study. This analysis was conducted for biomass stand-alone electric power and electric-led CHP applications. Thermal energy pathways, which have significantly different life-cycle carbon due to higher efficiencies, were not considered in this analysis. We produced an analysis of existing and proposed biomass electric power facilities in the context of a forested landscape. The study area encompassed more than 88 million acres over seven states.

This study used carbon accounting principles that are consistent with accepted forest carbon protocols to examine the consequences of atmospheric carbon balance relative to a baseline that is geographically constrained to the affected area.

Our findings indicate that in the current situation, 17 biomass electric facilities generate 159 megawatts and pellet manufacturers produce 1,775,000 tons of pellets. The megawatts are generated here in the United States and the pellets are manufactured here with some shipped to domestic plants but most bound for Europe. The facilities we examined were producing improved atmospheric carbon balance relative to using other energy fuels and technologies to provide equivalent power at a landscape scale. We modeled an additional 22 biomass power facilities that would generate 1,014 MW of electricity and pellet plants that produce 3,050,000 tons of pellets (mostly shipped to Europe) to represent the proposed expansion (as of May 2011) of the biomass electric-generating sector in the Southeast in the next several years. These additional biomass facilities were also favorable relative to the alternatives, in the long term, because of the sustained production of wood fiber, assuming all stands are replanted or naturally regenerated to achieve full restocking, and no forest land conversion. A carbon debt period of 35-50 years, however, was required for woody biomass to achieve a beneficial atmospheric carbon profile relative to the other pathways examined at a landscape scale.

This multi-decade carbon debt period is consistent with other studies (Manomet 2010, McKechnie 2011) that have used life-cycle analysis, forest carbon accounting, and a "business-as-usual" baseline to compare biomass to other forms of energy production. The Manomet modeling produced a 42-year payback period for biomass versus coal-generated electricity, and the McKechnie modeling indicated 17-38 year payback periods for generating electricity with biomass instead of coal. Although these patterns are basically consistent, the actual differences in debt periods are expected in different forest types and harvest scenarios. In addition, our model includes a more precise modeling of actual harvesting methods in real stands distributed across the landscape and linked to specific facilities. There are significant differences in the payback periods required to re-sequester all the emitted carbon and return to what may be termed a "carbon-neutral" situation. Our modeling indicates a 53-year time period while the Manomet results for Massachusetts indicate more than 100 years are required.

Assumptions regarding the required biomass supply per unit of power produced an effect on the atmospheric carbon balance for the build-out of the proposed facilities. A higher figure for biomass per unit of power produced showed that the number of years was extended before biomass was shown to be better than fossil fuels.

Naturally regenerated hardwood forest types were also shown to store as much or more carbon on a per-acre basis than most other forest types and plantations, even when regularly harvested for biomass in integrated sawtimber and pulpwood harvests. Tradeoffs between utilizing pulpwood and residuals for biomass energy were found to be most appropriately addressed at project- or stand-level scales.

This study suggests that the atmospheric carbon balance of biomass electric power is better in the long term relative to fossil fuel pathways. A period of decades is required, however, to achieve this result due to the changes in the stored carbon on the landscape relative to a baseline. As biomass demand increases with more facilities beyond the 22 currently proposed, the ability of the forested landscape to provide biomass supply and store carbon may become more limited, particularly in localized areas with strong demand. As this occurs, other factors may become more important in determining the atmospheric carbon balance of biomass energy such as the extent to which biomass demand drives new forest conversion or diversion of wood from other existing uses.

3.2.0 INTRODUCTION

One of the major tasks of this study is to provide a landscape life-cycle analysis of three major feedstocks under two likely scenarios for biomass electric power and electric-led CHP.

This chapter addresses the landscape carbon life-cycle analysis. It provides a section on introduction, methods, and findings. Technical details are presented in the appendix. An executive summary that addresses the full scope of the project that integrates all the tasks is also provided. Eight specific questions were posed to the research team for analysis:

1. What are the GHG consequences of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?
2. What are the GHG consequences of operating the existing biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants?
3. What are the GHG consequences of varying the amounts of biomass required to make a specific amount of electricity?
4. What are the GHG consequences of using forest-derived biomass versus non forest-derived biomass?
5. What are the GHG consequences of using tops and limbs (residuals) for biomass supply versus pulpwood (main stems)?
6. What are the GHG consequences of using natural stands versus plantations to fuel an expansion of biomass electric power in the Southeast?
7. What are the GHG consequences of varying levels of pellet export to Europe for electric power generation from the Southeast?
8. Is there enough biomass available to supply 22 new biomass facilities while limiting the amount of residuals that can be removed to protect forest health?

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.0 METHODOLOGY

This analysis examined the GHG implications of biomass electric generation scenarios for a study area in the southeastern United States. The study area included four eco-sections representing a large portion of the Southeast (see Figure 9 on the opposite page). The study was restricted to these eco-sections to keep the analysis workload reasonable while allowing a large and representative portion of the region to be studied. The following discusses the facilities studied, technology pathways considered, forest growth simulations, and carbon-accounting simulations.

To understand the GHG implications of increased demand, we examined 17 existing facilities and the addition of 22 new biomass electric power facilities to represent the proposed expansion of the biomass electric sector in the Southeast. In order to inform the question of GHG impacts of biomass energy, we examined the GHG implications of the emissions associated with burning biomass feedstock from the forest in relation to other sources of fuel and technology pathways. We also conducted sensitivity analyses on a number of factors to understand how the GHG accounting might be affected.

The atmospheric carbon analysis was divided into specific sub-tasks that were used to produce the work in this report. The sub-tasks are described in the following sections with detailed information provided in the appendix. Below is a list of the sub-tasks:

- Sub-Task 1. Geospatial Analysis
- Sub-Task 2. Definition of Silvicultural Prescriptions for Eco-Regions, Forest Types, and Stand Origin
- Sub-Task 3. Inventory Data Preparation
- Sub-Task 4. Forest Modeling
- Sub-Task 5. Carbon Accounting
- Sub-Task 6. Definition of Landscape and Facilities-Modeling Framework
- Sub-Task 7. Integration of Geospatial and Attribute Data
- Sub-Task 8. Carbon Landscape Analysis
- Sub-Task 9. Sensitivity Analysis
- Sub-Task 10. Draft Final Report
- Sub-Task 11. Final Report

3.3.1 Geospatial Analysis

The purpose of this task was to generate spatial data that allowed the study to be conducted at the landscape level using an integrated all-lands approach. This analysis produced information that reflected the realities of the landscape as they exist today with no assumptions made about land-use change or changing market dynamics. This task quantified vegetation type, transportation distances, constraints on forest management, and operational restrictions as they currently exist in the region. What follows is a summary.

Vegetation Type

There were four eco-sections used for analysis, which may be found in Description of Ecological Subregions: Sections of the Conterminous United States (McNab et al., 2005). Figure 9 on the next page shows the location of these eco-sections with the major forest types. Table 27 on the next page shows the acres estimated from the Forest Inventory and Analysis (FIA) databases for each eco-section and forest-type group.

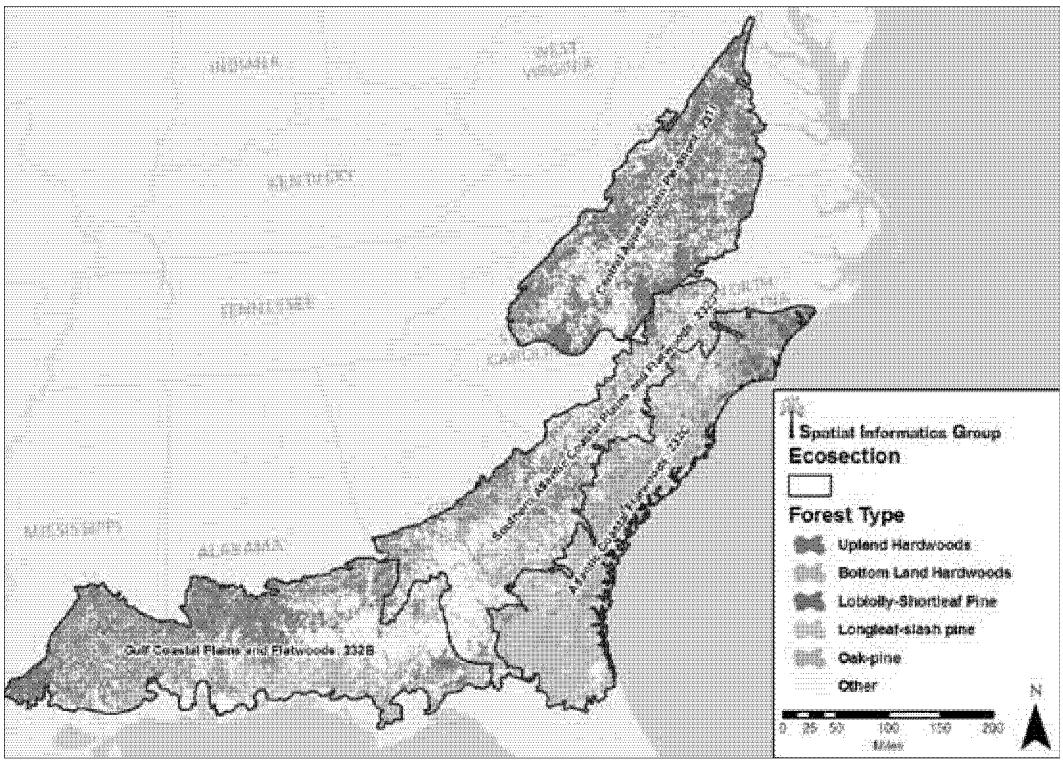


Figure 9.

Map of eco-sections and forest types within the study area. The study area was composed of the four eco-sections shown.

Table 27. Acres by Forest-Type Group, Stand Origin, and Eco-Section

Forest-Type Group	231I-Central Appalachian Piedmont	232B-Gulf Coastal Plains and Flatwoods	232C-Atlantic Coastal Flatwoods	232J-Southern Atlantic Coastal Plains and Flatwoods
Bottomland Hardwoods	629,766	2,735,943	3,118,925	2,418,890
Loblolly/Shortleaf Natural	1,431,249	2,086,954	1,371,449	1,374,118
Loblolly/Shortleaf Plantation	1,748,837	4,574,524	2,459,067	2,673,421
Longleaf/Slash Natural	4,349	928,478	513,542	695,605
Longleaf/Slash Plantation	260	1,124,209	1,835,337	1,061,007
Upland Hardwood-Oak Hickory	5,832,079	3,866,263	1,025,381	2,257,467
Mixed Pine-Oak Natural	1,350,490	1,754,184	1,002,367	1,182,812
Mixed Pine-Oak Plantation	215,802	610,307	260,002	248,034

Source: FIA (2011)

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Section 231I-Central Appalachian Piedmont. This section is east of the Blue Ridge Mountains in central Virginia and North Carolina. It belongs to the Southeastern Mixed Forest Province (231), which "has generally uniform climate with mild winters and hot, humid summers. Annual precipitation is evenly distributed, but a brief period of mild-to-late summer drought occurs in most years." It has high and low hills with deep weathered soils. Forest vegetation is loblolly-shortleaf pine and oak-hickory types. The Central Appalachian Piedmont section is 32,806 square miles.

Section 232B-Gulf Coastal Plains and Flatwoods. This section extends along the Gulf of Mexico coast from southwestern Georgia and the Florida panhandle west through southern Alabama and ending in southern Louisiana. It belongs to the Outer Coastal Plain Mixed Forest Province (232), which "is an eco-region of humid, maritime climate; winters are mild and summers are warm. Precipitation is abundant with rare periods of summer drought. Upland forest vegetation is dominated by conifers, with deciduous hardwoods along major floodplains." It has a flat weakly dissected landscape of irregular or smooth plains. Vegetation is mainly longleaf-slash pine, loblolly-shortleaf pine, and oak-hickory cover types with oak-gum-cypress along rivers. The Gulf Coastal Plains and Flatwoods section is 43,495 square miles.

Section 232C-Atlantic Coastal Flatwoods. This section extends along the Atlantic coast from southern North Carolina south through South Carolina and Georgia into the northeastern part of Florida. This section belongs to the Outer Coastal Plain Mixed Forest Province (232), which "is an eco-region of humid, maritime climate; winters are mild and summers are warm. Precipitation is abundant with rare periods of summer drought. Upland forest vegetation is dominated by conifers, with deciduous hardwoods along major floodplains." It is a weakly dissected flat alluvial plain. Vegetation is mainly longleaf-slash pine and loblolly-shortleaf pine, with oak-gum-cypress along rivers. The Atlantic Coastal Flatwoods section is 30,215 square miles.

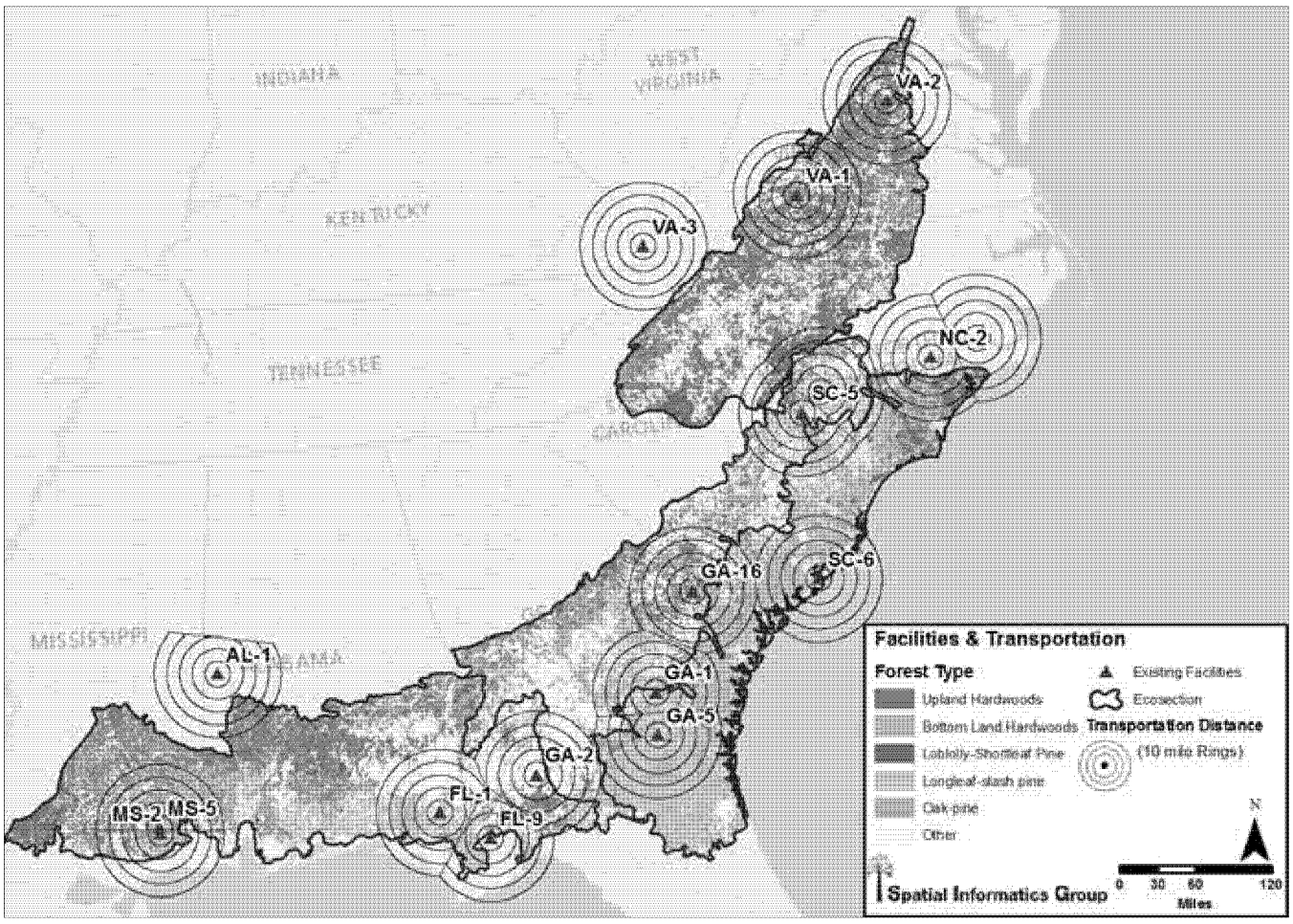
Section 232J-Southern Atlantic Coastal Plains and Flatwoods. This section extends from southern Georgia northeast through central South Carolina and south-central North Carolina. It belongs to the Outer Coastal Plain Mixed Forest Province (232), which "is an eco-region of humid, maritime climate; winters are mild and summers are warm. Precipitation is abundant with rare periods of summer drought. Upland forest vegetation is dominated by conifers, with deciduous hardwoods along major floodplains." This section is weakly dissected irregular or smooth plains. Vegetation is mainly a mixture of loblolly-shortleaf pine, longleaf-slash pine, oak-pine, and oak-gum-cypress cover types. The Southern Atlantic Coastal Plains and Flatwoods section is 31,802 square miles.

Transportation Distance

Existing and proposed facilities data was assembled by the Southern Environmental Law Center (SELC). In order to quantify the biomass supply and transportation emissions to facilities, five concentric transportation rings of 10 miles radius from each facility were constructed. This was done for existing and for existing plus proposed facilities (Figure 10, Figure 11). Wood supply for facilities was modeled using distance to the facilities with equal weight given to each; in other words the distance was equally split between them. Therefore, up to a 50-mile radius was allowed for the wood supply area for a facility unless restricted by neighboring facilities. While this study relies on individual facility data, no attempt was made to characterize the individual facilities, only the aggregate data.

Figure 10.

Existing facilities (17) with transportation rings, showing study area and forest types.



3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

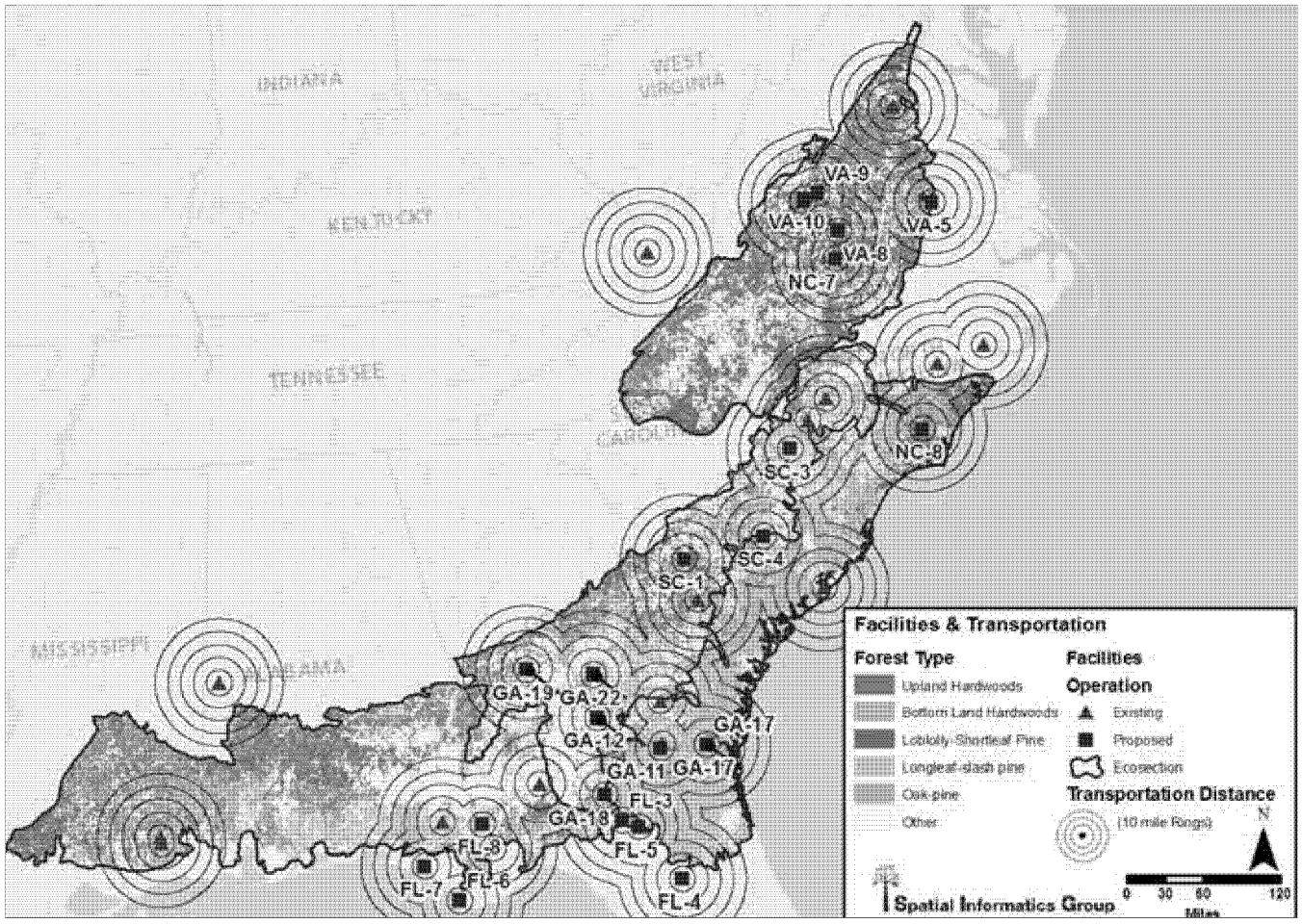


Figure 11.

Existing (17) and proposed (22) facilities with transportation rings, showing study area and forest types. (Some of the points overlap with one another).

Constraints on Forest Management

In order to estimate forest management response to biomass markets so that feedstock supply and subsequent carbon accounting could also be estimated, we identified constraints on forest management applied to private lands in the study area. We considered family forest landowners that would not harvest based on typical economic incentives and physical constraints of the terrain to operations.

The National Woodland Owner's survey results (Butler, 2008) were used to estimate the proportion of the private forested landowners in the study area that would not generally respond to a market by harvesting their lands. Family forests make up 67.4 percent of the private forests and 31 percent do not have a history of harvesting their lands. Therefore we estimate that 20.9 percent of the private forest landscape is in a no-harvest scenario.

Operational Restrictions

Operational acres were those with willing landowner participants and unrestricted access. The acreage required to meet a facilities biomass fiber demand was calculated. The acres remaining after consideration of biomass supply, reserve acres and operationally restricted acres was allocated to the business as usual (BAU). Biomass supply acres were assigned silvicultural prescriptions that incorporated biomass harvesting and BAU acres were assigned baseline silvicultural prescriptions. These prescriptions were assigned by forest-type group so that the appropriate starting inventory was used. Operational restrictions were estimated using FIA data by eco-section and forest-type group (Table 28 below). Restricted acres were defined as those with the following attributes:

- Broken terrain
- Mixed wet and dry soils
- Slopes greater than 40 percent, or
- Water year-round

Table 28. Percent of Operational-Restricted Acres by Eco-Section and Forest-Type Group

Eco-Section	Forest-Type Group	Percent Restricted
231I	Bottom Land Hardwoods	19.5
231I	Upland Hardwoods	3.7
231I	Oak-pine	1.5
231I	Loblolly-shortleaf pine	0.8
232B	Bottom Land Hardwoods	19.6
232B	Upland Hardwoods	2.2
232B	Oak-pine	2.0
232B	Loblolly-shortleaf pine	0.6
232B	Longleaf-slash pine	1.0
232C	Bottom Land Hardwoods	1.0
232C	Upland Hardwoods	1.1
232C	Oak-pine	6.9
232C	Loblolly-shortleaf pine	0.9
232C	Longleaf-slash pine	1.0
232J	Bottom Land Hardwoods	10.7
232J	Upland Hardwoods	1.6
232J	Oak-pine	3.6
232J	Loblolly-shortleaf pine	1.3
232J	Longleaf-slash pine	0.4

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.2 Definition of Silvicultural Prescriptions for Eco-regions, Forest Types, and Stand Origin

The purpose of this sub-task was to define a BAU baseline for silvicultural practices as they exist today from current on-the-ground activity along with a viable biomass alternative. These silvicultural prescriptions were to be assessed by eco-regions, forest type, stand origin, and ownership type. The Forest Guild took the lead in developing these options based on its extensive in-field networks and sustainable silvicultural expertise.

The Forest Guild set up a local forester input process that assisted with defining the BAU- and biomass-affected silvicultural methods used for the forest types and eco-sections considered in this study. The silvicultural simulations by forest type and eco-section are listed in Tables B-1 to B-3 in Appendix B. Note that prescriptions repeat over time. Also in Appendix B, Table B-4 shows the age distribution for one eco-section, for illustration. A set of no-harvest scenarios was also simulated for each eco-section, stand-origin, and site-class category.

Site productivity was grouped into low and high using the FIA site classes: 1-3 were high and 4-7 were low. Three general prescriptions were modeled:

- Baseline, with a biomass market and with no harvesting
- Baseline harvests cut trees down to 4 inches dbh
- Biomass harvests took trees down to 0 inches dbh

Regeneration harvests may have site preparation and burning simulated. Default Forest Vegetation Simulator, Southern Variant (FVS-SN) values were used for naturally regenerated stands except for longleaf pine, which was broadcast burned. Plantations were 100 percent site prepared. The FVS-SN default values were 20 percent treated mechanically, 5 percent burned, and 75 percent untreated. No differences were assumed in site preparation and burning for the baseline versus the biomass harvests.

These simulations represent plausible depictions and are intended to provide data for comparisons between treatments and fiber utilization scenarios. They are not intended to provide predictions of landscape changes over time, which would require a regional timber supply model.

3.3.3 Inventory Data Preparation

The purpose of this sub-task was to prepare the FIA data for analysis. Two elements need to be investigated when preparing FIA data for analysis—data quality and the issue of regeneration.

Data Quality

The FIA data were extracted from eight state-level databases using the *FiaToFvs utility* (Keyser, 2011), which created FVS-formatted databases. These databases were filtered and combined into four databases corresponding to the four eco-sections. FIA plots, which are 4-plot clusters, were treated as stands composed of four plots. The most recent measurement cycle was used for characterizing current conditions. The previous inventory cycle was used in conjunction with the other data for the growth model evaluation. A common starting year of 2010 was used regardless of the actual measurement year of the plot. The most recent (2010) FIA survey summary was used and relative plot weights were retained. In some cases, age was missing from the FIA plots. Since age was used as a trigger for some silvicultural treatments, random ages were assigned to stands where this occurred.

Each set of plots that were projected under a silvicultural scenario were averaged using the FIA expansion factors. This produced a yield stream that reflected the application of the prescription to the average landscape for a particular eco-section, forest-type group, and site group. The two site groups were then averaged together using their relative representation on the landscape. This averaged yield stream was then used in conjunction with vegetation maps to model carbon dynamics.

Regeneration

Regeneration assumptions are important to long-term forest growth projections. Plantation densities (TPA) were based on expert opinion. Natural stand regeneration was based on FIA data queries. Tables B-5 to B-6 in Appendix B show the regeneration assumptions for two examples of forest types for an eco-section. Data in these tables were derived from FIA plots in trees 0-5 inches dbh. Sprouting species automatically sprout when harvested in FVS-SN, so only non-sprouting species were regenerated from seedlings. Regeneration was input 10 years after harvest, at the sapling/pole stage. Sprouting was set to the following to avoid overstocking the stands, which was observed from the simulations using the defaults.

- If stand density index (SDI) less than 100, use 100 percent of default sprouting model
- If SDI 100 to 200, use 90 percent of default sprouting model
- If SDI 200 to 300, use 80 percent of default sprouting model
- If SDI more than 300, use 70 percent of default sprouting model
- If the quadratic mean diameter (QMD) less than 10 (young stands), use 10 percent of default sprouting model (for pre-commercial thinning)
- If the QMD less than 10 and more than 700 trees per acre, use 1 percent of default sprouting model

This appeared to create a generally stable stocking situation over the simulation period. The no-harvest scenarios did not have regeneration modeled.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.4 Forest Modeling

This sub-task focused on quantifying forest biomass dynamics using the above information and standard modeling approaches. Several elements were selected for this analysis, including the data and software used, specifics concerning the growth and yield models, and approaches to evaluating growth. In general, non-merchantable wood (*residuals*) was considered as the first lowest cost supply material, up to the amounts allowed under the sensitivity analysis described below. Clean woodchips from fiber defined as meeting pulp merchantability standards (*pulpwood*) was provided next, also up to the amounts allowed by the sensitivity analysis below. These elements are discussed in detail as follows.

Data and Software

The FIA data (FIA, 2010) was used to develop stand-level data for simulating growth, harvest, and mortality. Eco-section summaries were also queried from the FIA data.

The FVS-SN (version 2/16/2011)(Keyser, 2010), was used for modeling stands. Pine plantations were evaluated using simulations in PTAEDA version 4 (Burkhart et al., 2008), a loblolly-pine plantation model. SUPPOSE (Crookston, 1997) was used for FVS simulations. R statistical software was used for some analysis and graphics (R, 2011). Microsoft Excel was used for data checking, calculations, and graphics. Microsoft Access was used for plot and tree-data storage as well as carbon outputs, which were linked to SUPPOSE software using the database extension (Crookston et al., 2011). The Fia2Fvs utility, available on the FVS website, was used to translate FIA data to an FVS readable Access database.

Growth and Yield Modeling

Non-renewable fuels such as oil, natural gas, and coal do not currently have an operational and economical sequestration component. Forests do naturally remove carbon from the atmosphere, however, and a complete GHG accounting of biomass energy should account for this fact. We considered only private lands for our analysis, which produce 96 percent of the roundwood in the Southeast (Johnson et al., 2009). We modeled forest growth, harvest, and mortality over a 100-year period to understand the long-term GHG implications of supplying biomass.

Each of the five major forest-type groups (Table 27 on page 69) in each of the four eco-sections was modeled under a BAU baseline, with a biomass market and unharvested. This allowed us to construct landscape scenarios that matched generalized landowner responses to available markets. The FIA data (FIA, 2010) were used for the starting conditions.

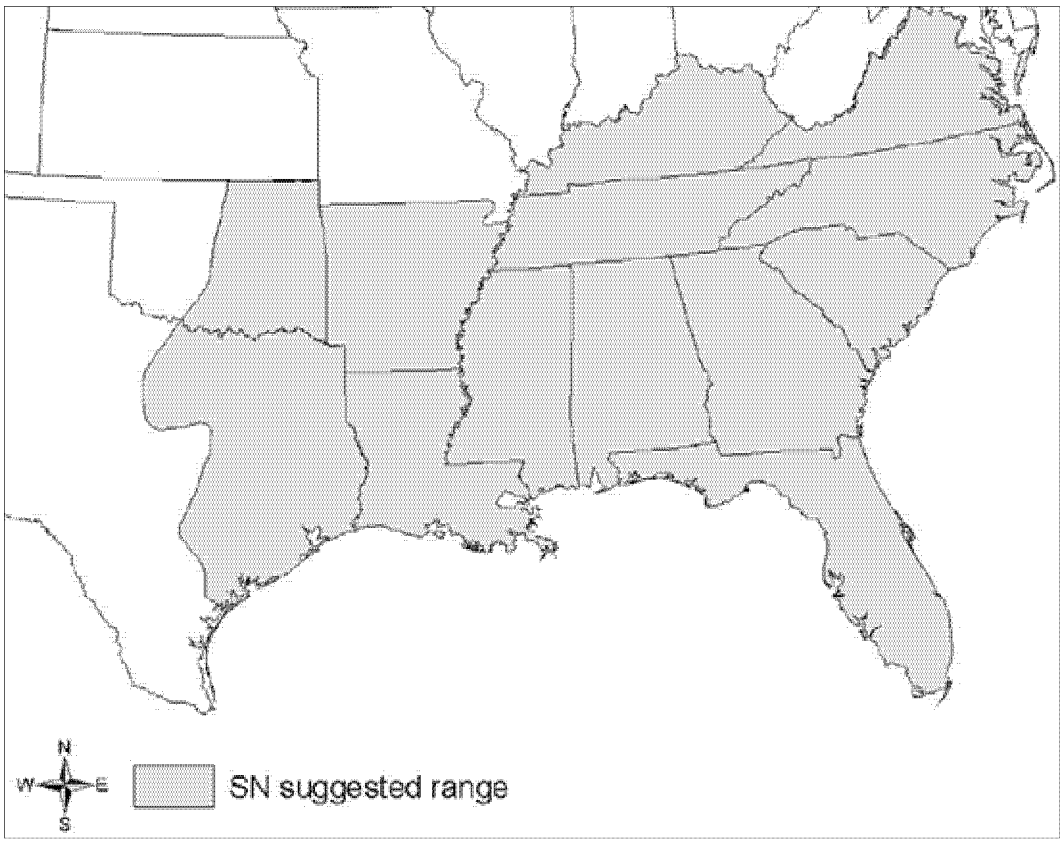


Figure 12.

Geographic range for the southern variant of FVS. From Keyser (2010).

The FIA databases for each state in our study area were downloaded from the FIA website. Data were queried from the databases to create tree lists for growth simulation. Tree-list queries were constructed for private lands by age, site productivity, stocking, eco-section, and forest type. Within each category, a random sample of plots was taken for the purposes of modeling. At least 250 plots were modeled for each category, when available, so that landscape variation was represented without unnecessary redundancy in data. Regional forest-characterization queries were conducted to ensure FIA data matched with GIS vegetation coverages.

Age class distributions were examined, by category, to characterize starting conditions. Where ages were missing, they were randomly allocated since age was a parameter used for some silvicultural treatments.

FVS-SN (Figure 12 above) was used to model all simulations for 100 years in 5-year increments. Harvests in the no-biomass-harvest baseline scenarios assumed that all non-merchantable wood fiber was left in the woods. Harvests in the biomass scenarios assumed that a minimum of 10 percent of the non-merchantable wood fiber was left in the woods; this assumption allows for 10 percent being a minimum so that between 10-100 percent of non-merchantable wood fiber may be allocated to biomass pools. This amount was varied for the sensitivity analysis.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

The merchantability standards used were the FVS-SN defaults shown in Table 29 below. Other default specifications used in modeling are shown in Table 30 at the bottom of the page. A minimum harvest level of 1,000 cubic feet per acre of merchantable wood fiber was specified for commercial thins, to avoid un-economical harvest simulations.

Table 29. Merchantability Standards from FVS-SN

Pulpwood Volume Specifications		
Minimum DBH/Top Diameter Inside Bark	**Hardwoods**	**Softwoods**
All locations codes	4.0 / 4.0 inches	1.0 / 1.0 inches
Stump Height	**1.0 foot**	**1.0 foot**
Sawtimber Volume Specifications		
Minimum DBH/Top Diameter Inside Bark	**Hardwoods**	**Softwoods**
All location codes	12.0 / 9.0 inches	10.0 / 7.0 inches
Stump Height	**1.0 foot**	**1.0 foot**

Source: Keyser (2010)

Table 30. Default Parameters Used in FVS-SN

	Eco-Section			
Parameter	**Central Appalachian Piedmont (231I)**	**Atlantic Coastal Flatwoods (232C)**	**Southern Atlantic Coastal Plains and Flatwoods (232J)**	**Gulf Coastal Plains and Flatwoods (232B)**
Location Code	81110	81201	81201	80103
Ecol. Unit Code (EUC)	232BIC	232CA	232JA	232BI

Carbon storage from onsite forest pools and long-term storage in wood products and landfills was estimated. Production from residual fiber and wood meeting pulpwood merchantable standards was estimated. The yield streams were annualized to match the demand units for the facilities.

The yields from each forest type were averaged across natural and plantation origin based on the relative abundance of each in each eco-section (see Table 31 below). Harvest of non-merchantable wood was set to a maximum removal of 90 percent for biomass harvesting.

Table 31. Acres of Plantations by Eco-Sections and Forest Type Groups

Eco-Section	Forest Type	Acres	Acres in Plantation	Percent in Plantation
231 I	Loblolly-shortleaf pine	4,946,320	2,720,149	55.0%
232B	Loblolly-shortleaf pine	6,810,148	4,082,053	59.9%
232B	Longleaf-slash pine	4,608,327	2,222,395	48.2%
232B	Oak-pine	2,900,973	568,323	19.6%
232C	Loblolly-shortleaf pine	1,891,406	1,047,443	55.4%
232C	Longleaf-slash pine	5,152,756	3,276,062	63.6%
232J	Loblolly-shortleaf pine	3,074,770	1,829,583	59.5%
232J	Longleaf-slash pine	2,685,180	1,447,152	53.9%
Total		32,069,879	17,193,160	53.6%

Source: FIA

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

The simulations projected individual FIA clusters under a variety of silviculture. Even-aged management was simulated in all but the upland hardwood stands where selection management was simulated (Appendix B). An example showing the initial harvest, regeneration, pre-commercial thin, mortality over time, and clearcut cycle is shown in Figure 13 below.

Figures 14 and 15 on the next page show examples of the averaged yields of stored CO_2e for two specific eco-section and forest type combinations. In general, the biomass prescriptions had lower stored carbon than the no-biomass harvest prescriptions. The no-harvest prescriptions generally stored substantially more carbon than the two-harvest scenarios. These results provided inputs to the landscape analysis. There could be significant atmospheric benefits if the landscape were converted to a no-harvest scenario where leakage was limited and alternative energy had a small carbon footprint. This is a scenario that we are currently not experiencing, but there are major initiatives underway to explore the possibilities. The landscape-level no-harvest scenario was not included in our modeling or results.

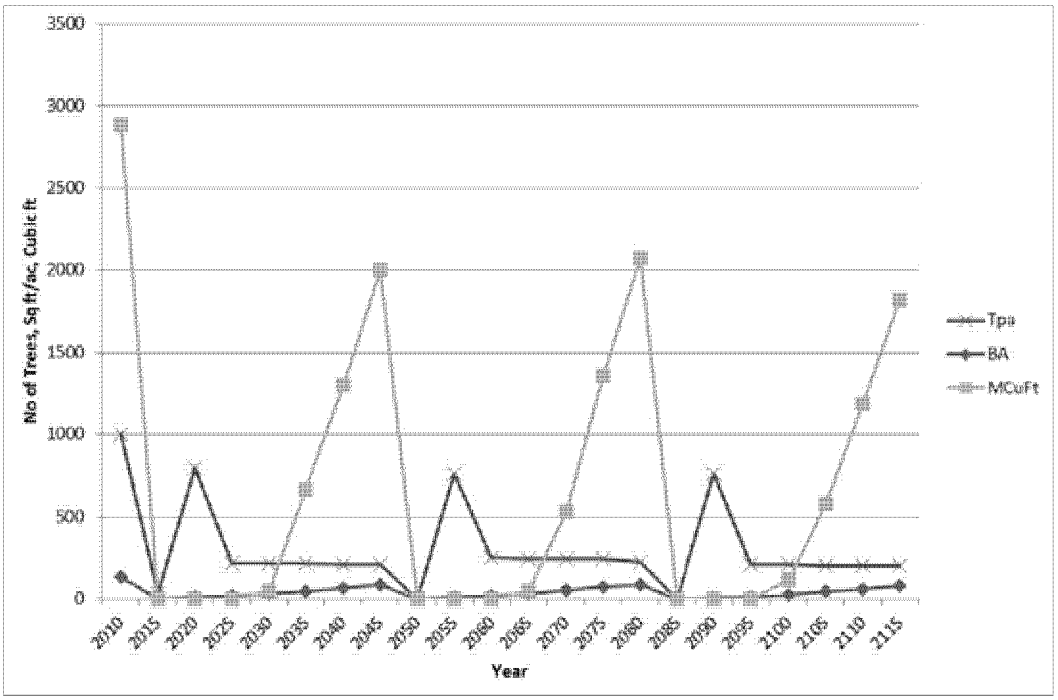


Figure 13.

An example of a plot cluster projection.

This is for a 47-yr old loblolly pine plantation in eco-section 231I, low site, with biomass harvest. A pre-commercial thin occurs early in the rotation, which is seen in the drop in trees per acre (TPA). The basal area (BA) and merchantable cubic foot volume (MCuFt) increase over each 35-year rotation. Slight variations are seen in each rotation due to FVS stochasticity and changes in sprouting species.

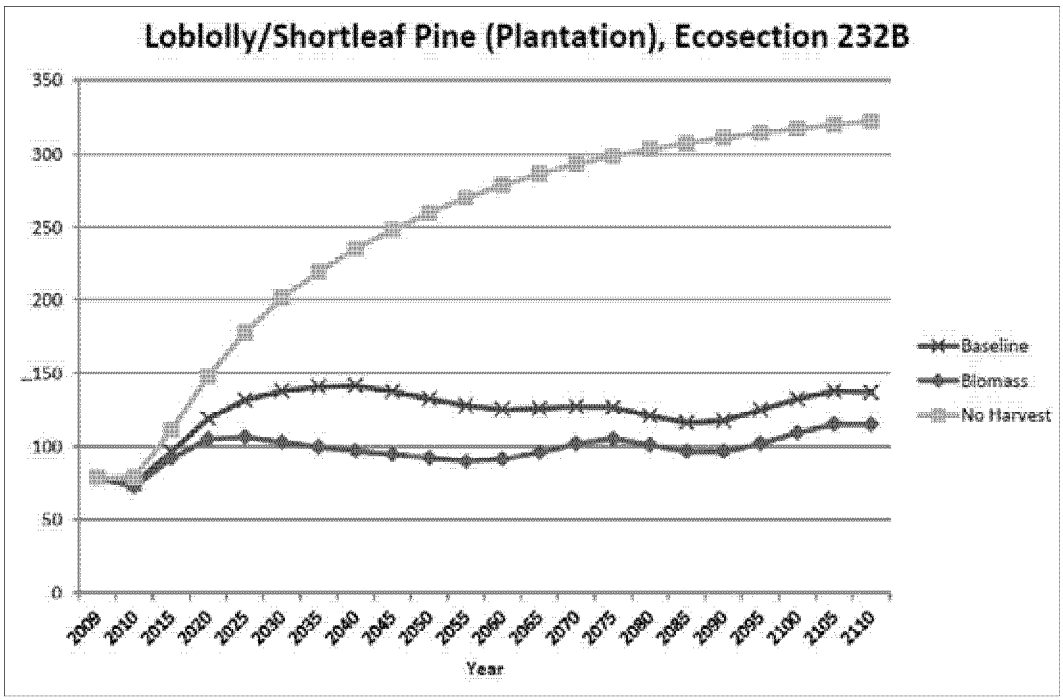


Figure 14.

Averaged projections of carbon storage in the forest and wood products (in-use and landfills) for naturally regenerated loblolly-slash pine in eco-section 231B (Gulf Coastal Plains and Flatwoods) using three silvicultural prescriptions.

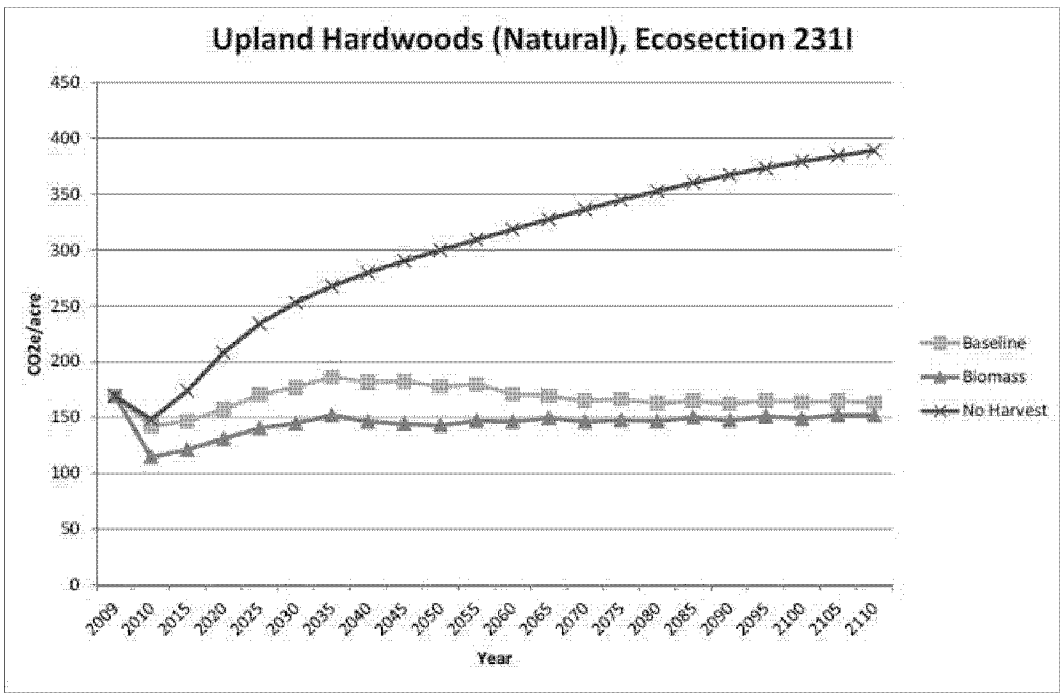


Figure 15.

Averaged projections of carbon storage in the forest and wood products (in-use and landfills) for naturally regenerated upland hardwoods in eco-section 231I (Central Appalachian Piedmont) using three silvicultural prescriptions.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

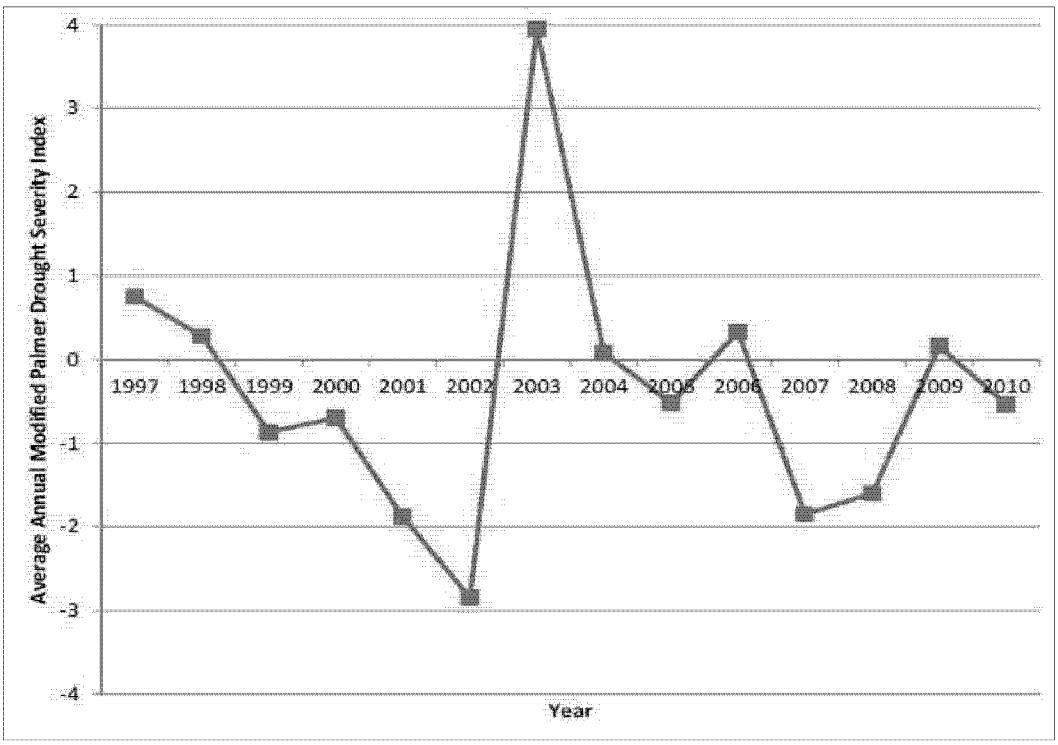
Growth Evaluations

The Southern variant of FVS covers a large geographic region, which may contain deviations from projected average growth locally or regionally. To account for possible bias, the model was evaluated for one of the eco-sections for 5-year bias in above-ground live tree carbon. FIA plots that had been re-measured using the annual inventory method were projected using the FVS carbon model (Rebain, 2010; Jenkins et al., 2003 biomass equations). Plots that had treatments were excluded. The annualized changes in carbon were compared and the model was found to overestimate by almost 60 percent. The period of growth was marked by generally dry-to-drought conditions (see Figure 16 below) however, which makes generalizing conclusions difficult without a longer-time series of data. The FVS functions were fit to data from previous time periods, which were likely nearer normal. The other eco-sections were not examined as the entire Southeast experienced similar climate during this period.

Figure 16.

Average annual modified Palmer Drought Severity Index for the North Carolina Piedmont region.

Palmer classifications are: -4 to -3 severe drought, -3 to -2 moderate, -2 to -1 mild, -1 to 1 dry to normal to wet, >1 wet.



Source: State Climate Office of North Carolina website (www.nc-climate.ncsu.edu)

An additional evaluation was conducted by comparing Loblolly plantation projections of FVS-SN with the projections from the Loblolly plantation model PTAEDA version 4 (Burkhart et al., 2008). Table 32 below shows the results of this comparison. While there were larger deviations for the harvested volumes, total yields were 10-12 percent for the entire rotation. This was felt to be an adequate level of accuracy for a regional analysis.

Finally, overall projections of per-acre yields were subjectively compared to regional averages (McClure and Knight, 1984) and found to be reasonable. This was done for each of the major forest types.

Table 32. Comparison of Simulations Using Non-Biomass Prescriptions for FVS-SN and PTAEDA Version 4

		Ending		Harvest	Total Yield	
Simulator	**Site**	**BA**	**Volume (ft^3/ac)**	**Volume (ft^3/ac)**	**Volume (ft^3/ac)**	**Difference (%)**
FVS-SN	Low	108	2,829	4,113	6,942	10%
PTAEDA		90	3,525	2,740	6,264	
FVS-SN	High	112	3,389	4,616	8,005	12%
PTAEDA		93	3,729	3,345	7,074	

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.5 Carbon Accounting

The focus of this sub-task was to quantify the GHG implications of different technology types and fuels sources for producing energy in the Southeast. This information will be used to gain a better understanding of the implications for potential energy policy and markets on climate change. This sub-task specifically tracks the fuel production and transportation emissions, facility emissions, and forest carbon dynamics for the region. We analyzed stand-alone electric power and electric-led CHP technology pathways; thermal-led energy pathways were not examined. Carbon yields over time from the forest, harvesting, transportation, and facilities emissions were combined in an Access database where queries were used to produce analysis datasets. These datasets were then read into an Excel spreadsheet for final analysis. Below is a detailed description of the major elements associated with this sub-task.

Major Assumptions

The biomass carbon accounting included the onsite forest pools of above- and below-ground live trees, standing dead wood, and down dead wood. Storage of wood products in in-use and landfill pools was also included. Harvest emissions were estimated using a factor of 0.015 tonnes of CO_2 per bone dry ton (BDT) of material produced. This assumed 16.65 lbs. CO_2 per green ton (Manomet, 2010). Truck transportation emissions were estimated using a factor of 0.000134 tonnes of CO_2 per BDT-mile, which assumed 12.5 tons per truck, 6 miles per gallon and 22.2 lbs. CO_2 per gallon of diesel fuel (EPA, 2005). The miles transported were estimated using the center radius of the transportation rings. Pellet mills were assumed to export 90 percent of their material to northern Europe; an emissions factor of .262 tonnes CO_2 per BDT was assumed for shipping (Henningsen et al., 2000). This was varied for the sensitivity analysis.

Biomass Facilities

Existing and proposed facilities data were assembled by the Southern Environmental Law Center (SELC, 2011). It should be noted that the number of proposed facilities is growing and has grown after the initial data were used as input, including a 75 MW co-gen plant consuming 870,000 tons per year in Covington, Virginia and a new 400,000 ton per year pellet plant in Northampton County, North Carolina.

Each of these facilities had information regarding type of power/fuel, location, status, anticipated supply sources, and capacity. Note that proposed facilities included existing facilities that are closed but may re-open. This analysis assumed that it takes a supply of 6,868 BDT per year per MW for older biomass facilities and 6,244 BDT per year per MW for new biomass facilities (see Appendix A). Biofuel facilities were not considered in this analysis due to their current relatively small impact and uncertain near-term growth.

Biomass Supply and Transportation Emissions

In order to quantify the biomass supply and transportation emissions to facilities, five concentric transportation rings of 10 miles radius from each facility were constructed. This was done for existing and for existing plus proposed facilities (See Figures 10 and

11 on pages 71 and 72). Wood supply for facilities was modeled using distance to the facilities with equal weight given to each; in other words, the distance was equally split between them. Therefore, up to a 50-mile radius was allowed for the wood supply area for a facility unless restricted by neighboring facilities. In practice, there is a lot of overlap in the woodsheds of the proposed facilities. The methodology used in this study was designed to give a conservative estimate of regional transportation emissions by pushing the biomass to the nearest facility.

Source of Supply

Pellet mills were assumed to use only clean chips from merchantable logs that would otherwise be categorized as pulpwood, although not necessarily sold as such as this is determined by local markets. Otherwise, for power plants and CHP, supply was assumed to first be filled by non-merchantable material (residuals) including tops of boles, small trees, and crown branches. If supply was not met by residual material, then wood that met pulpwood merchantable standards was used. Sawtimber was assumed to not be available as biomass feedstock.

Technology Pathways and Facility Emissions

An analysis of the GHG accounting related to biomass energy production may be considered as a function of both the fuel and technology used. We examined 11 technology pathways that varied based on fuel and the kind of energy that was produced. These pathways were selected to represent a likely suite of possible scenarios to be found in the Southeast either currently or in the future and consequently included stand-alone electric power generation and electric-led CHP technologies. Appendix A lists the 11 technology pathways examined along with the attributes of each.

Facility emissions were based on their associated technology pathways. Pellets were assumed to be used in facilities having new energy production from wood pathways (Pathway #2A). Almost all pellets were consumed in European facilities. Emissions were estimated by multiplying the amount of fuel used by a ratio of CO_2 produced per unit of fuel burned. The ratio of CO_2 produced per unit of biomass fuel burned was estimated to be 1:87.

Common Geographic Boundaries

The forested area was defined to be the area of the four eco-sections that included the existing and proposed facility woodsheds, which were defined by a 50-mile radius. By having a common geographic area, the two scenarios of existing facilities and full build out of proposed and existing facilities could be compared. The acreage of proposed facility woodsheds was assigned the baseline no-biomass harvest silviculture when analyzed using existing facilities only. The new facilities would then increase biomass use within the defined landscape.

Pro-Rating Facilities Boundaries

Facilities outside the four eco-sections in the study were included when their 50-mile wood supply radius overlapped with the study area. The wood fiber demand was pro-rated based on the amount of supply area in the study area relative to the entire terrestrial supply area for a facility. Demand for each facility was also adjusted by the amount of supply estimated to be taken from the forest as opposed to wood waste from mills and other sources.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Common Non-Harvested Lands

The sequestration of carbon by non-harvested lands (20.9 percent) did not contribute to the facility-based analysis since it was the same in both the current and full build-out scenarios. The woodsheds of facilities that were partially in the study area were pro-rated based on their acres in the study area relative to their total acreage.

Temporal Period

Annual GHG emissions and forest carbon dynamics were tracked over 100 years on an annual and cumulative basis. In addition to the technology pathways defined by the list of facilities we used, we also considered the GHG implications of producing equivalent electricity or thermal energy using all the non-wood biomass technology pathways.

Forest Carbon Pools

Forest carbon pools that were tracked under the baseline and treatment scenarios included live tree above and below ground, standing dead above and below ground, lying dead wood, and wood products storage in in-use and landfill pools. The carbon submodel of the FVS-FFE extension (Rebain, 2010) was used for carbon estimates in live trees and dead wood. The set of allometric equations from Jenkins et al. (2003) were used for live tree biomass estimates, above and below ground. FVS-FFE can use the Jenkins equations, which rely on species and dbh, down to a 1-inch dbh tree. Below 1-inch is interpolated. Wood density, which varies by species, is multiplied by the volume to get biomass estimates. Below-ground dead biomass occurs when trees die or are harvested. FVS-FFE uses a default root decay of 0.0425, which is what we used. Aboveground dead biomass used the FVS-FFE functions.

Wood Products Storage Pools

Wood products storage pools were estimated from the DOE 1605(b) guidelines (DOE, 2007). This was implemented in FVS-FFE based on the 2002 regional estimates (Adams et al., 2006) from Smith et al. (2006). Harvested trees less than 9 inches dbh for softwood and 11 inches dbh for hardwood were assumed to be in the pulpwood merchandising category; larger trees were assumed to be used as sawlogs. The age classes of the wood products pools for in-use and landfill were tracked by FVS-FFE with age 0 at the beginning of the 5-year period where harvest was simulated. Two other wood product pools were available—the emitted with energy capture and emitted without energy capture—but these were ignored for this analysis since this data feeds into an energy-use analysis.

Carbon Pools NOT Tracked

The soil, forest floor, and understory vegetation were not tracked due to the expectation that there would not be significant changes in these pools between the scenarios (Gershenson et al., 2011) and because of the lack of accurate prediction models.

Estimating Carbon Stock Changes

Changes in carbon stocks over time were used to estimate GHG flux between the biosphere and atmosphere. Biomass was converted to carbon by multiplying by 0.5 (Penman et al., 2003; Rebain, 2010). Carbon was converted to CO_2 equivalence (CO_2e) by multiplying carbon estimates by 3.67, which is the ratio of the atomic weights. CO_2e was reported in metric tons (tonnes) per acre or in total tonnes. All results were reported in CO_2e.

Estimating Methane Production

Methane production from slash burning was estimated using the CO_2 emitted from the biomass burned multiplied by a factor of 0.07 (CDM 2011; IPCC 2006) increasing the emissions by 7 percent. Methane production from decomposition of dead wood in the forest was assumed to be negligible (e.g., IPCC, 2006).

3.3.6 Sensitivity Analysis

A model, including the parameters indicated above, was constructed to analyze the GHG consequences of two different levels of biomass utilization and power production in the Southeast. To help examine the effects of varying different potential market and policy actions, the model was designed to manipulate four different parameters. These parameters were set to default settings for the basic analysis of the two scenarios. Then the parameters were altered to see if they resulted in significant changes to the atmospheric carbon profiles of the two scenarios and to answer the specific questions asked of the study. The following four factors were used for the basic sensitivity analysis:

- ***Wood Supply Directly from the Forest (Forest Supply).*** Some existing and proposed facilities receive 100 percent of their biomass supply either from the forest or from non-forest sources such as mill residues or urban tree trimmings. Some facilities, however, claim a variable amount of their supply directly from the forest; for those facilities we varied the forest supply by setting it at 20 percent, 50 percent, and 80 percent.
- ***Wood Supply from Pulpwood (Pulp Supply).*** Where appropriate (non-pellet mills), residuals were used to fulfill biomass demand first and pulpwood was used when needed. Given that competition may exist for pulpwood for use as pulp and paper, we set limits on the availability of pulp at 0 percent, 50 percent, and 100 percent. For example, a 0 percent from pulpwood would mean that there is no pulpwood allowed in the system for biomass utilization and more residuals would have to be produced.
- ***Wood Supply from Residuals (Non-Merchantable Supply).*** There are physical, economic, and Best Management Practices (BMP) limits to how much of the residuals (non-merchantable wood, bark, foliage) can be removed from the forest. We examine the implications of this by setting the amount of residual removal at 30 percent and 60 percent.
- ***Export of Wood Pellets (Pellet Exports).*** to northern Europe was set at 90 percent and 40 percent.
- ***Efficiency of Biomass Utilization.*** Examined a higher biomass requirement per MW-year of power produced, which was 8,234 BDTs per year per MW for older less-efficient biomass facilities and 6,868 BDTs per year per MW for newer, more-efficient biomass facilities. This specific parameter was examined in its own separate analysis and was not included in all combinations of the general set of 4 parameters described above.

The sensitivity analysis was run using multiple scenarios that allowed the research team to test individual parameters. The scenarios, parameters, and their values were developed using a collaborative process that took into consideration local knowledge, field data, and existing literature. All results are reported for existing facilities and proposed facilities across the entire study area. A list of the simulations used can be found in Table 33 on the following page.

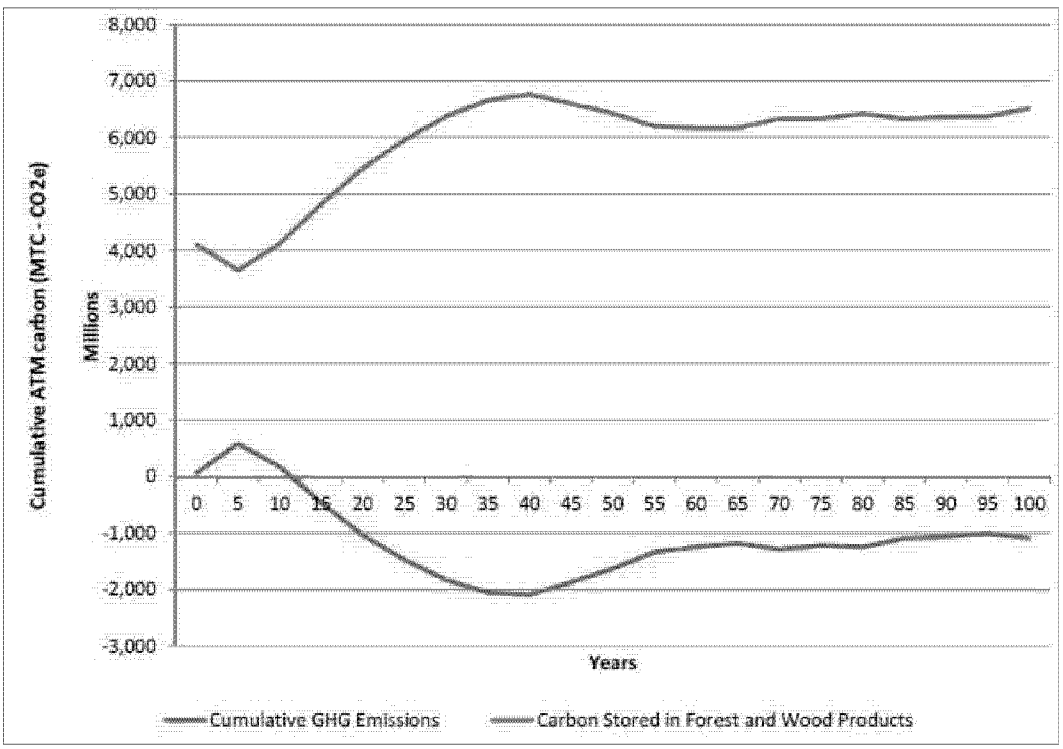
3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Table 33. Summary of Sensitivity Analysis Scenario Development (percent)

Scenario	Efficiency (BDTs/MW-yr)	FA: Forest Supply	PS: Pulp Supply	NM: Non-Merchantable Supply	EP: Pellet Exports
Default	**6868 old/6,244 new**	**50**	**50**	**60**	**90**
Forest Supply Min.	6868 old/6,244 new	**20**	50	60	90
Forest Supply Max.	6868 old/6,244 new	**80**	50	60	90
Pulp Min.	6868 old/6,244 new	50	**0**	60	90
Pulp Max.	6868 old/6,244 new	50	**100**	60	90
NonMerch Min.	6868 old/6,244 new	50	50	**30**	90
Pellet Export Min.	6868 old/6,244 new	50	50	60	**40**
Facility Efficiency	**6868 high/8000 Low**	50	50	60	90

Figure 17.

Cumulative atmospheric carbon balance of existing facilities over time (lower line) and carbon stored in the forest, in-use wood products, and landfills (upper line).



3.4.0 FINDINGS

In order to understand the implications of market and policy drivers in the development and expansion of a biomass electric power market in the Southeast, we analyzed the current condition and a scenario adding 22 additional biomass power plants to represent the proposed expansion of the biomass power sector in the Southeast over the next few years. A study of actual (and proposed) facilities in the context of the forested landscape and fiber supply area provided a more realistic analysis than a hypothetical comparative analysis. This analysis produced several key findings based on the questions defined above.

The 22 facilities selected for this simulation are all proposed for the next few years and there is the likely possibility that there will be more facilities planned, in addition to the 22, over a longer time period. Findings are presented in this report using the following format:

- **Question.** Define key policy question
- **Result.** Describe the key result from the analysis
- **Explanation.** Describe how the model and sensitivity tools were used to answer the question and discuss key findings

1. What are the atmospheric carbon implications of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?

Result. Our findings indicate that the existing biomass facilities examined were generally producing improved atmospheric carbon balance relative to fossil fuels and technologies to provide equivalent power at the regional scale. The macro-patterns remained the same for all the sensitivity-level combinations, including Wood Supply Directly from the Forest (Forest Supply), Wood Supply from Pulpwood (Pulp Supply), Wood Supply from Residuals (Non-Merchantable Supply), and Export of Wood Pellets (Pellet Exports). This would suggest that continuing to run these existing biomass power plants as they are currently sized and scaled today would result in lower atmospheric carbon in the short and long term than shutting them down and shifting to fossil fuels.

Explanation. There were 17 existing biomass electric power facilities (producing 159 MW and 1,775,000 tons of pellets) identified in the study area. The GHG profile produced was a function of the modeling of forest growth, harvest, and mortality; facility emissions based on identified technology pathways; and transportation and extraction emissions. We first present the atmospheric carbon balance for the existing facility landbase, without consideration of proposed facilities. The difference between the carbon storage using biomass harvests and baseline harvests without biomass is incorporated into the profile.

The cumulative atmospheric carbon balance is shown in the lower line in Figure 17 on the previous page. The shape of the cumulative emissions incorporates and is driven by the carbon storage factor, which is illustrated in the top line of Figure 17. The specific nuances of the curves are a function of modeling assumptions and harvest scheduling; the trend of the lines over time is primarily of interest.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 18 on the following page shows the cumulative carbon balance comparison of the existing biomass energy facilities (red line in Figure 17) compared to other possible means to meet the same energy demand. Emissions are occurring as harvests are initiated, which is the positive "bump" in the beginning of the line. After the initial emissions, the biomass scenario generally emits less carbon to the atmosphere than the other fuels and pathways. The specific shape of the curve is largely driven by modeling parameters; we are interested in the general trends.

In order to compare the effects of building the proposed biomass facilities, we need to consider the effects on the forested acres impacted by those new facilities. When only existing facilities are in place, those acres outside existing facility woodsheds, but destined to be included in the acreage of the proposed facility woodsheds, were modeled using a business-as-usual (BAU) harvesting scenario that did not include biomass harvesting.

The difference in the carbon balance between the two land bases is illustrated in Figure 19 on page 92. The larger land base sequesters more carbon because the additional acres are sequestering more carbon and are not being biomass harvested. This full land-base analysis will be needed when calculating the effects of the full build-out. This allows us to factor in those acres that are not currently being harvested for biomass utilization in the BAU.

Sensitivity Analysis of Running Existing Facilities

We tested whether the atmospheric carbon balance of the existing biomass facilities relative to the other pathways can be changed by altering the assumptions. When the parameters for the four other assumptions are varied, no significant change in carbon balance was identified (Figure 20). The macro pattern, however, compared to fossil fuel type remains the same for all scenarios modeled (they were all beneficial).

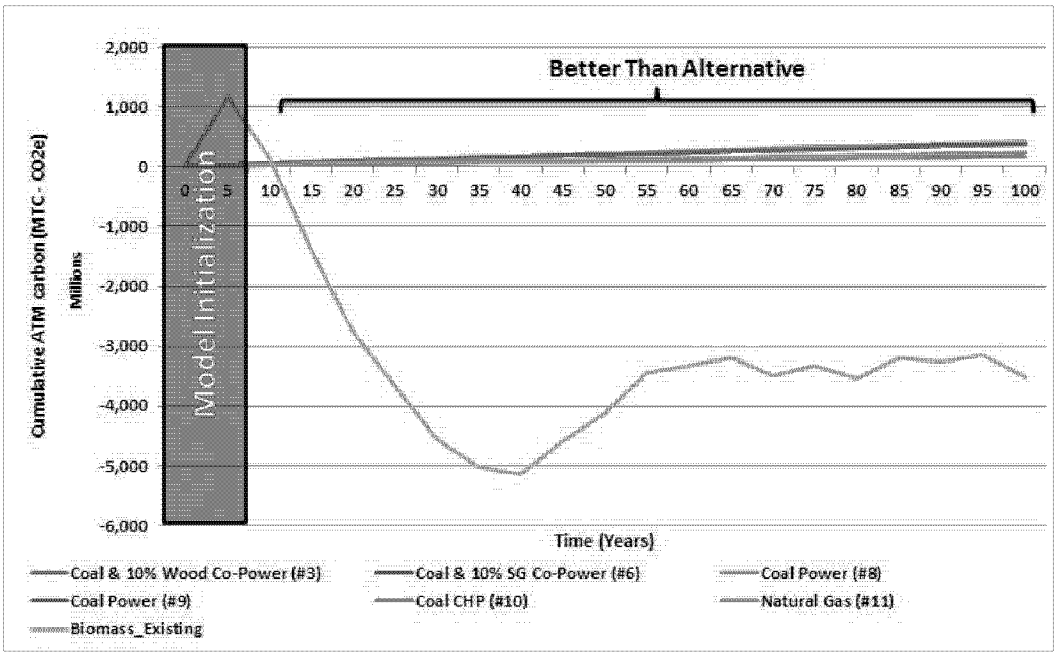


Figure 18.

Cumulative carbon balance of existing biomass facilities with other pathways for comparison.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 19.

Comparison of the carbon balance for the existing biomass facilities considering different forested land bases: the wood-sheds of the existing biomass facilities versus the full build-out acres.

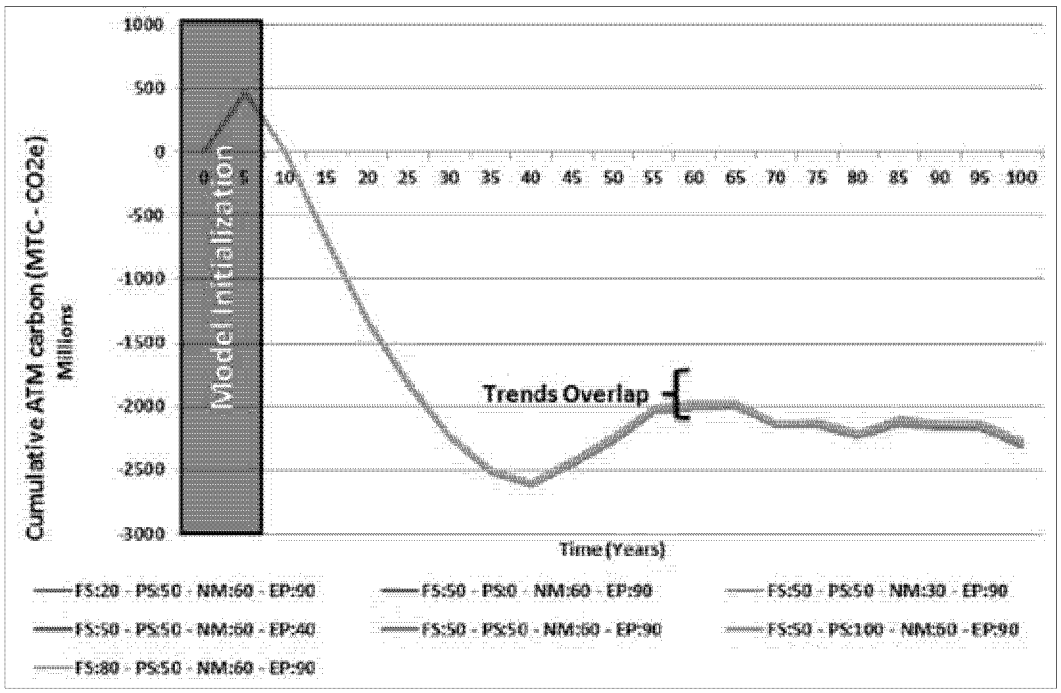


Figure 20.

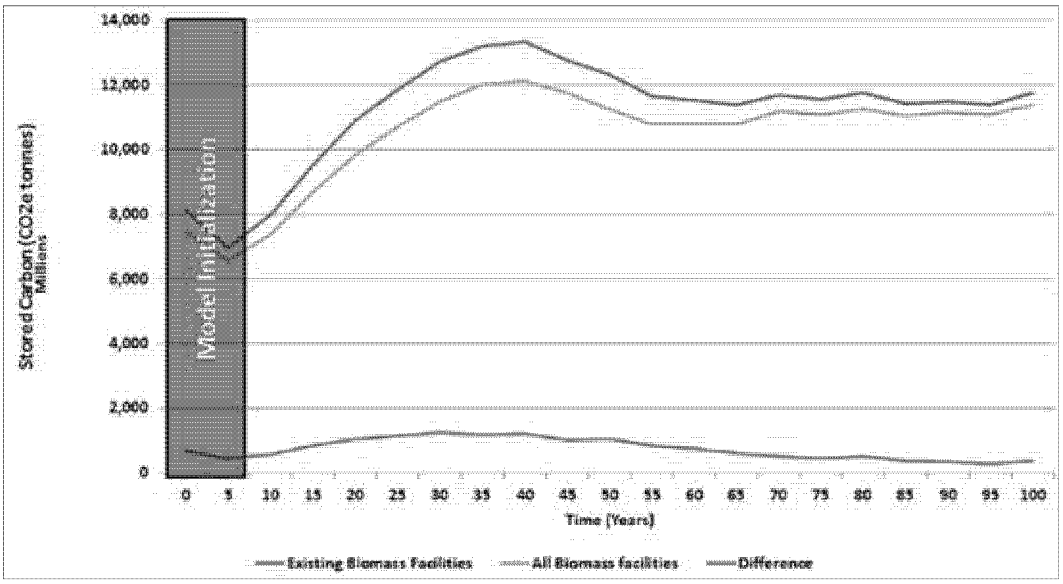
Sensitivity Analysis Conducted for Existing Biomass Facilities.

Results are presented in the following order: Wood Supply Directly from the Forest (FS: Forest Supply) at 20, 50, and 80 percent, Wood Supply from Pulpwood (PS: Pulp Supply) at 0, 50, and 100 percent, Wood Supply from Residuals (NM: Non-Merchantable Supply) at 30 and 60 percent, and Export of Wood Pellets (EP: Pellet Exports) at 40 and 90 percent. The table is keyed in the following format: Forest-Pulp-NonMerch-Pellet. The lines overlap showing that there is no difference between them from a cumulative atmospheric carbon point of view.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 21.

Forest and long-term carbon storage (wood products and landfill) for the existing biomass facilities, full build-out of proposed biomass facilities and existing facilities, and the difference between the two (proposed facilities).



2. What are the atmospheric carbon implications of operating the existing biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants?

Result. Additional biomass facilities had reduced long-term atmospheric carbon relative to other fuels and technology pathways at a short-term atmospheric carbon cost. The biomass option recovered the carbon debt in 35-50 years depending on the fossil fuel scenarios being compared. The macro-patterns remained almost the same for all the sensitivity-level combinations, including Wood Supply Directly from the Forest (Forest Supply), Wood Supply from Pulpwood (Pulp Supply), Wood Supply from Residuals (Non-Merchantable Supply), and Export of Wood Pellets (Pellet Exports). The results were sensitive to biomass efficiency.

Explanation. We identified a total of 39 facilities, 17 existing, and 22 proposed facilities. The additional 22 biomass power facilities represented 1,014 megawatts of electricity and 3,050,000 tons of pellets. Actual information from facility applications and other public sources, as compiled by SELC (2011), was used to represent the proposed expansion of the biomass electric generating sector in the Southeast over the next several years. The proposed facilities increased demand for wood fiber by 5.2-6.3 million tons a year depending on assumed biomass operational efficiencies (see next section).

We examined the GHG implications of meeting the increased demand using the proposed biomass facilities and compared that to coal and natural gas technology pathways.

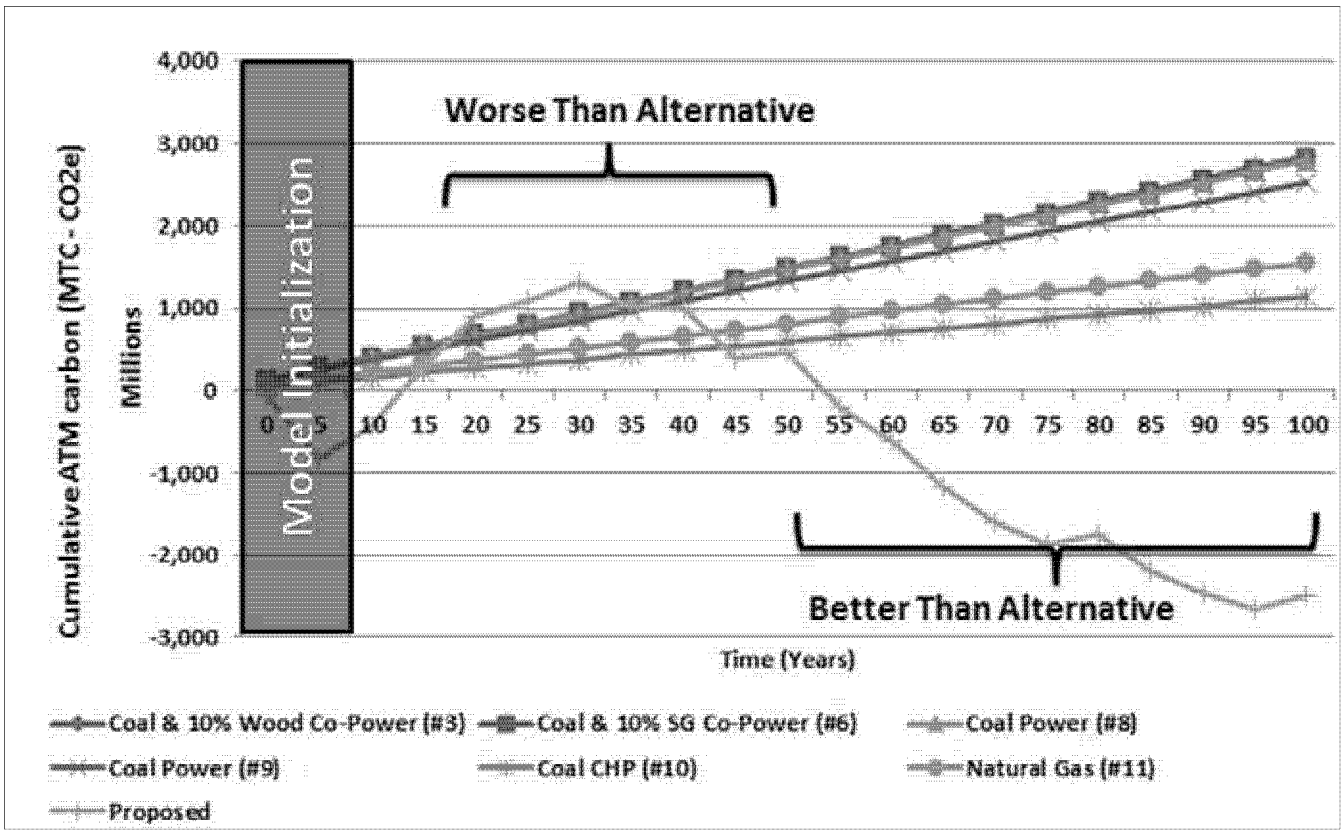


Figure 22.

Cumulative atmospheric carbon balance over 100 years using coal, and natural gas technologies to meet energy demand of proposed biomass facilities.

Biomass baseline for proposed facilities is shown for comparison. Coal #3 and #6 are hidden under coal #8. These results were based on the following assumptions: Forest Supply 50%, Pulp Supply 50%, Non-Merchantable Supply 60%, and Pellet Export 90%.

Assuming full build-out of the currently proposed facilities using biomass energy, we examined the atmospheric carbon balance effects of varying assumptions regarding pulpwood utilization, residual extraction from the forest, amount of woods-supplied versus residue-supplied raw material, pellet mill exports, and biomass efficiency.

Biomass Facility Build-out

A full build-out of the currently proposed biomass facilities requires biomass harvesting to occur in the woodsheds of those facilities. Relative to the existing facility situation this causes a reduction in stored carbon, which varies over time. Figure 21 shows the stored carbon for the existing biomass facility and full build-out facility scenarios, along with the difference between the two scenarios. The difference characterizes the stored carbon impacts of the 22 proposed facilities. The curve generally shows an increase in atmospheric carbon between the two scenarios for about 40 years before leveling off.

The actual shapes of the cumulative carbon balance lines (red and green lines) in Figure 21 will vary depending on many policy and market factors. We are not attempting to make a prediction of the actual future condition, but are interested in a realistic depiction of the difference between the two scenarios. The initial apparent sequestration in the graph is a modeling artifact. It is a function of the simulation resolution and is due to the 5-year simulation cycle with harvests simulated mid-decade. This creates a 5-year growth period before harvest simulation.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Comparison of Biomass to Other Technologies for Build-out

The use of the proposed biomass facilities for full build-out was used as a reference to compare against other technology options for meeting the same energy demand. Figure 22 on the previous page shows the cumulative atmospheric carbon balance for various fuels and technologies relative to producing the same amount of energy using biomass for the proposed facilities. These scenarios include the carbon storage that would have occurred without the proposed biomass facilities being utilized.

In all cases the alternatives appear to have fewer net atmospheric carbon emissions than biomass for 35-50 years with biomass having fewer emissions after that time.

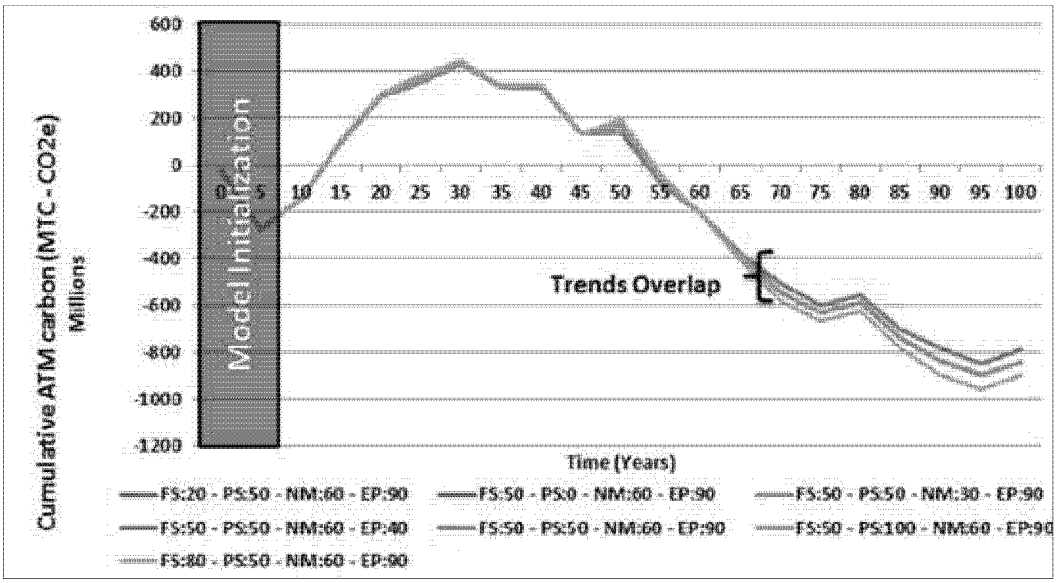


Figure 23. Sensitivity Analyses Conducted for New Biomass Facilities.

Results are presented in the following order: Wood Supply Directly from the Forest (FS: Forest Supply) at 20, 50 and 80 percent, Wood Supply from Pulpwood (PS: Pulp Supply) at 0, 50, and 100 percent, Wood Supply from Residuals (NM: Non-Merchantable Supply) at 30 and 60 percent, and Export of Wood Pellets (EP:Pellet Exports) at 40 and 90 percent. The table is keyed in the following format: Forest-Pulp-NonMerch-Pellet. None of these changes caused a substantial shift in atmospheric carbon.

The CHP scenarios for coal was the best due to the efficiency improvements with CHP. In general, natural gas performed the best of the nonrenewable fuel/technology scenarios without CHP technology (Figure 22, #11 line). Coal power showed a range of responses that depended on the technology pathway. Soil sequestration and land-use change were not considered with any scenarios.

The performance of the proposed biomass facilities relative to the other fuels/pathways was primarily due to the change in forest and long-term carbon storage that was modeled to occur with the increased biomass demand. These results were examined when the input parameters were varied.

Sensitivity Analysis of Full Build-out Using Biomass

A number of input assumptions were varied to observe the response in atmospheric carbon for the 22 proposed biomass facilities. Four primary sensitivity parameters were analyzed: wood supply directly from the forest, wood supply from pulpwood, wood supply from residuals and the amount of export of wood pellets to Northern Europe. In addition, the assumptions regarding the efficiency of the biomass facilities were varied for an additional analysis. None of the four primary input assumptions showed a substantial shift in atmospheric carbon (see Figure 23 on the previous page). The biomass efficiency assumption was analyzed separately for the full build-out scenario and is illustrated in Figure 24 on page 98.

IMAGE COURTESY ZANDER EVANS

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 24.

Facility Efficiency.

Both systems have short- term cost and a long-term benefit. When the biomass line is above the fossil fuel line, then it is emitting more carbon into the atmosphere compared to the fossil fuels. The atmospheric carbon impact is the same where the lines intersect. Carbon neutrality is achieved when the biomass line intersects the origin. This simulation was run using the following assumptions: (Forest Supply) 50%, (Pulp Supply) 50%, (Non-Merchantable Supply) 60 %, and (Pellet Exports) 90%.

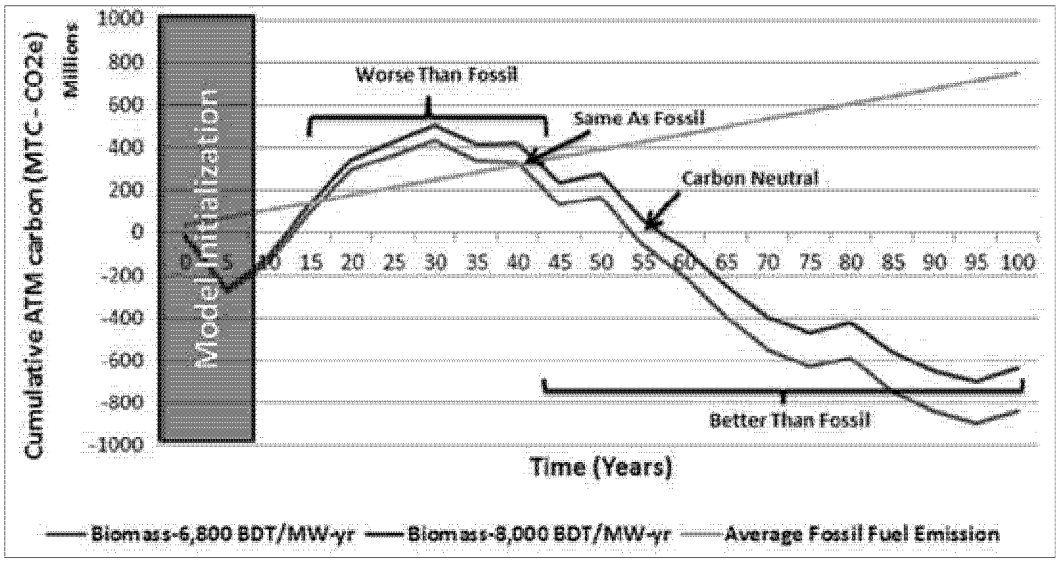
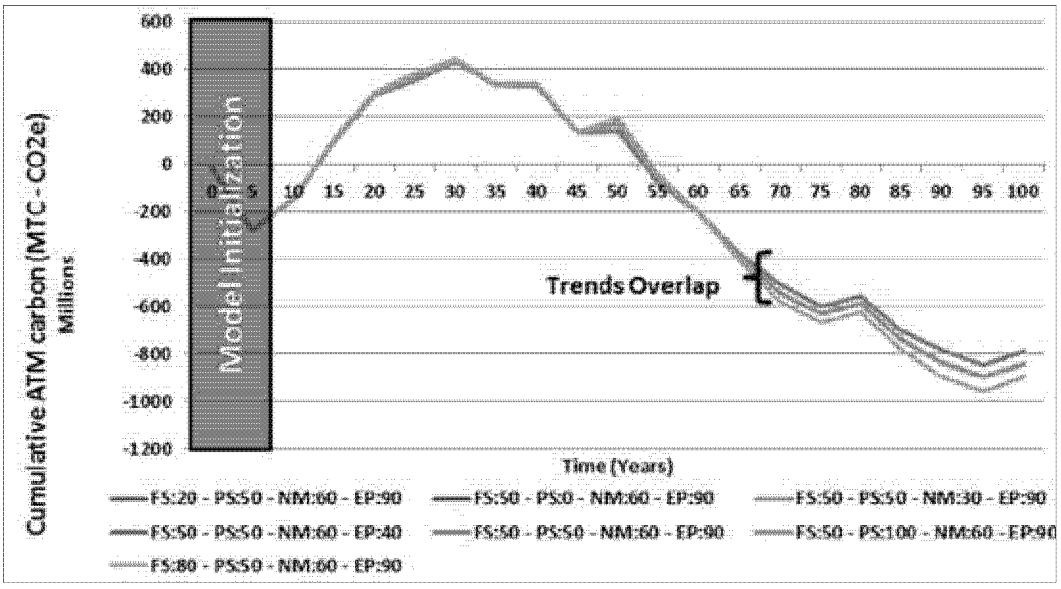


Figure 25.

Sensitivity Analyses Conducted for Wood Supply Directly from the Forest (Forest Supply) at 20, 50, and 80%, Wood Supply from Pulpwood (Pulp Supply) at 50%, Wood Supply from Residuals (Non-Merchantable Supply) at 60%, and Export of Wood Pellets (Pellet Exports) at 90%. The table is keyed in the following format: Forest. FS:20 and FS:50 overlap.



3. What are the GHG consequences of varying the amounts of biomass required to make a specific amount of electricity?

Results. Biomass utilization per unit of power produced was a critical factor and can alter the outcome of the atmospheric carbon balance over time. We showed that a more conservative (higher) assumption of biomass demand per unit of power produced altered the eventual outcome and delayed the breakeven point relative to the other fuels and pathways. There are a range of values associated with how much biomass is required to produce a given amount of electricity. Using a mid-range target of 6,868 BDT per MW per hour per year provided the payback period of 35-50 years. The model was sensitive to this parameter and payback periods were extended when the high range of about 8,000 BDT was used.

Explanation. The model was sensitive to the biomass facility efficiency assumptions. The proposed facilities are compared to the other fuel and technology pathways assuming the high end of a range of possible biomass requirements for power production (see Figure 24 on the previous page). In this figure, the other technology pathways were averaged to achieve a single carbon accumulation line. The less-efficient assumption yielded higher cumulative atmospheric carbon due to the fact that the facilities consumed a larger amount of biomass. Specific details behind this value can be found in the technology pathways section of the report.

4. What are the GHG consequences of using forest-derived biomass versus non forest-derived biomass?

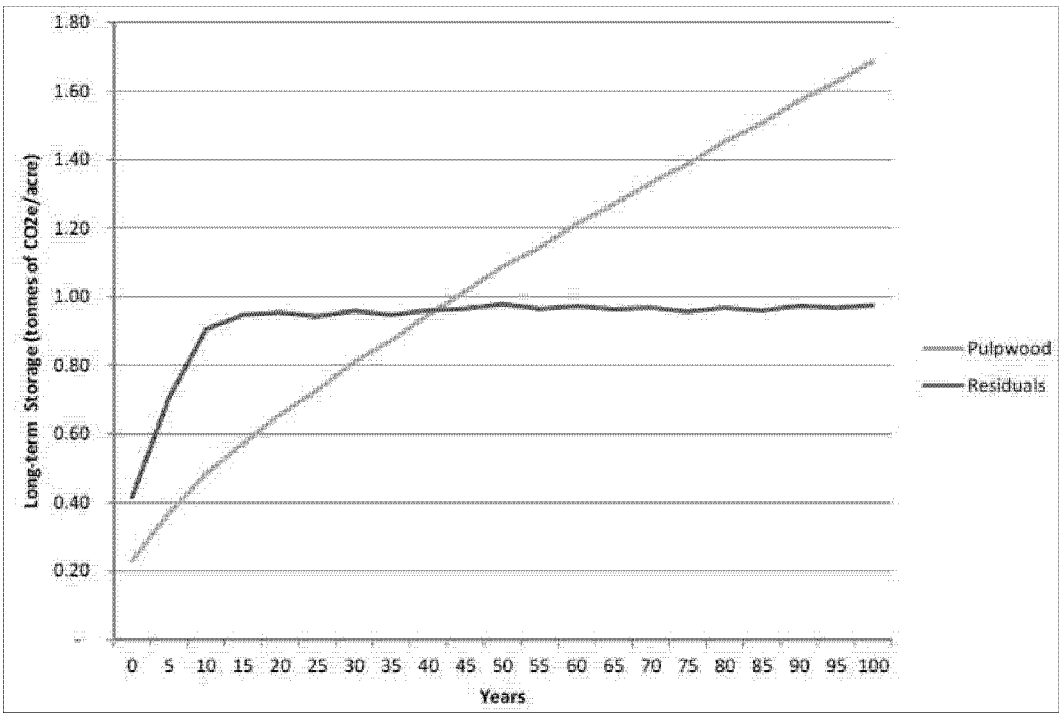
Results. The forest supply sensitivity analysis did not cause a substantial difference for the scenarios modeled at the landscape scale.

Explanation. There was sufficient biomass supply from the forest for the existing and proposed facilities within the landscape of interest using the defined assumptions. The model used the best available information on specific facility use of forest versus non forest-derived biomass. Local supply issues could occur where facility woodsheds overlap, which could have ecological impacts if best management practices for wood retention are not in place. Some biomass facilities receive 100 percent of their biomass supply from the forest or from non-forest sources such as mill residues or urban tree trimmings. Some facilities, however, claim a variable amount of their supply directly from the forest; for those facilities we varied the forest supply by setting it at 20 percent, 50 percent, and 80 percent. The sensitivity analysis does not show a substantial difference between these scenarios over the short term (see Figure 25 on the previous page). Over the long term, the results indicate a slightly lower atmospheric carbon profile for supply coming directly from the forest. Our results were surprising. We expected a benefit from using non-forest biomass feedstocks considering that this biomass has lower processing and transportation emissions as well as avoided decomposition emissions benefits. We found that at the regional scale there were no significant differences in landscape level GHG accumulation because the integrated carbon profiles of the different feedstocks were similar to one another (the net magnitude of emissions between the processing, transportation, and avoided decomposition) and the forest was responding with increased growth and storage of wood products when forest material was harvested for biomass.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 26.

Example of the relative carbon storage over time of pulpwood utilized for pulp and paper products versus residuals retained in the forest.



5. What are the GHG consequences of using tops and limbs (residuals) for biomass supply versus pulpwood (main stems)?

Results. The residual versus pulpwood supply sensitivity analysis did not cause a substantial difference for most of the scenarios modeled at the landscape scale, however, this result needs to be considered in the context of the model. The use of residuals versus main stems would reduce atmospheric carbon accumulation in those situations where there are adequate amounts of residuals available from current harvests. This conclusion is based on the higher relative carbon storage of pulpwood versus residuals (see Figure 26 above). This general rule also holds true for situations where no pulp market exists and standing trees might be left to grow and sequester carbon.

Since residuals are not the driver of timber harvests, when a landscape model is asked to service biomass facilities only from residuals and the required amount of residuals is not readily available from timber harvests, it causes more acres to be harvested. Thus, when this model was instructed to supply the 22 new facilities with only residuals, it did not cause a substantial difference in the GHG consequences versus pulpwood.

An accurate depiction of the pulpwood versus residual utilization comparison requires a spatially specific and market dependent analysis beyond the scope of this study. Such a study would incorporate different market scenarios that would influence the carbon emissions such as: active sawtimber market, active sawtimber and pulp market, no markets, and active pulp market.

Explanation. An analysis of pulpwood utilization relative to residuals is complicated by the fact that more acres are generally required using residuals to supply the same quantities of biomass. Since harvests are integrated for sawtimber, pulp, and residuals, the emissions increase to obtain residual biomass supply because more carbon is removed from the forest through more harvesting. These results at the model scale should not lead to erroneous conclusions regarding the GHG differences of standing trees versus residuals because residuals are not drivers of timber harvest, but rather by-products. This comparison does not include leakage effects that might occur if biomass demand were to cause pulpwood supply to shift to other areas.

Pulpwood

The percentage of pulpwood utilized relative to harvest residuals was varied at 0, 50, and 100 percent of pulpwood utilization. In the context of the entire study area, there was not a substantial tradeoff identified between utilizing pulpwood that was destined to be made into pulp and paper products and using the same material for biomass energy (see Figure 27 below). This was not a complete life-cycle analysis in that the pulp and timber markets were not analyzed, including potential leakage effects of displaced pulp supply.

Designing a More Accurate Model for the Residuals versus Main-Stems Question

A complete depiction of the pulpwood versus residual utilization comparison requires a spatially specific and market-dependent analysis beyond the scope of this study. For simplicity in framing the conceptual model, we are assuming that no competition from other biomass facilities exists, however, the map of existing and proposed facilities (see Figure 11 on page 72) shows that a number of facilities have overlapping sourcing areas. This could cause a situation where biomass is being moved farther distances for use in facilities designed with different efficiencies driven by specific market demands.

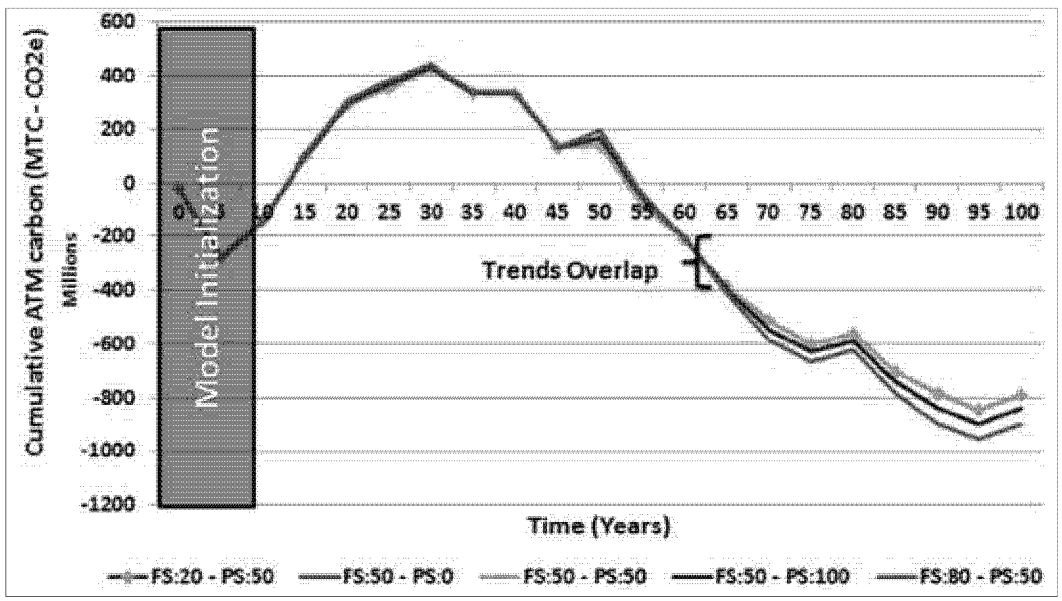


Figure 27.

Sensitivity Analyses Conducted for Wood Supply Directly from the Forest (Forest Supply) at 20, 50, and 80% and Wood Supply from Pulpwood (Pulp Supply) at 0, 50, and 100%, Wood Supply from Residuals (Non-Merchantable Supply) recovered at 60%, and Export of Wood Pellets (Pellet Exports) at 90%. The table is keyed in the following format: Forest-Pulp. FS-PS, 20-50, 50-50, and 50-0 all overlap.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Market demands could be incorporated into a future study by defining different market scenarios that would influence the carbon emissions such as: active sawtimber market, active sawtimber and pulp market, no markets, and active pulp market.

Scenario 1-Active Sawtimber Market. This setting includes intensive sawtimber activity in the proposed facility woodshed and no existing pulp demand. In this case, we assume that an ample supply of both residuals and pulpwood is available. Since there is no existing residual or pulpwood demand, we can assume that when a sawtimber harvest occurs, this wood is either left to become emissions over time from decay if part of a sawtimber tree, or if a partial harvest, left on the stump. The larger harvested pulpwood pieces will take longer to decay so there is a timing element, but in general either of these sources for biomass would have the same atmospheric carbon effects when derived from sawtimber trees. This is because neither source was being utilized a priori. Leaving the pulpwood-size pieces on the stump and utilizing the residuals from the harvested sawtimber, however, will clearly be beneficial from an atmospheric carbon perspective.

Scenario 2-Active Sawtimber and Pulp Market. This setting includes intensive sawtimber activity in the proposed facility woodshed and existing pulp demand. In this case, we assume that an ample supply of residuals exists, but pulpwood is already being utilized for paper products with the associated long-term storage in in-use and landfill pools. Since there is no existing residual demand, we can assume that when an integrated sawtimber and pulpwood harvest occurs that the residual wood is left to become emissions over time from decay. In general, using residuals will have improved atmospheric carbon effects relative to pulpwood. This is because the residuals were not being utilized a priori while a portion of the pulpwood was placed into long-term (100-year) storage. Taking the pulpwood instead of the residuals would cause the long-term storage to be negated; this would be offset in the shorter term by more residuals in the woods but that would reach a steady state. Also, if this meant a displacement of pulp supply, then the carbon analysis would depend on the leakage effects. This scenario fits with much of the "existing" landscape condition in the Southeast; except of course for the recent drop-off in timber production. For example, sawmills in Alabama are currently running at about 50 percent capacity.

Scenario 3-No Markets. This setting includes a low level of sawtimber activity in the proposed facility woodshed and no existing pulp demand. In this case we assume that a low level of supply of both residuals and pulpwood is available. In order to provide biomass supply, harvests would have to be initiated based on biomass demand, not as a side consequence of other harvests. In this case it might seem logical to utilize both pulpwood and residuals from harvests. This might minimize the reduction of stored carbon in the forest, not considering land conversion issues, by minimizing the acres harvested. Relative to a baseline of no harvest, however, this would not be beneficial to the atmospheric carbon balance. There would likely be some acreage in this category where a biomass market may make marginal harvest scenarios profitable. We did not attempt to quantify this effect for the study area.

Scenario 4-Active Pulp Market. This setting includes a low level of sawtimber activity in the proposed facility woodshed and an existing pulp demand. In this case, we assume that a supply of both residuals and pulpwood is available, but pulpwood is already being utilized for paper products with the associated long-term storage in in-use and landfill pools. Utilizing the residuals associated with pulpwood harvests would have the most beneficial carbon effect. This illustrates that a pulpwood- versus residual-utilization question is really a site specific one, which has policy implications regarding GHG accounting for a proposed facility. Our modeling did not account for this level of sophistication, which would require a spatially explicit timber/pulp supply model.

Professional forestry and forest management have long been involved with the sustainable production of wood fiber for use by society. The production of wood fiber for biomass energy affects the amount of carbon exchange between the biosphere and atmosphere through both the production of energy and carbon stored on the landscape and in other pools. By accounting for these flows, we can identify when landscapes may become limiting to sustainable and environmentally favorable outcomes. We have assumed in our modeling here that any harvesting will be followed by replanting or natural regeneration so that all stands are fully restocked in a reasonable and relatively short time frame.

This analysis can inform policy and management decisions. We can also use our existing tools of silviculture and planning to assist with mitigating effects where feasible for the best environmental and economic outcomes. The accounting for the consequences of atmospheric carbon balance relative to a baseline that is geographically constrained to the affected area is consistent with project carbon accounting as found in forest protocols for carbon projects.

6. What are the GHG consequences of using natural stands versus plantations to fuel an expansion of biomass electric power in the Southeast?

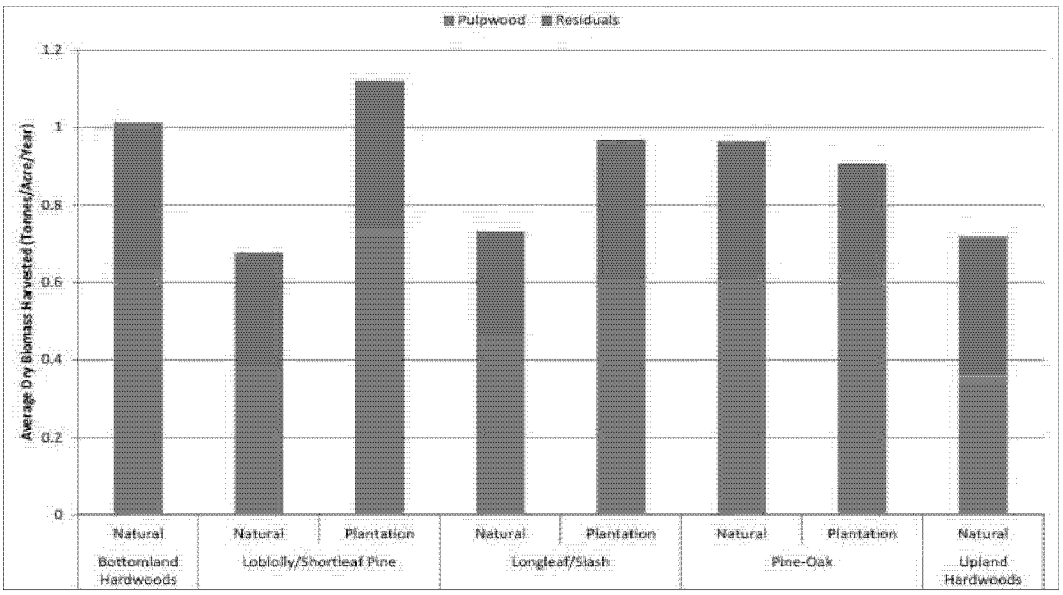
Results. The model design did not allow a direct comparison of natural stands versus plantations at the stand level, however, additional research indicated that converting from natural bottomland hardwoods to a loblolly pine plantation would have substantial negative carbon storage effects, and should probably be avoided. This could also be true for converting upland hardwoods. We also found that for a given acre, plantations can produce more biomass than natural stands over time. This may be a function of site productivity, improved genetic stock from planting, and silvicultural methods. For example, loblolly plantations produced considerably more biomass than natural upland hardwoods, but stored less carbon than upland hardwoods. This did not hold for the pine-oak forest types. The bottomland hardwoods, which are regenerated naturally, were highly productive second only to loblolly/shortleaf pine plantations. We did not find substantial GHG effects, however, at a regional scale.

Explanation. The model considers existing plantations at the study scale and was not designed to alter the amount of plantations nor the effects of converting natural stands to plantations, however, additional research was useful in providing information about the difference between natural stands and plantations. The average carbon stored over 100 years by forest type and stand origin is shown in Figure 29 on page 105. In general, the naturally regenerated hardwood types stored more carbon than softwood types. The baseline management, which assumes sawtimber and pulp production but not biomass, generally stored more carbon than when biomass management is added. There was not a clear pattern of carbon storage for the forest types that had both plantation and natural stand regeneration.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 28.

Average biomass produced (harvested) over 100 years for the study area, by forest type, and stand origin.



In some forest types, plantations can grow more biomass than natural stands. This does not imply, however, that conversion of natural stands to plantations should occur to meet demand. The current placements of plantations were in response to economic and social choices in the past, which may not apply to existing natural stands since they represent different productive, ecological, and economic conditions. Naturally regenerated stands may also store more carbon while also producing substantial biomass feedstock as the bottomland hardwoods clearly show. Figure 29 on page 105 shows that in the forest types where plantations occurred, more than 50 percent of the area is already in plantations.

In areas where the pulp market has declined, biomass demand may provide a market for existing plantations. This would be beneficial to the atmosphere if the market prevented conversion from forest to other uses. Degraded natural stands could also benefit from a biomass market where improvement treatment costs could be offset by selling biomass.

Several additional elements would need to be added to this comparison to achieve accurate predictions of impacts to atmospheric carbon. These would include: harvest recovery technology, transportation distances and efficiencies, and biomass utilization efficiencies.

There is a general atmospheric carbon benefit associated with dense biomass recovery locations that are found in close proximity to efficient biomass facilities. In addition, sustainable forest management practices are a necessity to avoid a release in stored forest carbon. There are also examples where biomass utilization has made restoration efforts economically feasible. These elements should all be taken into consideration when prioritizing between natural stands and plantations.

It should also be noted that we are assuming all plantations harvested will be replanted. There may be instances when the landowner sells his plantation stands for biomass and then converts the land to development. Since we did not take into consideration land-use/ land-cover changes within the model, this carbon would not be recaptured and should be considered as an emission. Since forest carbon regeneration is a key component to landscape level GHG emissions; credit should be given only to areas where regeneration is an explicit part of the long-term management plan. Landholdings that are currently forested, and then are type converted into another non-forest land use (such as a development) should be explicitly excluded from regional GHG benefits assessments or quantified as a long-term emission.

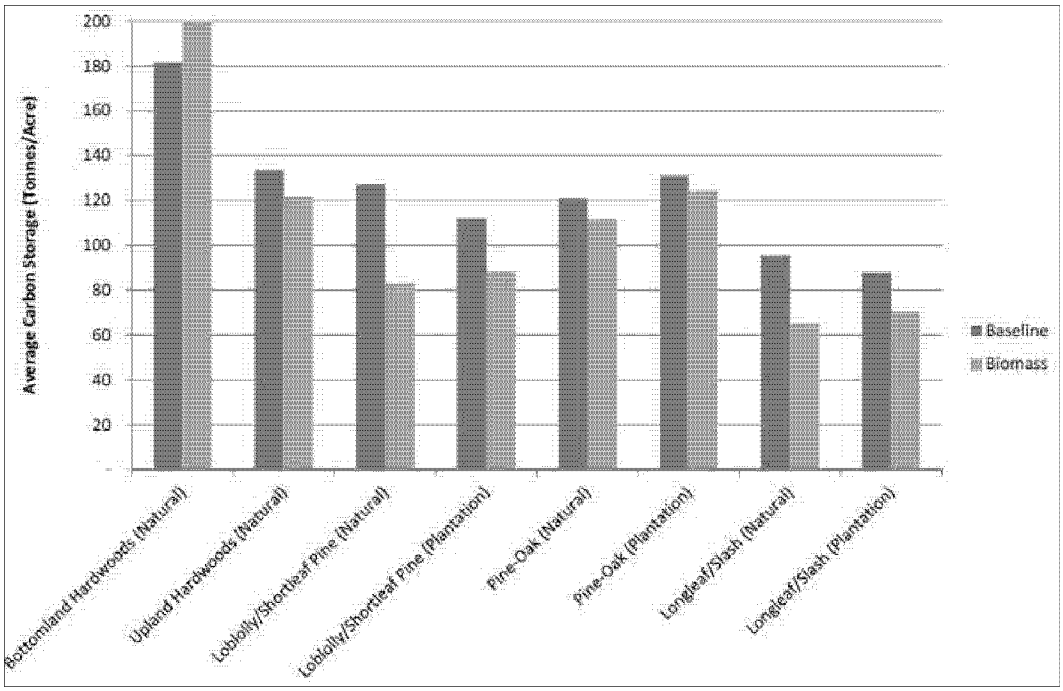


Figure 29.

Average carbon (CO_2) stored over 100 years for the study area, by forest type, stand origin, and management regime.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

7. What are the GHG consequences of varying levels of pellet export from the Southeast to Europe for electric power generation?

Results. The current biomass facilities and full build-out of currently proposed facilities scenario were not highly sensitive to the amount of wood pellets that were exported.

Explanation. A factor analyzed in our sensitivity analysis was the exporting of pellets. Our default setting was an assumption of 90 percent exports to Northern Europe. We also examined the effects of reducing the export of pellets to 40 percent.

Figure 30 below shows that reducing the export of pellets does not substantially improve the atmospheric carbon balance of using biomass for the proposed facilities. This is a factor of the relatively small atmospheric carbon cost of shipping pellets as ocean freight. It is important to note that the European Union (EU) is not accounting for the carbon emissions from burning wood pellets. Rather, the EU Emissions Trading System considers biomass resources to be carbon neutral and European industries are essentially getting a free pass on biomass carbon accounting. The wood pellet manufacturing, shipping, and combustion costs as well as the sequestration effects of wood products and in-forest carbon are all factors in a comprehensive carbon accounting.

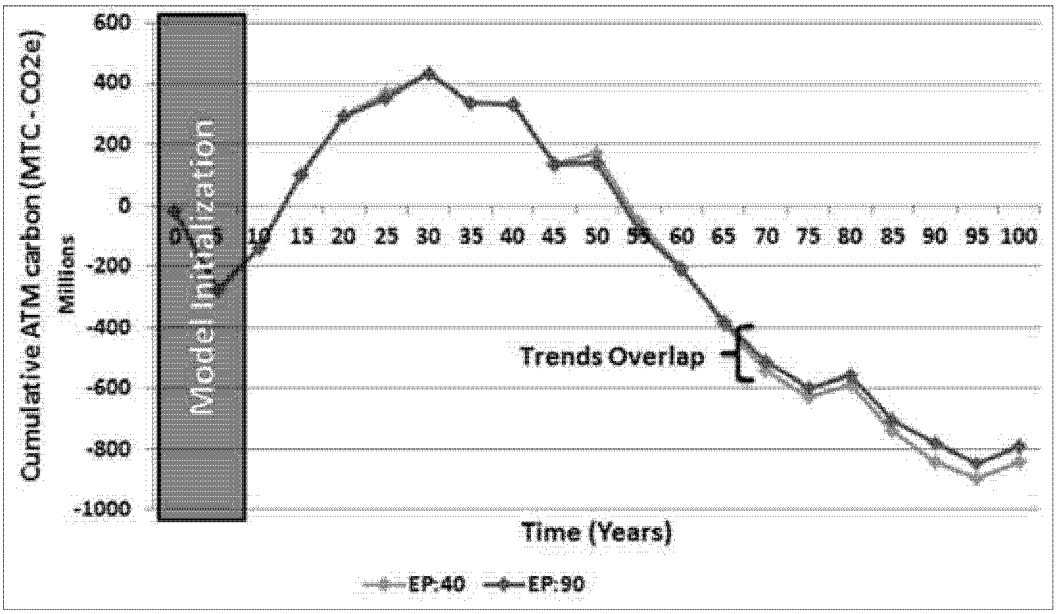


Figure 30.

Cumulative atmospheric carbon balance over 100 years using the 40% and 90% export options. Wood Supply Directly from the Forest (Forest Supply) at 50 percent and Wood Supply from Pulpwood (Pulp Supply) at 50 percent, and Wood Supply from Residuals (Non-Merchantable Supply) at 60 percent. The table is keyed in the following format: Export %.

8. Is there enough biomass available to supply 22 new biomass facilities while limiting the amount of residuals that can be removed to protect forest health?

Results. Although the sensitivity analysis did not indicate a significant change in carbon balance related to the amount of residuals allowed for removal, the analysis did indicate that limiting the amount of removal of residuals to either 30 or 60 percent of what is available after harvests did not present a limiting factor to supply at the scale and using the current model construct (see Figure 23 on page 96). This indicates that at least for the proposed additional capacity modeled, retaining sufficient residual biomass to maintain ecological health should not be limiting to biomass supply.

Explanation. There are physical, economic, and Best Management Practice limits to how much of the residuals (non-merchantable wood, bark, and foliage) can be removed from the forest. The results indicate that there is enough available material in other categories to fill a limitation on residual removal. The existing landscape, its current land use, existing markets, and energy demands provide a matrix where there is sufficient feedstock availability given the assumptions used in the analysis. Forest management practices that were used in this study reflect current methods. These methods could be improved upon to yield healthier forests and a more stable future feedstock for facilities that are scaled appropriately to the landscape that they serve. In short, there has to be sufficient activity on the landscape to produce the residuals or a difference will become apparent.

3.5.0 POLICY CHALLENGES: INCORPORATING FOREST BIOMASS AND CARBON MODELING INTO SOUND CLIMATE CHANGE POLICY

The Challenge of Evaluating Forest Carbon Flux

Recent studies at the Massachusetts Institute of Technology (MIT) reveal that participants from highly educated study groups repeatedly used flawed conceptual reasoning and violated fundamental physical principles when asked to anticipate the atmospheric effects of basic approaches to controlling carbon emissions (Sterman, 2008; Sterman 2007). People have difficulty conceptualizing flows of carbon stocks between different carbon pools such as forests and the atmosphere. Researchers confirm that the survey participants produce the wrong answer when they use a problem-solving approach called pattern matching to assume that an output of a system should look like its inputs. Researchers call this "stock-flow failure" (Cronin, 2009).

In the MIT studies, this stock-flow failure led people to believe that GHG accumulation in the atmosphere could be lowered merely by lowering the yearly emissions (Sterman, 2007). In other words, they believe that simply lowering the rate of emissions would lower the total stock of carbon in the atmosphere. In reality, however, GHG concentrations in the atmosphere can fall only when emissions drop below sequestration rates.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Furthermore, in the real world, time lags and movement between different types of carbon pools create complexities that create even greater challenges for those crafting climate change policy (Sterman, 2006). To assist readers in applying the results of this report and to assist the policy discussion, the following guideposts may be useful.

The Fundamental Cause of Long-Term Atmospheric Carbon Accumulation

Climate is changing due to increased levels of carbon in the atmosphere. Atmospheric carbon is increasing primarily because we burn fossil fuels and release carbon that was sequestered in geologic formations millions of years ago. Forest destruction and large-scale land-use change also increase atmospheric carbon. Forests and other carbon pools such as oceans, rocks and sediments, grasslands, or peatlands can sequester carbon but cannot absorb net increases in atmospheric carbon from combustion of fossil fuels or large-scale deforestation fast enough to be meaningful for environmental policy over the next few centuries. Forests re-sequester carbon relatively quickly but the worldwide forest pools cannot deal with the tremendous amount of carbon already released from both the fossil carbon pool and the forest carbon pool (31 gigatons in 2009) nor future releases from these pools (Henson, 2011). The full level of atmospheric carbon loading will eventually be determined by the total amount of carbon released from combustion of fossil fuels and conversion of forests to non-forest uses.

We have already added 300 gigatons of carbon pollution to the atmosphere over the last 150 years. The IPCC low-growth emissions scenario B1 anticipates the addition of another 700 gigatons. Regardless of final carbon levels, it is clear that it will take thousands of years for oceans, rocks and sediments, and terrestrial systems to reabsorb this carbon (Stager, 2011). This means that the effects of our current fossil fuel use will be felt by human beings and the earth's ecosystems for a long time. The management, harvest, destruction, and creation of forests will play a role in this situation, particularly in the short term, but over the long run, the story will be largely dictated by the total amount of fossil fuel carbon we release.

Acknowledging Long- and Short-Term Perspectives

The results of atmospheric life-cycle carbon assessments will prompt analysis from two different perspectives, both of which are necessary for development of effective climate policy. Those holding a long-term perspective will pay attention to the levels of atmospheric carbon that will be realized over centuries and millennia. The operative question for these long-term thinkers trying to determine the effects of atmospheric carbon on global climate is not how much we are emitting on a yearly basis (the flow) but what will be our total fossil fuel emissions (the stock) over time. Individuals with a long-term perspective will note that forest biomass is a biogenic source of energy and see the decades-long forest carbon debt and payback flux as relatively inconsequential in the long run—a mere short-term biogenic carbon flux in the context of the larger relatively permanent global geologic carbon flux.

Individuals with shorter-term perspectives will likely interpret the results of the current study differently and ask different questions. If there is a carbon emissions level policy target that is only decades away, then the use of more forest biomass may not help meet that specific short-term goal. A series of other questions will arise from the short-term perspective. What damaging climate events might be triggered through additional short-term carbon loading of the atmosphere? How do we weigh the short-term increase in carbon emissions from biomass against the larger longer-term benefits of substituting biomass for fossil fuels? How long will we utilize fossil fuels, when do we anticipate a total global switch to non-fossil alternatives, and how will the debt cycle of forest biomass overlap with that transition? Will an early emphasis on forest biomass help us transition to carbon-free alternatives like solar or wind or will it delay their implementation? Are there hidden ecological or carbon costs in the use of forest biomass of which we are not now aware?

Balancing Long- and Short-Term Perspectives

Two factors are critical to setting policy that balances the complicated short- and long-term flux dynamics of forest biomass. The first one is an estimate of when we can expect to transition fully away from fossil fuels. If this transition lies within the debt cycle of biomass systems, the policy response will be different than if the transition lies outside the debt cycle of biomass. In either case it should be realized that when full transition occurs that is also the point in time when biomass plants could theoretically be shut down and the forest allowed to recover and re-sequester the carbon that the biomass energy system has moved to the atmosphere while it was operating. (Of course this assumes that biomass harvesting is followed by forest regeneration and not the conversion of forest land to other uses.) An accounting and comparison to other alternatives could include this re-sequestration that would begin at this time.

The second factor pertains to the goals of climate policy—what policies are adopted to mitigate the effects of climate change to society and ecosystems. At some point in the future there will be an atmospheric carbon peak followed by a variety of physical global warming responses related to that peak. The warming will lead to climate events that will have repercussions on human society and natural ecosystems. Recognizing the linkages and timing of these events and matching them to the stocks and flows of forest carbon will be critical in setting the most effective policies.

The combustion of biomass for energy and subsequent release of carbon into the atmosphere is linked to a sequestration component when the material is produced from sustainably managed forests. Carbon is initially released as forests are harvested for biomass, and then re-sequestered over time as the forest recovers. This is unlike fossil fuels, which have no sequestration component. Biomass also has a longer payback period than other renewables such as wind and solar. Consequently, the carbon implications of biomass are much more difficult to decipher and prone to an endemic confusion over stocks and flows. It is neither immediately carbon neutral, nor can the payback periods be summarily dismissed as unhelpful to climate goals. Therefore, biomass deserves a full and comprehensive discussion of its potential to help meet climate change goals through close attention to proper GHG accounting methodologies.

CONCLUSIONS

OVERALL

This study confirms that the life-cycle carbon implications of biomass when used for energy production are complex and do not lend themselves to simple or blanket public policy options. It is important to remember that the results in this study apply only to an analysis of biomass electric power and electric-led CHP in a specific region of the southeastern United States. It does not apply to thermal-energy pathways as these have significantly higher efficiencies and consequently different carbon life-cycle analyses. Nor does it directly apply to other regions with different forest types, utilization trends, or market conditions.

Forestry and forest management have long been involved with the sustainable production of wood fiber for use by society. The production of wood fiber for biomass energy affects the carbon exchange between the biosphere and atmosphere. By accurately accounting for this exchange through a full life cycle carbon analysis, this study illustrates how utilizing our forests for biomass energy can affect yearly emissions and the eventual accumulation of green house gases in the atmosphere when compared to using fossil fuels. The manipulation of important parameters in the model also allow us to test which policy and forest management decisions may create a more or less positive outcome for the use of biomass. These results can be combined with other factors, such as a weighing of short and long term carbon accumulation in regard to damaging climate events or the ecological effects of harvesting more biomass to inform policy and management decisions.

WOOD SUPPLY

- Most studies conducted in the past six years quantify the gross or total amount of woody biomass material generated on an annual basis and do not quantify how much is already being used. Most of these studies focus on residues produced from other primary activities while evidence suggests nearly all the mill and urban wood residues are already used by existing markets.
- The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).
- Whether logging slash, whole trees, or pulpwood will be used in the expansion of biomass energy in the Southeast will depend on:
  1. Which market the wood is going to (pellet mills need high-quality fiber from pulpwood while biomass plants are less particular about quality)
  2. How much demand increases within the pellet and power market sectors over time
  3. What happens with the pulp and paper industry in the southeast region in the future
- Prior to 2009, most fuel availability studies presented estimates of supply without any acknowledgment of the influence price has on the availability of these woody biomass resources. Since then, different studies have examined the economics using different indicators, making it

difficult to compare results between the studies. For a clear assessment of the economics of woody biomass resources, the total delivered price paid by the receiving facilities is the best indicator to use.

- Various studies reviewed in this chapter used widely divergent assumptions regarding what percentage of the total amount of logging residue can be recovered from a harvested area. While the range observed in the literature was from roughly 50-100 percent, it should be noted that there is a difference between how much residue *can* be recovered and how much *should* be recovered when ecological factors are taken into account. While examining how much wood fuel could be generated if 100 percent of this material was recovered is useful for academic purposes, it is unrealistic to assume that such a high level can and should be realized. Ideally, studies would look at two critical issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered.
- The availability of logging residues will largely depend on extraction methods. Where whole-tree harvesting systems can be used, these residues can be cost-effectively accessed, however, the ecological effects of whole-tree logging need to be considered. Where mechanized cut-to-length and manual stem-only harvesting are used, these residues will not be easily accessible. Further analysis that determines how much whole-tree harvesting systems versus stem-only harvesting systems are used across this region would be very useful.
- Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential. In contrast, Alabama and Tennessee both had very little publicly available reports estimating biomass resources.
- Evidence suggests that there is likely enough wood to meet a 15 percent federal RES standard applied to each of the seven states (with the exception of Florida) when woody biomass sourced from local forests accounts for no more than 20 percent of the overall renewable electric generation target. It also appears, however, that adequate wood fuel resources are quite sensitive to the RES allocation. For example, if 30 percent of a 15 percent RES was allocated to forest biomass, it is likely there would not be enough wood fuel available within the region. A more aggressive RES standard for biomass leads to a higher likelihood of shortages and a greater probability of pulpwood displacement.
- Capacity to access and utilize residues is also a function of how much roundwood harvest occurs. More demand for roundwood generates more residues. The extent to which biomass power plants transition their wood procurement away from residues and toward roundwood is governed by the strength of the rest of the forest products industry. If the forest products industry strengthens as a result of greater lumber demand, it will increase its wood fiber consumption and, as a result, biomass power plants would procure more residues at a lower cost and less pulpwood at a higher cost. If the forest products industry as a whole continues to contract, however, biomass power plants will likely transition toward procurement of chipped fuel from whole trees *assuming* they can absorb the higher cost associated with that transition.

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from

CONCLUSIONS *(cont'd)*

the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher-fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood. Therefore, pellet mills and biomass power plants have somewhat complementary (almost symbiotic) procurement needs. Pellet production, especially the export market to Europe, will continue to play the wildcard role in future wood fuel markets.

- The potential recovery rate for harvest residue is a key variable in determining the quantity of available wood fuel. Further research is needed to assess both the current achievable residue recovery rates and reasonable future recovery rates. Projected recovery rates need to consider woody biomass retention rates to meet wildlife and biodiversity, water quality, and soil productivity needs.
- The supply chapter undertakes a hypothetical exercise looking at current forest growth rates versus current removals to generate some rough estimates of the state and regional potential woody biomass supply for energy. This exercise suggests that meeting 20 percent of a 15 percent renewable electricity standard with woody biomass would be possible in the Southeast region. Meeting 30 percent of a 15 percent RES would likely exceed the projected supply. This exercise points out that there are distinct limits on how far woody biomass supply in the region can go toward meeting renewable energy targets.

CARBON LIFE-CYCLE ANALYSIS

The conclusions provided here are grouped to track with the key questions the study is intended to address.

What are the atmospheric carbon implications of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?

Our findings indicate that the 17 existing biomass facilities (149 MW and 1.755 million tons of pellets) now generate and would continue to generate an improved atmospheric carbon balance relative to fossil fuels to provide equivalent power. Continuing to run these existing 17 biomass power plants would result in lower atmospheric carbon in the short- and long-term than shutting them down and shifting to fossil fuels.

What are the atmospheric carbon implications of operating the existing 17 biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants?

Answering this includes a range of sensitivity analyses, including the impacts of varying the proportions of residuals versus pulpwood and natural forests versus plantations.

Additional biomass facilities produced long-term atmospheric carbon benefits for a short-term atmospheric carbon cost. The biomass option recovered the carbon debt in 35-50 years depending on the fossil fuel scenarios being compared.

What are the GHG consequences of varying the amounts of biomass required to make a specific amount of electricity?

Biomass utilization per unit of power produced is a factor and can alter the outcome of the atmospheric carbon balance over time. We showed that a lower assumption of biomass demand per unit of power produced shortened the payback period relative to the other fuels and pathways. There are a range of values associated with how much biomass is required to produce a given amount of electricity. Using a mid-range target of 6,800 BDT per MW per hour per year provided the payback period of 35-50 years.

What are the GHG consequences of using forest derived biomass (tops, limbs, pulpwood) versus non-forest derived biomass (mill wastes and urban tree thinning)?

The forest supply sensitivity analysis did not show a substantial difference for the scenarios modeled at the landscape scale. The study does show that using non-forest biomass generally has a slightly lower atmospheric carbon profile. These results were surprising. A much larger benefit from using non-forest biomass feedstocks was expected considering that this biomass has lower processing and transportation emissions as well as avoided decomposition emissions benefits. What we found was, at the regional scale, there were no significant differences in landscape level GHG accumulation because the integrated carbon profiles of the different feedstocks were similar to one another (the net magnitude of emissions between the processing, transportation, and avoided decomposition were similar, Figure 25).

What are the GHG consequences of using tops and limbs (residuals) for biomass supply versus pulpwood (main stems)?

The forest supply sensitivity analysis did not cause a substantial difference for most of the scenarios modeled at the landscape scale. This result, however, needs to be considered in the context of the model. The use of residuals versus main stems would reduce atmospheric carbon accumulation in those situations where there are adequate amounts of residuals available from current harvests. This result is based on the higher relative future carbon storage of pulpwood versus residuals. This general rule also holds true for situations where no pulp market exists and standing trees might be left to grow and sequester carbon. Since residuals are not the driver of timber harvests, however, when a landscape model is asked to service biomass facilities only from residuals and the required amount of residuals is not readily available from existing timber harvests, it causes more acres to be harvested. Thus, when this model was instructed to supply the 22 new facilities with only residuals, it had to include more acres of overall harvest to generate these residuals and consequently did not cause a substantial difference in the GHG consequences versus pulpwood.

An accurate depiction of the pulpwood versus residual utilization comparison requires a spatially specific and market-dependent analysis beyond the scope of this study. Such a study would incorporate different market scenarios that would influence the carbon emissions such as: active sawtimber market, active sawtimber and pulp market, no markets, and active pulp market.

CONCLUSIONS *(cont'd)*

What are the GHG consequences of using natural stands versus plantations to fuel an expansion of biomass electric power in the Southeast?

The model design did not allow a direct comparison of natural stands versus plantations at the stand level. Additional research, however, indicated that converting from natural bottomland hardwoods to a loblolly pine plantation would have substantial negative carbon storage effects, and should probably be avoided. This could also potentially be true for upland hardwoods. We also found that for a given acre, plantations can produce more biomass than natural stands over time. This may be a function of site productivity, improved genetic stock from planting, and silvicultural methods. This did not hold for the pine-oak forest types. The bottomland hardwoods, which are regenerated naturally, were highly productive second only to loblolly/shortleaf pine plantations. Nevertheless, we did not find substantial GHG effects at a regional scale.

What are the GHG consequences of varying levels of pellet export to Europe for electric power generation from the Southeast?

The current biomass facilities and full build-out scenario were not highly sensitive to the amount of wood pellets that were exported and did not improve significantly as more pellets were consumed domestically.

Is there enough biomass available to supply 22 new biomass facilities while limiting the amount of residuals that can be removed to protect forest health?

Limiting residual amount removal to either 30 or 60 percent of what is available after harvests did not present a limiting factor to supply using the current model construct. This indicates that at least for the proposed additional capacity modeled, retaining sufficient residual biomass to maintain ecological health should not be limiting to biomass supply. We did not find a significant GHG affect when the amount of residuals removed was varied.

POLICY IMPLICATIONS

This analysis of using forest biomass to supply electric power generation in the Southeast replicates the multi-decade payback pattern from similar studies that integrate life-cycle carbon accounting with forest carbon accounting. This pattern remained consistent even though this study incorporated more accurate harvest regimes, operated in a region with an active pulp market, and examined specific woodsheds and facility placement as compared to other recent forest carbon modeling work. This suggests that the leading factor in the long payback periods is the low efficiency of power generation and not forest harvest or growth variables or regional forest types. Similar studies in other regions will be necessary to confirm this.

The multi-decade debt and payback periods for biomass power reinforce the benefits of using biomass for more efficient heating or cooling applications or CHP applications in regions where appropriate. It suggests a policy of prioritization for the use of forest biomass that focuses first on thermal applications where possible and appropriate and then on power applications.

Interpreting these multi-decade payback results in terms of long- and short-term climate change goals requires a deeper policy discussion than has yet occurred. Regulating atmospheric carbon for climate change goals requires sophisticated carbon stock-flow accounting—a dynamic that is not intuitively easy for the public to understand. Interjecting biomass into this accounting magnifies the challenge because the use of biomass for energy, unlike fossil fuels, comes associated with a sequestration component that must be accounted for over time. Effort should be made to more clearly represent this accounting for greater understanding and to avoid unintended faulty policy decisions.

For example, interpreting these results by relating them strictly to yearly emission targets at some specified point in time would be inaccurate as it fails to account for the eventual payback. The results of this study should prompt a closer evaluation of the short-term costs and long-term benefits and relate them to actual atmospheric carbon accumulations and climate change goals over a timeframe appropriate to the future trends of climate change.

Depending on the importance assigned to long-term benefits and short-term debt, the prospect of adding 22 new generating or pellet facilities may look favorable or unfavorable for climate goals. The carbon storage capacity of natural forests indicates it may be harmful to convert natural forest to plantations for carbon benefits even though plantations may out-produce natural stands in some situations (and this practice would have other serious ecological consequences that must be considered as well). The use of residuals, where available, would provide greater carbon benefits, however, since intensive removals of residuals could result in negative ecological impacts, the study examined the results from limiting the removals and determined there would still be adequate supply for the facilities that were modeled.

This study can be useful for policy development involving programs with incentives for biomass production and regulatory efforts. It is most readily adaptable for programs involving incentives as it allows different policy approaches to be compared and evaluated in relation to one another. The data provide a relative difference among approaches that may facilitate the ranking of different technologies for their support of climate goals and an assignment of different levels of incentives to different technologies.

CONCLUSIONS *(cont'd)*

This study may also be helpful for regulatory mechanisms. It offers EPA additional information to develop an appropriate framework for accounting for the emissions of biogenic carbon from stationary sources. In EPA's September 2011 report, it selected a "reference-point" approach for setting a baseline although it acknowledged the benefits of using the "comparative" approach used in this study. The EPA report championed the "reference-point" approach because it was "straightforward" and met a list of criteria, including ease of use, ease of understanding, and accuracy in prediction of carbon outcomes. The "reference point" predicts if the system has more or less carbon stored at the end of the assessment period than at the beginning while the "comparative" approach determines if there is more or less carbon than there would have been if the energy was created by fuel sources other than biomass. This study provides an example of how the "comparative" approach can be used for a specific region. It can be further evaluated by EPA to see if it meets its criteria and is useful for developing regulations.

The carbon accounting linkage between the source of the emission and the forest means that the potential of biomass as a renewable fuel is directly connected to the future of forest management. The development of biomass markets can have positive or negative effects on forest management and, conversely, the types of forest management practiced in the future will directly affect carbon payback periods. The sensitivity analysis from this study and results from other studies indicate that payback periods for biomass can vary widely depending on critical variables.

This suggests that a more comprehensive, sophisticated, and targeted approach for biomass policy that includes forest management could produce shorter payback periods and greater climate change benefits. Some potential policy targets include the following.

More Efficient Technologies

Use of biomass for thermal and CHP applications yield far shorter payback periods and greater benefits than power generation. Thermal and CHP applications can be 70-80 percent efficient while biomass power is only 25 percent efficient. Where appropriate, policy can direct forest biomass for use in these applications.

Smaller-Scale Applications

Smaller-scale heat or CHP applications can minimize transportation costs and target localized forest supply from forest situations that yield a shorter payback period. For example, localized supply of downed material or fire-prone material destined for quick carbon release to the atmosphere might show favorable payback periods if used to displace fossil fuel use for production of efficient thermal energy.

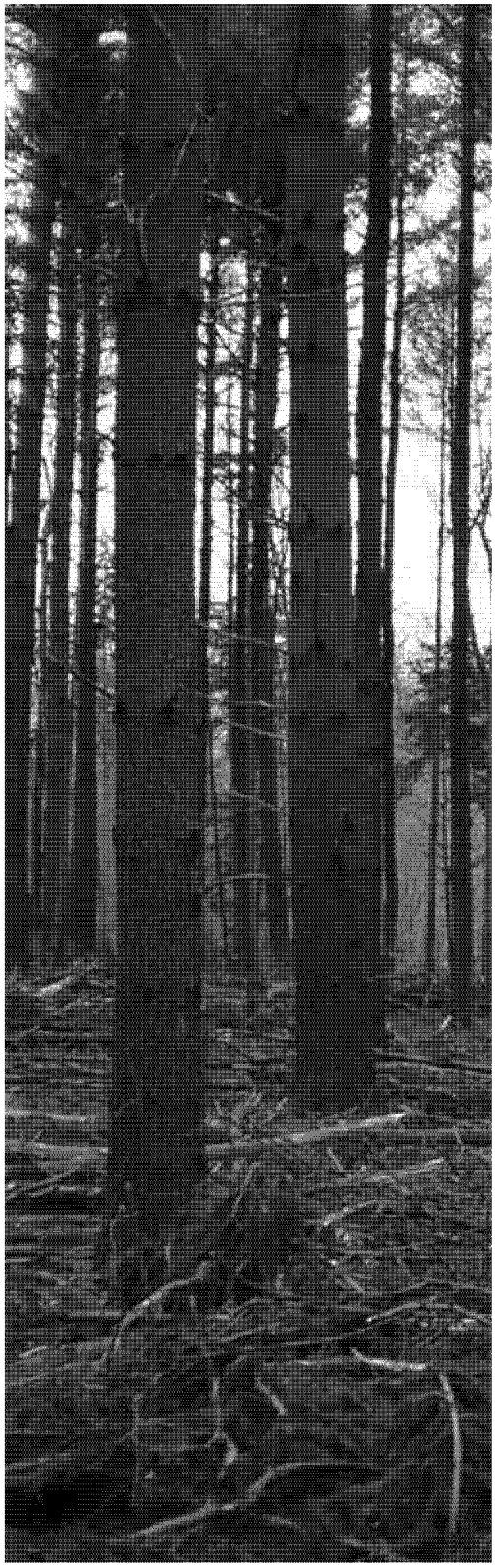
Enhanced Ecosystem Services

Biomass markets that allow forest improvement practices to protect water quality or increase carbon sequestration may improve ecosystem services that have an accompanying carbon benefit, thus lowering payback periods.

Improved Forest Management

Necessary forest-restoration work, perhaps to shift forest types to better adapted species or conduct pre-commercial thinnings, can be facilitated by biomass markets. The improved forestry can yield more forest products that offset other, more carbon-intensive products or increased revenue yields that help landowners keep forests as forests.

This study focuses on the carbon implications of increased biomass use and does not deal directly with other ecological impacts. Any policy encouraging the increased use of biomass must also account for effects on ecological values of the forest and should enhance the quality of forest management. The study results indicate a lowering of the average amount of carbon in the forest as compared to not harvesting these forests for biomass. More information is needed to fully evaluate the effects of lower carbon levels on wildlife and forest systems dynamics, including soil and water quality. An extension of best management practices to include biomass retention and harvesting guidelines is recommended. The Forest Guild has completed a set of retention and harvesting guidelines for the Northeast and is due to release a similar report for the Southeast by the end of this year.



ENDNOTES

[1] Disclaimer: We did not address agricultural residues such as corn stover, wheat straw, or manure. Furthermore, the study did not factor spent black liquor from pulping, bio-solids from waste-water treatment plants, or landfill gas, even though these materials may be vital resources that could contribute toward achieving target amounts of biomass energy in the RPSs.

[2] During the course of the literature search, numerous presentations and testimonies were found on-line and many of these presentations contained helpful information. However, these sources were not directly included as part of our literature review and critique because it is often very easy to take information contained in PowerPoint presentations out of context and misinterpret the meaning.

[3] Chip prices are for residual chips delivered to pulpmills and do not reflect the prices of chips sourced from chipmills.

[4] These model runs employed different rates of harvest residue utilization reaching upward to 85% over time.

[5] This technical potential estimate uses 85% harvest residue recovery rate for softwoods and 70% for hardwoods. These recovery rates are generally considered to be on the high end of the range of what is viable.

[6] It should also be noted that this resource assessment not only included North Carolina but also border counties of Virginia and South Carolina counties that fall within Duke or Progressive Energy's service territories.

[7] Based on the assumption of a 50% harvest residue recovery rate.

[8] Consistent but not necessarily the most accurate! While different studies may have presented more recent estimates using more sophisticated methods, these studies did not address all seven of the states and so a single data source providing "wall-to-wall" coverage was necessary.

[9] In-growth (new trees) + Accretion (growth of existing trees) – Mortality (natural death) = Net growth

[10] All data obtained from published FIA factsheets for each of the seven states.

[11] This information on inventory comes from the USDA Forest Service's Forest Inventory and Analysis (FIA) program, which generates reliable estimates of the condition and health of the forest resource and how it is changing over time. The program uses a statistically designed sampling method to select hundreds of plots for measurement by field crews and includes plots that were counted in previous inventories. The re-measurements on the same plots yield valuable information on how individual trees grow. Field crews also collect data on the number, size, and species of trees, and the related forest attributes.

[12] Data for Total Inventory is for growing stock volume. Growing stock is the traditionally merchantable wood contained in live trees greater than five inches.

[13] The amount of wood derived from trees that would be otherwise used by Virginia lumber and pulp manufacturers is capped at 1.5 million green tons annually.

[14] Note that each year's percentage requirement refers to the previous year's electricity sales (i.e., the 2021 standard is 12.5% of 2020 retail sales).

[15] Other Renewables includes biogenic municipal solid waste, wood, black liquor, other wood waste, landfill gas, sludge waste, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind.

[16] Other gases includes blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.

[17] Other includes non-biogenic municipal solid waste, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, tire-derived fuels and miscellaneous technologies.

[18] MW electric produces approximately 136 MMBtu/hr of heat. Residential heating typically uses 40 Btu's/sq ft. Based on a 3,000 square foot house, heating requirement is 120,000 Btu's/hr, or 1,137 homes.

[19] Graph information is derived from Appendix A. See that Appendix for data and sources.

[20] Chart information is derived from Appendix A. See that Appendix for sources.

[21] Graph information is derived from Appendix A. See that Appendix for data and sources.

[22] Chart information is derived from Appendix A. See that Appendix for sources.

[23] Graph information is derived from Appendix A. See that Appendix for data and sources.

[24] Chart information is derived from Appendix A. See that Appendix for sources.

[25] Graph information is derived from Appendix A. See that Appendix for data and sources.

[26] Chart information is derived from Appendix A. See that Appendix for sources.

[27] Graph information is derived from Appendix A. See that Appendix for sources.

[28] Chart information is derived from Appendix A. See that Appendix for sources.

BIBLIOGRAPHY

Adams, D.M., R.W. Haynes, and A.J. Daigneault. Estimated timber harvest by U.S. region and ownership, 1950-2002. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-659:64. 2006.

Alavalapati, J.R.R., Hodges, A.W., Lal, P., Dwivedi, P., Rahmani, M., Kaufer, I., Matta, J.R., Susaeta, A.,

Kukrety, S., Stevens, J.T. Bioenergy Roadmap for Southern States, (SAFER Draft report). 2008.

Biomass Energy Resource Center. On the Coast of Denmark, a Quietly High-Performing Woodchip Gasifier Is Producing District Heat and Power. http://www.biomasscenter.org/resources/case-studies/communityde/214-harboore.html. 2010.

Burkhart, H.E., R.L. Amateis, J.A. Westfall, and R.F. Daniels. PTAEDA 4.0: Simulation of individual tree growth, stand development and economic evaluation in loblolly pine plantations. Virginia Tech, Dept. of Forestry. 23. 2008.

Butler, B.J. Family Forest Owners of the United States, 2006. General Technical Report NRS-27:72. 2008.

Cronin, Matthew A., Cleotilde Gonzalex, John D Sterman. Organizational Behavior and Human Process. 108, 116-130. 2009.

Crookston, N.L. Suppose: An Interface to the Forest Vegetation Simulator. in Forest vegetation simulator conference. 1997 February 3-7, Fort Collins, CO, Teck, R., M. Moeur, and J. Adams (eds.). Gen. Tech. Rep. INT-GTR-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 1997.

Crookston, N.L., D.L. Gammel, S. Rebain, D. Robinson, and C.E. Keyser. User's guide to the database extension of the Forest Vegetation Simulator version 2.0. USDA Forest Service, Forest Management Service Center. 56. 2011.

Department of Energy. Technical guidelines, voluntary reporting of greenhouse gases (1605(b)) program. Office of Policy and International Affairs, US Dept. of Energy. 280. 2007.

Department of Energy, Energy Efficiency and Renewable Energy. http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html. 2011.

Environmental Protection Agency. Average carbon dioxide emissions resulting from gasoline and diesel fuel. P. 3. United States Environmental Protection Agency, Washington, DC. 2005.

Environmental Protection Agency. Renewable Fuels: Regulations & Standards. http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm. 2011.

Environmental Protection Agency. News Release - EPA Proposes to Defer GHG Permitting Requirements for Industries that Use Biomass/Agency aims for science-based, reasonable approach to biomass. March 14, 2011.

Environmental Protection Agency. Accounting Framework For Biogenic CO2 Emissions From Stationary Sources. http://www.epa.gov/climatechange/emissions/biogenic_emissions.html. September 2011.

European Environment Agency (EEA). Opinion of the EEA Scientific Committee on Greenhouse Gas Accounting in relation to bioenergy. European Environment Agency, Copenhagen, Denmark. Available online at www.eea.europa.eu/about-us/governance/scientific-committee/sc-opinions/opinions-on-scientific-issues/sc-opinion-on-greenhouse-gas, last accessed November 18, 2011.

Forisk Consulting. Wood Bio-energy US. June 28, 2011

Galik, C. Abt, R. and Wu, Y. Forest Biomass Supply in the Southeastern United States—Implications for Industrial Roundwood and Bioenergy Production. Journal of Forestry. March 2009.

Garik, Christopher S., Robert C. Abt. An Interactive Assessment of Biomass Demand and Availability in the Southeastern United States. http://www.nicholasinstitute.duke.edu/events/Biomass-Model/. March 2011.

Georgia Forestry Commission. Forest Biomass Sustainability. http://www.gfc.state.ga.us/ForestMarketing/ForestBiomass-Sustainability.cfm. 2009.

Harris, R. Potential for Biomass Energy Development in South Carolina. South Carolina Forestry Commission. 2004.

Henningsen, R.F., K.O. Skjolsvik, A.B. Andersen, J.J. Corbett, and J.M. Skjelvik. Study of greenhouse gas emissions from ships: Final report to the International Maritime Organization. MARINTEK. 170. 2000.

Henson, Robert, The Rough Guide to Climate Change, Rough Guides Ltd. London, P37. 2011.

International Energy Agency. Good Practice Guidelines: Bioenergy Project Development & Biomass Supply. Paris: International Energy Agency. 2007.

International Energy Agency. Bioenergy- A sustainable and Reliable Energy Source. Energy Resource Center of the Netherlands, E/4Tech, Chalmers University of Technology, and the Copernicus Institute of the University of Utrecht. 2009.

Intergovernmental Panel on Climate Change. Land Use, Land Use Change and Forestry. 2000.

Intergovernmental Panel on Climate Change. 2006 IPCC guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HAS. Volume 4: Agriculture, forestry and other land uses. 2006.

Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey. National-scale biomass estimators for United States tree species. Forest Science 49(1):12-35. 2003.

Johnson, T.G., J.W. Bently, and M. Howell. The South's timber industry - an assessment of timber product output and use, 2007. Resour. Bull. SRS-164. Asheville, NC. USDA Forest Service, Southern Research Station:52. 2009.

Keyser, C.E. 2010. Southern (SN) Variant Overview – Forest Vegetation Simulator. Internal Rep. U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 69.

La Capra Associates. North Carolina's Renewable Energy Policy: a Look at REPS Compliance to Date, Resource Options for Future Compliance, and Strategies to Advance Core Objectives. North Carolina Energy Policy Council. June 2011.

Malmshimer, R.W., J.L. Bowyer, J.S. Fried, E. Gee, R.L. Izlar, R.A. Miner, I.A. Munn, E. Oneil, and W.C. Stewart. Managing forests because carbon matters: Integrating energy, products, and land management policy. Journal of Forestry. 109(7S):S7–S5. 2011.

Manomet Center for Conservation Sciences. Biomass Sustainability and Carbon Policy Study. Available at http://manomet.org/sites/manomet.org/files/Manomet_ Biomass_Report_Full_LoRex.pdf. 2010.

Mayfield, C. A., C.D. Foster, C.T. Smith, J. Gan, and S. Fox. Opportunities, barriers, and strategies for forest bioenergy and bio-based product development in the Southern United States. Biomass and Bioenergy 31: Pp631-637. 2008.

McClure, J.P., and H.A. Knight. Empirical yields of timber and forest biomass in the Southeast. USDA Forest Service Research Paper SE-245:75. 1984.

McKechnie, J., Columbo, S., Chen, J., Mabee, W., Maclean, H. Forest Bioenergy or Forest Carbon? Assessing Trade-Offs in Greenhouse Gas Mitigation with Wood-Based Fuels Environmental Science Technology 2011, 45, 789-795. 2011.

McNab, W.H., D.T. Cleland, J.A. Freeouf, J.E. Keys Jr., G.J. Nowacki, and C.A. Carpenter. Description of ecological subregions: sections of the conterminous United States [CD-ROM]. U.S. Department of Agriculture, Forest Service. 80. 2005.

Mendell B., Lang, Sydor, Freeman. Availability and Sustainability of Wood Resources for Energy Generation in the United States. American Forest and Paper Association. June 2010.

Milbrandt, A. A Geographic Perspective on the Current Biomass Resource Availability in the United States, Technical Report. National Renewable Energy Laboratory, NREL/TP-560-39181, Dec. 2005.

Millard, G. Eastern Hardwood Forest Region Woody Biomass Energy Opportunity. USDA Forest Service. http://spfnic.fs.fed.us/werc/finalrpts/06-DG-300.pdf. October 2007.

Oak Ridge National Laboratory. Biomass Energy Data Book. http://cta.orn.gov/bedb. 2011.

Parhizkar and Smith. Application of GIS to Estimate the Availability of Virginia's Biomass Residues for Bioenergy Production. Forest Products Journal. March 2008.

Penman, J., M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe, and F. Wagner. Good practice guidance for land use, land use change, and forestry. Hayama, Kanagawa, Japan: Institute for Global Environmental Strategies for the IPCC. 502. 2003.

Perlack, R.D., L. L. Wright, A. F. Turhollow, R. L. Graham, B. J. Stokes, and D. C. Erbach.

Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory, DOE/GO-102005-2135, 59p.

http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf. 2005.

Perlack, R.D. and Stokes, B.J. U.S. Billion Ton Update: Biomass Supply for a Bio-energy and Bio-products Industry. US Department Of Energy. August 2011.

R. R Statistical Package. The R foundation for statistical computing. 2011.

Rebain, S.A. The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated Model Documentation. Internal Rep. U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 361. 2010.

BIBLIOGRAPHY *(cont'd)*

Rossi, et al. Woody Biomass for Electricity Generation in Florida: Bioeconomic Impacts under a Proposed Renewable Portfolio Standard (RPS) Mandate. University of Florida. March 2010.

Searchinger, TD., Hamburg, S., Melillo,J., Chameides,W., Havlik, P., Kammen, D., Likens,G., Lubowski, R., Obersteiner, M., Oppenheimer,M., Robertson,G., Schlesinger,W., Tilman,G. Fixing a Critical Climate Accounting Error. SCIENCE VOL 326 23. October 2009.

Smith, J.E., L.S. Heath, K.E. Skog, and R.A. Birdsey. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. USDA Forest Service General Technical Report GTR NE-343:222. 2006.

Southern Forest Research Partnership. Fact Sheets. http://www.forestbioenergy.net/training-materials/fact-sheets/module-2-fact-sheets/. 2011.

Stager, Curt. Deep Future: The Next 100,000 Years of Life On Earth. p.35 Thomas Dunne Books, New York. 2011

Staudhammer et al., Wood to Energy: Using Sothern Interface Fuels for Bioenergy. Southern Research Station USDA Forest Service. http://www.interfacesouth.org/products/publications/wood-to-energy-using-southern-interface-fuels-for-bioenergy/index_html. January 2011.

Sterman, John D. Learning From Evidence in a Complex World, American Journal of Public Health, March 2006,Vol 96, No. 3. pp 505-514. 2006.

Sterman, John D., Linda Booth Sweeney, Understanding Public Complacency About Climate Change: Adults Mental Models of Climate Change Violate Conservation of Matter, Climatic Change. 80:213-238. 2007.

Sterman, John D. Risk Communication on Climate: Mental Models and Mass Balance. Science, October 24, 2008 Vol 322. 2008.

Southern Environmental Law Center. Spreadsheet data on biomass facilities in the Southeast United States. June 16, 2011.

Susaeta, A., Alavalapati, J.R.R., Carter, D., (under review) Modeling Impacts of Bioenergy Markets on

Nonindustrial Private Forest Management in the Southeastern United States. 2011.

UNFCCC/CCNUCC CDM Executive Board. Estimation of non-CO2 GHG emissions resulting from burning of biomass attributable to an A/R CMD project activity. Version 03.1.0.60 Annex 11. 7. 2011.

USDA Forest Service. Forest Inventory and Analysis Program. USDA Forest Service, Washington, D.C. 2011.

Walker, Thomas, Peter Cardellichio , John S. Gunn , David S. Saah , and John M. Hagan. Carbon Accounting for Woody Biomass from Massachusetts (USA) Managed Forests: A Framework for Determining the Temporal Impacts of Wood Biomass Energy on Atmospheric Greenhouse Gas Levels. Journal of Sustainable Forestry. 2012.

Wear, D. N., Carter, D. R., Prestemon, J. The U.S. South's timber sector in 2005. A prospective analysis of recent change. USDA Forest Service Southern Research Station, Asheville, NC. 2007.

Wear, D.N., and Greis, J.G. The Southern Forest Resource Assessment Summary Report. USDA Forest Service. 114 p. 2002.

Biomass Supply and Carbon Accounting for Southeastern Forests

APPENDICES

A. Technology Pathways Database

B. Forest Growth Simulation

Appendix A

TECHNOLOGY PATHWAYS SUMMARY

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	p	Q	R	S	T	U	V	W	Z	Y	Z	AA	AB
1																												
2								(F)*(H)*(I)*3.412			(J)/(K)		(M)/(N)	(O)/(J)	(O)*8.6667/(M)	(J)*(U)/M	(Q)-(R)	(Q)*(M)/(J)		(T) - (U)		(W)*(M)/(J)	(Q)/3.6667	(R)/3.6667	(Y)+(Z)	(T)/3.6667	(U)/3.6667	(AB)+(AC)
3	1 Exisiting woody biomass	Electricity		20	MW	8,760	100%	597,782	25.6%	25.6%	2,335,088	8,500	137,358	459.56	215.7	4.2	219.9	842.5	16.5	859.1	0.007054	0.0276	58.8230	1.1555	59.9785	229.7775	4.513481829	234.2910
4	power plants											(btu/lb)																
5	2 New woody biomass	Electricity		50	MW	8,760	100%	1,494,456	28.2%	28.2%	5,307,017	8,500	312,177	417.78	215.7	4.7	220.8	765.9	16.5	782.5	0.007054	0.0250	58.8230	1.2710	60.0940	208.8887	4.513481829	213.4021
6	power plants											(btu/lb)																
7	2A Pellet exportation	Electricity		50	MW	8,760	100%	1,494,456	28.2%	28.2%	5,307,017	8,500	312,177	417.78	215.7	68.8	284.5	765.9	244.4	1010.3	0.007054	0.0250	58.8230	18.7691	77.5922	208.8887	66.65164706	275.5403
8	(European power plants)																											
9	3 Co-firing power plants	Electricity		450	MW	8,760	100%	13,450,104	32.3%	32.3%	5,253,947	8,500	309,056	45.96	215.7	0.4	216.1	84.3	1.7	85.9	0.007054	0.0028	58.8230	0.1155	58.9386	22.9778	0.451348183	23.4291
10	90% coal									(coal)	37,523,539	12,500	1,500,942	223.19	205.3	6.2	211.5	572.8	19.2	591.9	0.003306	0.0092	55.9904	1.6849	57.6753	156.2038	5.222743259	161.4266
11	10% woody biomass										42,777,486	12,100	1,809,997	269.14	206	6.6	212.9	656.3	20.8	677.1	0.003681	0.0117	56.2737	1.8004	58.0741	178.9760	5.674091442	184.6501
12																												
13	4 Woody biomass	Electricity		5	MW	8,760	100%	398,026	75.0%	28.2%	530,702	8,500	31,218	156.86	215.7	6.1	221.7	287.6	8.1	295.6	0.007054	0.0094	58.8230	1.6500	60.4730	78.4307	2.2	80.6307
14	CHP		Thermal	248,581	MMBtu							(btu/lb)																
15			Electrical	149,446	MMBtu																							
16	5 Switchgrass			50	MW	8,760	100%	1,494,456	28.2%	28.2%	5,307,017	7,200	368,543	493.21	229.2	4.7	233.8	813.8	16.5	830.4	0.007054	0.0250	62.4995	1.2710	63.7705	221.9442	4.513481829	226.4577
17	power plants											(btu/lb)																
18	6 Co-firing power plants	Electricity		450	MW	8,760	100%	13,450,104	32.5%	32.5%	4,776,315	7,200	331,689	49.32	229.2	0.5	229.6	81.4	1.7	83.0	0.007054	0.0025	62.4995	0.1271	62.6266	22.1944	0.451348183	22.6458
19	90% coal									(coal)	37,228,114	12,500	1,489,125	221.43	205.3	6.2	211.5	568.2	19.2	587.4	0.003306	0.0092	55.9904	1.6982	57.6886	154.9740	5.222743259	160.1968
20	10% switchgrass										42,004,430	11,970	1,820,813	270.75	208	6.7	214.4	648.6	20.8	669.4	0.003681	0.0115	56.6413	1.8253	58.4666	176.8898	5.674091442	182.5639
21																												
22	7 Switchgrass	Electricity		5	MW	8,760	100%	398,026	75.0%	28.2%	530,702	7,200	36,854	185.19	229.2	6.1	235.2	305.6	8.1	313.6	0.007054	0.0094	62.4995	1.6500	64.1495	83.3327	2.2	85.5327
23	CHP		Thermal	248,581	MMBtu							(btu/lb)																
24			Electrical	149,446	MMBtu																							
25	8 Existing coal	Electricity		450	MW	8,760	100%	13,450,104	33.0%	33.0%	40,757,891	12,500	1,630,316	242.42	205.3	7.0	212.3	622.1	21.3	643.4	0.003306	0.0100	55.9904	1.9150	57.9054	169.6679	5.803048066	175.4709
26	power plants											(btu/lb)																
27	9 New coal	Electricity		600	MW	8,760	100%	17,933,472	36.8%	36.8%	49,403,504	12,500	1,976,140	220.39	205.3	7.7	213.0	565.6	21.3	586.8	0.003306	0.0091	55.9904	2.1065	58.0969	154.2435	5.803048066	160.0466
28	power plants											(btu/lb)																
29	10 Coal	Electricity		5	MW	8,760	100%	339,649	75.0%	33.0%	452,865	12,500	18,115	106.67	205.3	16.0	221.3	273.7	21.3	295.0	0.003306	0.0044	55.9904	4.3523	60.3427	74.6539	5.803048066	80.4569
30	CHP		Thermal	190,203	MMBtu							(btu/lb)																
31			Electrical	149,446	MMBtu																							
32	11 New natural gas			800	MW	8,760	100%	23,911,296	42.0%	42.0%	56,931,657	102,800	553,809,894	23.16	117.0	33.8	150.8	278.6	80.4	359.0	0.00022	0.0005	31.9088	9.2075	41.1163	75.9733	21.92262603	97.8960
33	power plants											(btu/therm	therms	therms/MMBtu														

Grey cells are estimates

Blue cells are sourced figures

Green cells are calculations

D3	Average capacity of exisiting biomass plants in seven-state study region - cta.ornl.gov/bedb/biopower/Current_Biomass_Power_Plants.xls
D5, D14, D21	Average capacity of existing coal plants in seven-state study region http://www.eia.gov/electricity/data.cfm#gencapacity By Energy Source, by Producer, by State (EIA-860)XLS
D9, D18, D25	Estimate of likely size of thermal-led CHP projects feasible in seven-state study region
D23	Average capacity of coal plants constructed in seven-state study region since 2000 - http://www.eia.gov/cneaf/electricity/page/capacity/existingunits2008.xls
G3, G21, G23, G28	Average capacity factors for electrical generation plants - http://www.eia.gov/oiaf/aeo/pdf/2016levelized_costs_aeo2011.pdf
G9, G18, G25	Average capacity factor of CHP plants estimateded to be 10% lower than electrical only generation
G5, G14	Capacity factors for co-firing assumed to be the same as coal
G13	Average capacity factor of switchgrass plants assumed to be the same as woody biomass
I3, I9	Efficiencies of biomass electrical and CHP plants from IEA - Energy Technology Essentials
I21, I28	Efficiencies of coal and natural gas from EIA - Electric Power Annual 2009Released: November 23, 2011
I12, I18	Efficiencies of switchgrass plants assumed to be the same as biomass plants
J	Electrical efficiency of CHP plants assumed to be 10% lower than electrical-only effiencieny for that fuel type due to projected efficiency losses in process of heat recovery
L2, L5, L9	Assumes 0% moisture content ("bone-dry") - cta.ornl.gov/.../The_Effect_of_Moisture_Content_on_Wood_Heat_Content. Xls
L6, L15, L21, L23, L25	EIA Heating Fuel Comparison Calculator - http://www.eia.gov/neic/experts/heatcalc.xls
L12, L14, L18	Assumes 0% moisture content - Forest Product Lab Fuel Value Calculator - http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf
O2, O5, O9	Assumes wood is 50% carbon by weight - Economics and Carbon Offset Potential of Biomass Fuels - REAP - Canada
O12, O14, O18	Assumes switchgrass is 45% carbon by weight - Economics and Carbon Offset Potential of Biomass Fuels - REAP - Canada
O6, O14, O21, O23, O25, O28	Voluntary Reporting of Greenhouse Gases Program Fuel Emissions Coefficients - http://www.eia.gov/oiaf/1605/coefficients.html
Q	Voluntary Reporting of Greenhouse Gases Program Fuel Emissions Coefficients - http://www.eia.gov/oiaf/1605/coefficients.html

Appendix B. Forest Growth Simulation.

This appendix contains information related to the forest growth, mortality and harvest simulations.

Table B-1. Prescriptions used in eco-section 2311 (Central Appalachian Piedmont) for forest and regeneration types, by site class and biomass utilization. Treatment codes with associated metrics are: N=Natural regeneration in trees per acre; P=Planted in trees per acre; F-Fertilized; STS=Single Tree Selection to residual basal area (sq ft/ac); H=Herbicide treatment of competing vegetation; PT=Pre-commercial Thin to percent volume; TH=Thin from below to residual basal area (sq ft/ac); CC=Clearcut.

					Age																													
		Site (50-yr)			0		5		10		15		20		25		30		35		40		45		50		55		60		65		70	
Type	Regen	Class	Index	Biomass	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric
Loblolly/Shortleaf	Natural	Low	74	No	N										TH	80					CC													
		High	90	No	N								TH	80					CC															
		Low	74	Yes	N						PT	65%V			TH	80					CC													
		High	90	Yes	N				PT	65%V			TH	80					CC															
	Planted	Low	80	No	P,F	500	H						TH	80			TH	70			CC													
		High	102	No	P,F	550	H				TH	90			TH	70			CC															
		Low	80	Yes	P,F	700	H		PT	60%V			TH	80			TH	70			CC													
		High	102	Yes	P,F	700	H		PT	70%V	TH	90			TH	70			CC															
Pine-Oak	Natural	Low	75	No	N																												CC	
		High	94	No	N																										CC			
		Low	75	Yes	N												TH	60															CC	
		High	94	Yes	N										TH	60															CC			
Upland Hardwood	Natural	Low	78	No	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High	102	No	N																		STS	70							CC			
		Low	78	Yes	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High	102	Yes	N								TH	50									STS	70							CC			
Bottomland Hardwood	Natural	Low	86	No	N										TH	80									CC									
		High	116	No	N										TH	80							CC											
		Low	86	Yes	N						TH	80					TH	60							CC									
		High	116	Yes	N								TH	70			TH	50					CC											

Table B-2. Prescriptions used in eco-sections 232C (Atlantic Coastal Flatwoods) and 232J (Southern Atlantic Coastal Plains and Flatwoods) for forest and regeneration types, by site class and biomass utilization. Treatment codes with associated metrics are: N=Natural regeneration in trees per acre; P=Planted in trees per acre; B=broadcast burn; F-Fertilized; STS=Single Tree Selection to residual basal area (sq ft/ac); H=Herbicide treatment of competing vegetation; PT=Pre-commercial Thin to percent volume; TH=Thin from below to either residual basal area (sq ft/ac) or trees per acre (p=pine, h=hardwoods); CC=Clearcut.

					Age																													
		Site (50-yr)			0		5		10		15		20		25		30		35		40		45		50		55		60		65		70	
Type	Regen	Class	Index	Biomass	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric
Loblolly/Shortleaf	Natural	Low		No	N								TH	70			TH	60			CC													
		High		No	N						TH	85			TH	75			CC															
		Low		Yes	N		PT	400					TH	65			TH	60			CC													
		High		Yes	N		PT	450			TH	75			TH	75			CC															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550			PT	400			TH	65			TH	60	CC															
		High		Yes	P,F	550			PT	400	TH	80	TH	80			CC																	
Longleaf/Slash	Natural	Low		No	B,N								TH	70			TH	60			CC													
		High		No	B,N						TH	85			TH	75			CC															
		Low		Yes	B,N		PT	400					TH	65			TH	60			CC													
		High		Yes	B,N		PT	450			TH	75			TH	75			CC															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550			PT	400			TH	65			TH	60	CC															
		High		Yes	P,F	550			PT	400	TH	80	TH	80			CC																	
Pine-Oak	Natural	Low		No	N										TH	65p/50h					CC													
		High		No	N								TH	50p/50h			TH	45p/45h			CC													
		Low		Yes	N						TH	350p/200h			TH	70					CC													
		High		Yes	N								TH	50p/50h			TH	45p/45h			CC													
Upland Hardwood	Natural	Low		No	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		No	N										CT	80					STS	50			STS	30					CC			
		Low		Yes	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		Yes	N								TH	70					STS	50			STS	30							CC			
Bottomland Hardwood	Natural	Low		No	N										TH	80									CC									
		High		No	N										TH	80							CC											
		Low		Yes	N								TH	65					TH	80					CC									
		High		Yes	N								TH	70					TH	80			CC											

Table B-3. Prescriptions used in eco-section 232B (Gulf Coastal Plains and Flatwoods) for forest and regeneration types, by site class and biomass utilization. Treatment codes with associated metrics are: N=Natural regeneration in trees per acre; P=Planted in trees per acre; B=broadcast burn; F-Fertilized; STS=Single Tree Selection to residual basal area (sq ft/ac); H=Herbicide treatment of competing vegetation; PT=Pre-commercial Thin to percent volume; TH=Thin from below to either residual basal area (sq ft/ac) or trees per acre (p=pine, h=hardwoods); CC=Clearcut.

					Age																													
		Site (50-yr)			0		5		10		15		20		25		30		35		40		45		50		55		60		65		70	
Type	Regen	Class	Index	Biomass	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric
Loblolly/Shortleaf	Natural	Low		No	N								TH	70			TH	60			CC													
		High		No	N						TH	85			TH	75			CC														
		Low		Yes	N		PT	400					TH	65			TH	60			CC												
		High		Yes	N		PT	450			TH	75			TH	75			CC														
	Planted	Low		No	P,F	550					TH	70			TH	60			CC														
		High		No	P,F	550					TH	80	TH	80			CC																
		Low		Yes	P,F	550	PT	400					TH	65			TH	60	CC														
		High		Yes	P,F	550	PT	400			TH	80	TH	80			CC																
Longleaf/Slash	Natural	Low		No	B,N								TH	70			TH	60			CC													
		High		No	B,N						TH	85			TH	75			CC														
		Low		Yes	B,N		PT	400					TH	65			TH	60			CC												
		High		Yes	B,N		PT	450			TH	75			TH	75			CC														
	Planted	Low		No	P,F	550					TH	70			TH	60			CC														
		High		No	P,F	550					TH	80	TH	80			CC																
		Low		Yes	P,F	550	PT	400					TH	65			TH	60	CC														
		High		Yes	P,F	550	PT	400			TH	80	TH	80			CC																
Pine-Oak	Natural	Low		No	N										TH	65p/50h					CC													
		High		No	N								TH	50p/50h			TH	45p/45h			CC													
		Low		Yes	N						TH	350p/200h			TH	70					CC													
		High		Yes	N								TH	50p/50h			TH	45p/45h			CC													
	Planted	Low		No	Pl pine	500									TH	65p/50h					CC													
		High		No	Pl pine	300							STS	50p/50h			STS	45p/45h			CC													
		Low		Yes	Pl pine	500					TH	350p/200h			TH	70					CC													
		High		Yes	Pl pine	300							TH	50p/50h			TH	45p/45h			CC													
Upland Hardwood	Natural	Low		No	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		No	N										CT	80					STS	50			STS	30					CC			
		Low		Yes	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		Yes	N								TH	70					STS	50			STS	30							CC			
Bottomland Hardwood	Natural	Low		No	N										TH	80									CC									
		High		No	N										TH	80							CC											
		Low		Yes	N								TH	65					TH	80					CC									
		High		Yes	N								TH	70					TH	80			CC											

Table B-4. Age class distribution by forest type, regeneration type, and site class for eco-section 2311 (Central Appalachian Piedmont).

Type	Regen	Site Class	Age																										
			0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
Loblolly/Shortleaf	Natural	Low	0	9	29	26	29	24	27	21	13	27	26	21	17	13	11	5	4	2	1	2	0	0	0	0	0	0	0
		High	0	2	3	2	3	9	13	4	9	14	11	8	6	6	4	1	3	0	0	0	0	0	0	0	0	0	0
	Planted	Low	0	48	67	49	42	49	38	19	12	6	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		High	0	3	2	9	10	18	16	5	5	2	2	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Pine-Oak	Natural	Low	1	14	23	18	17	23	19	24	16	21	12	11	13	18	21	8	11	3	3	0	3	0	0	1	0	0	0
		High	0	2	0	1	3	2	5	6	6	9	4	4	3	7	2	0	2	1	1	0	0	0	0	0	0	0	0
Upland Hardwood	Natural	Low	3	94	80	83	47	41	58	55	57	80	79	94	89	95	76	69	65	50	36	15	23	15	11	1	1	2	0
		High	0	11	3	5	4	7	10	7	7	10	8	11	10	13	5	2	1	6	4	0	1	0	1	0	0	0	1
Bottomland Hardwood	Natural	Low	0	4	8	10	3	10	4	8	6	11	13	14	13	9	7	9	11	3	2	1	0	2	0	1	0	0	0
		High	0	0	0	0	2	2	2	3	2	1	2	0	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0

Table B-5. Non-sprouting regeneration data for loblolly-shortleaf pine plantations in eco-section 231I (Central Appalachian Piedmont). Since loblolly is planted it will not be naturally regenerated for the planation simulation.

Species	FIA_Code	FVS_Code	Sprout (1=yes)?	Trees/ac.	DBH (in)	Ht (ft)	CR (%)
eastern redcedar	68	OS	0	6.4	1.7	17	72
loblolly pine	131	LP	0	103.4	2.9	22	41
mockernut hickory	409	OH	0	4.2	1.7	22	41
pignut hickory	403	OH	0	2.7	1.7	23	51
shagbark hickory	407	OH	0	0.3	1.5	20	35
shortleaf pine	110	SP	0	0.5	4.6	34	34
Virginia pine	132	VP	0	23.0	2.4	21	36
willow oak	831	OH	0	2.5	2.5	24	38
river birch	373	OH	0	0.3	2.3	37	25

Table B-6. Non-sprouting regeneration data for natural upland hardwood stands in eco-section 231I (Central Appalachian Piedmont).

Species	FIA_Code	FVS_Code	Sprout (1=yes	Trees/ac.	DBH (in)	Ht (ft)	CR (%)
eastern hemlock	261	OS	0	0.1	1.0	12	90
eastern redcedar	68	OS	0	5.1	2.3	20	53
eastern white pine	129	WP	0	1.3	2.2	17	46
loblolly pine	131	LP	0	2.7	3.1	24	36
mockernut hickory	409	OH	0	2.3	2.4	27	37
pignut hickory	403	OH	0	4.4	2.4	26	34
shagbark hickory	407	OH	0	0.3	2.1	25	33
shortleaf pine	110	SP	0	0.2	3.9	45	28
Virginia pine	132	VP	0	3.6	2.5	22	32
willow oak	831	OH	0	0.9	2.0	24	49
river birch	373	OH	0	0.1	2.4	25	55
mountain or Fraser magnolia	655	OH	0	0.2	1.2	16	55
umbrella magnolia	658	OH	0	0.5	2.3	24	29
bitternut hickory	402	OH	0	0.5	2.4	30	22
red mulberry	682	OH	0	0.1	3.6	32	45
pitch pine	126	PP	0	0.2	3.4	21	30
American basswood	951	OH	0	0.2	3.7	34	35

BERC

Renewable • Reliable • Resourceful

Biomass Energy Resource Center

PO Box 1611, Montpelier, VT 05601-1611
ph 802-223-7770 x121 • fax 802-223-7772
info@biomasscenter.org • www.biomasscenter.org

From: Ohrel, Sara
To: Justin Baker (justinbaker@rti.org)
Sent: 11/15/2014 8:40:18 AM
Subject: more
Attachments: jof14009_1409371670863.pdf; NAFO Wood Bioenergy_Forestland Owners FINAL 20140212.pdf

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

REVIEW ARTICLE

J. For. 112(●):000–000
http://dx.doi.org/10.5849/jof.14-009
Copyright © 2014 Society of American Foresters

biomass, carbon & bioenergy

Forest Carbon Accounting Considerations in US Bioenergy Policy

Reid A. Miner, Robert C. Abt, Jim L. Bowyer, Marilyn A. Buford, Robert W. Malmsheimer, Jay O'Laughlin, Elaine E. Oneil, Roger A. Sedjo, and Kenneth E. Skog

Four research-based insights are essential to understanding forest bioenergy and "carbon debts." (1) As long as wood-producing land remains in forest, long-lived wood products and forest bioenergy reduce fossil fuel use and long-term carbon emission impacts. (2) Increased demand for wood can trigger investments that increase forest area and forest productivity and reduce carbon impacts associated with increased harvesting. (3) The carbon debt concept emphasizes short-term concerns about biogenic CO_2 emissions, although it is long-term cumulative CO_2 emissions that are correlated with projected peak global temperature, and these cumulative emissions are reduced by substituting forest bioenergy for fossil fuels. (4) Considering forest growth, investment responses, and the radiative forcing of biogenic CO_2 over a 100-year time horizon (as used for other greenhouse gases), the increased use of forest-derived materials most likely to be used for bioenergy in the United States results in low net greenhouse gas emissions, especially compared with those for fossil fuels.

Keywords: biogenic emissions, biomass energy, carbon debt, carbon dioxide, forestry investment, forest landowner, greenhouse gas, wood markets, wood products, wood fuel

A large and rapidly growing body of research focuses on the greenhouse gas (GHG) impacts of using forest bioenergy to substitute for fossil fuel and wood building products to substitute for concrete and steel, materials that require greater amounts of fossil fuel to produce than wood products. Forest bioenergy research on GHG impacts, especially from carbon dioxide (CO_2), sometimes produces widely varying and occasionally contradictory results. Differences can usually be explained by understanding the data used, the scenarios examined, the analytical framework employed, and the assumptions used in the analyses (e.g., see Cherubini et al. 2009, Lamars and Junginger 2013). In this review, we examine research on the GHG impacts of energy derived from forest biomass, which, for the purposes of this review, includes all parts of the tree, living and dead. The objective is to reveal insights that allow improved interpretation of research in this area. Our review is focused on the accounting for biogenic carbon and biogenic CO_2 and the potential impacts of CO_2 on global temperatures. Other concerns related to elevated atmospheric CO_2 (e.g., ocean acidity) are not addressed. GHGs other than CO_2 are discussed where relevant. This review does not address other aspects of using forest biomass for energy, such as the ecological implications of more intensive management for production of forest biomass. A number of potential issues have been identified regarding the sustainability of forest biomass removal including ecosystem structure, nutrient and carbon balances, biodiversity, and aquatic system impacts (e.g., see Berger et al. 2013). Biomass harvesting guidelines that attempt to address such issues are being developed (Evans et al. 2013a).

A Brief Review of the Research and Debate about GHG Benefits of Forest-Derived Energy

A review of research on GHG impacts of forest bioenergy reveals a 25-year transition from work that created a basic understanding of the life cycle benefits of displacing fossil fuels with forest biomass, to research focused on the timing of these benefits, and finally to research demonstrating the importance, in many settings, of markets and investment responses to the GHG mit-

Received January 24, 2014; accepted August 13, 2014; published online August 29, 2014.

Affiliations: *Reid A. Miner (rminer@ncasi.org), National Council for Air & Stream Improvement, Research Triangle Park, NC. Robert C. Abt (bob_abt@ncsu.edu), North Carolina State University. Jim L. Bowyer (jimbowyer@comcast.net), Dovetail Partners. Marilyn A. Buford (mbuford@fs.fed.us), USDA Forest Service Research and Development. Robert W. Malmsheimer (rwmalmsh@esf.edu), SUNY College of Environmental Sciences and Forestry. Jay O'Laughlin (jayo@uidaho.edu), University of Idaho. Elaine E. Oneil (eoneil@u.washington.edu), Consortium for Research on Renewable Industrial Materials, University of Washington. Roger A. Sedjo (sedjo@rff.org), Resources for the Future. Kenneth E. Skog (kskog@fs.fed.us), USDA Forest Service Forest Products Laboratory.*

Acknowledgments: *We thank Mr. John Barnwell of the Society of American Foresters for providing logistical support in the preparation of the manuscript.*

ED_000419-0007906

igation benefits of forest bioenergy and the timing of those benefits.

Research on GHG mitigation benefits of forest bioenergy and the timing of those benefits extends back to at least the late 1980s (e.g., see Marland 1989). By 1990, in its First Assessment Report, the Intergovernmental Panel on Climate Change (IPCC)[1] had identified a number of "short-term" forest-based options for limiting GHG emissions, including,

> Partially replac[ing] fossil energy sources [with] sustainably managed sources of biomass which would reduce net emissions of additional CO_2 (IPCC 1990, p. 80)

In the 1990s, Marland and Schlamadinger (Schlamadinger and Marland 1996, Marland and Schlamadinger 1997) researched the temporal dynamics of forest systems to store carbon and to produce wood to displace fossil fuels either directly, via use as fuels, or indirectly, via displacement of more fossil fuel-intensive products. A key finding from their work was that

> The relative effectiveness of alternative forest and bioenergy strategies and their impact on net C [carbon] emissions strongly depend, for example, on the productivity of the site, its current usage, and the efficiency with which the harvest is used (Schlamadinger and Marland 1996, p. 275)

They also highlighted

> the importance of C sequestration as a function of time. In some…scenarios, biofuels strategies result in long-term benefits in net C fluxes despite small or negative benefits in the early stages (Schlamadinger and Marland 1996, p. 294)

Thus, by the mid-1990s, although the term "carbon debt" had not yet been coined, the concept was clearly understood, i.e., as a situation in which net emissions increase in the short term before long-term benefits are realized.

Through the 1990s and into the early 2000s, research into the mitigation potential of forests and forest-derived products expanded enormously. In the Fourth Assessment Report issued in 2007, IPCC synthesized research on the use of forests and forest products for GHG mitigation and concluded that

> In the long-term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fiber or energy from the forest, will generate the largest sustained mitigation benefit. Most mitigation activities require up-front investment with benefits and co-benefits typically accruing for many years to decades (Nabuurs et al. 2007, p. 543)

The timing of impacts and benefits was characterized in a general way with a graphic depicting the benefits from using forest-derived materials as being sustained, repeatable, and ongoing (Nabuurs et al. 2007, p. 550). Other than a brief mention of the use of purpose-grown plantation wood for energy, the IPCC 2007 report did not specifically address the use of industrial roundwood for energy. Instead, it highlighted forest-related fossil fuel displacement opportunities from using forest residues for fuel and using wood to displace more fossil fuel-intensive building materials (Nabuurs et al. 2007).

In 2012, IPCC released a report on renewable energy (IPCC 2012). In the chapter dealing with biomass energy, IPCC reiterated the findings of earlier assessments while elaborating on the conditions needed to ensure benefits from biomass energy; namely, sustainable production, efficient utilization, and retaining or increasing land-based carbon stocks.

In the early 2000s, a number of developments led to growing anxiety about the extent to which whole trees might be used for energy and the effects this would have on forests and wood markets. In the United States, there was a flurry of activity on Renewable Portfolio Standards (RPS), with 18 states launching or modifying programs between 2004 and 2006 (Wiser et al. 2007). In the European Union (EU), subsidies were already in place to encourage the use of renewable energy, including biomass (International Energy Association 2014), and in 2009 an EU-wide program was established under the Renewable Energy Directive (RED), requiring 20% of the energy consumed in the EU to be renewable by 2020 (EU 2009). As the RED was being crafted, the European paper industry conducted a study

> demonstrat[ing] that achieving the target of generating 20% of Europe's energy from renewable sources by 2020…would create a shortfall in the supply of wood from EU forests (Confederation of European Paper Industries 2007, p. 2)

As the EU demand for wood fuel increased, some of the supply came from outside of the EU. Wood pellets were often favored because they ship well and can be burned without major modifications to boilers. Much of the import demand for pellets has been satisfied by North America. Pellet exports to Europe more than doubled from 2011 to 2013, with the US South accounting for 63% of the North American export volume (Wood Resources International 2014). Feedstocks for pellets include not only residual materials but also small roundwood (Spelter and Toth 2009).

Increased interest in liquid biofuels in the United States under the updated Renewable Fuel Standard (40 CFR 80 subpart M) and in the EU under new sustainability criteria (EU 2009) focused attention on the GHG attributes of liquid biofuels. Several researchers pointed out the potential for a considerable carbon debt if the feedstocks for liquid biofuels were produced under conditions that caused large losses in ecosys-

Management and Policy Implications

Wood products and energy resources derived from forests have the potential to play an important and ongoing role in mitigating greenhouse gas (GHG) emissions. The methods used to characterize the mitigation benefits of using biomass for energy, however, are being debated without considering some key insights from published research studies. Many recent proposals for biogenic carbon accounting are based on a narrow analysis of the short-term and direct GHG emissions impacts of using forest biomass. This review suggests that a broader view of forest-based activities is needed. Of particular importance to understanding the emissions impacts of increased use of biomass from forests are fossil fuel substitution effects, markets for wood, causes for ongoing gains and losses in forest area and forest carbon, landowners' motivations, benefits and timing of investments in forestry, and the warming impact of near-term and long-term increases in CO_2 emissions. Studies that consider forest growth dynamics, landowner investment responses, and the warming impacts of biogenic CO_2 over a time horizon consistent with that used for other GHGs reveal low warming impacts from biogenic CO_2 associated with increased use of the types of forest biomass most likely to be used for energy in the United States. Such studies also show, for roundwood in particular, the importance of investment responses in contributing to low net emissions.

ED_000419-0007907

tem carbon stocks, e.g., via deforestation (Fargione et al. 2008, Gibbs et al. 2008).

Concerns about deforestation and the prospect of roundwood used as fuel caused a reassessment of the methods used to calculate the carbon benefits of biomass fuels. In 2009, a Policy Forum contribution in the journal *Science* attracted headlines when it suggested that a lack of attention to the timing of benefits from biomass energy, land-use change, and international transfers of carbon had created a "critical climate accounting error" (Searchinger et al. 2009).

In the United States, the search for options to meet RPS led to additional scrutiny of the GHG benefits of forest bioenergy. In 2010, the Manomet Report was released. It was later summarized in the peer-reviewed literature (Walker et al. 2013). Manomet examined a range of scenarios for producing forest bioenergy in Massachusetts. The forest bioenergy systems showed net benefits with lag times ranging from a few years to many decades, depending on the type of biomass used (residuals or roundwood) and the fossil-fuel energy system being displaced. Based on the modeling framework, scenarios, and assumptions used in the analysis, the times required to show net benefits from using whole trees to displace fossil fuel were calculated to be 45–75 years, prompting an Associated Press headline "Wood Worse Polluter Than Coal" (LeBlanc 2010).

The studies that have captured headlines, however, represent only a small fraction of the work that has been, and is still being, performed to understand the GHG impacts of using biomass for energy. Many of the studies now being done represent elaborations on the initial findings from the work in the 1990s in that they focus on direct carbon impacts and show net GHG benefits from using forest-derived biomass for energy, with the time required to see benefits ranging from zero years to many decades and sometimes longer (e.g., see McKechnie et al. 2011, Lippke et al. 2012, Mitchell et al. 2012, Zanchi et al. 2012, Agostini et al. 2013, Lamars and Junginger 2013).

Most recently, IPCC reviewed the current state of knowledge on biomass energy in the IPCC Fifth Assessment Report (Smith et al. 2014). This material expands on the findings of the Fourth Assessment Report by examining the many factors that affect the net GHG benefits of biomass energy. It states that

> Bioenergy could play a critical role for climate change mitigation, if conversion of high carbon density ecosystems (forests, grasslands and peatlands) is avoided and best-practice land management is implemented (Smith et al. 2014, p. 6)

Well-established findings regarding the timing of benefits from forest-based energy are reiterated in the report in a statement indicating that

> …in the specific case of existing forests that may continue to grow if not used for bioenergy, some studies employing counterfactual baselines show that forest bioenergy systems can temporarily have higher cumulative CO_2 emissions than a fossil reference system… (Smith et al. 2014, p. 89)

The report highlights the low life cycle GHG emissions associated with biomass energy produced from residues and fast-growing tree species. Also noted are (1) the importance of combined biomass energy and carbon storage and sequestration systems for meeting long-term emissions targets, (2) the life cycle GHG benefits of sustainably produced long-lived wood products, (3) the variable timing in forest-based mitigation, and (4) the need for active forest management, especially in developed countries where the forest carbon sink is declining as forests mature. In discussing the role of market forces, IPCC notes that

> growing markets for tree products can provide incentives for maintaining or increasing forest stocks and land covers, and improving forest health through management (Smith et al. 2014, p. 93)

At the same time, the report and annex note the need for attention to a range of issues to ensure the overall sustainability of forest-based mitigation activities. Among these issues are competition for land, water availability, biodiversity, and land tenure and land-use rights (Smith et al. 2014).

Whereas much of the research since the 1990s extends the life cycle and carbon debt analyses to new materials and scenarios, some of the more recent research uses a broader, integrated assessment approach that includes market dynamics. This allows insights into the factors contributing to the size and timing of benefits from forest bioenergy. Relying on both old and new research, we have identified four important insights related to the GHG impacts of forest-based energy systems. These insights are not intended to replace the many studies that have been performed on this topic but rather to assist in their interpretation. These four insights speak to (1) the consensus on long-term GHG benefits associated with using sustainably produced wood (meaning, in this context, wood produced under conditions ensuring sustained yields while land remains in forest), (2) the importance of wood markets in achieving near-term and long-term GHG benefits from forests, (3) the need to evaluate carbon debt in a framework that also considers drivers of projected peak global temperatures, and (4) the need to evaluate biogenic CO_2 emissions using metrics that are consistent with those used for other GHGs and that reflect forest and market dynamics. Several of these insights involve timing of benefits and emissions. Regarding the discussion of timing in the following material, "near term" means a few decades or less and includes immediate impacts, whereas "long-term" generally means longer than a few decades. Not all of these insights are recent, but all are important to understanding the factors affecting GHG emissions impacts associated with increased use of forest biomass for energy and interpreting studies that attempt to characterize these impacts.

Research Insight 1

As long as land remains in forest, long-term carbon mitigation benefits are derived from sustainably managed working forests that provide an ongoing output of wood and other biomass to produce long-lived products and bioenergy, displacing GHG-intensive alternatives.

Although the *timing* of benefits from substituting sustainably produced forest-based fuels and products for more GHG-intensive alternatives is sometimes debated (Biomass Energy Resource Center [BERC] 2012, Mitchell et al. 2012, Walker et al. 2013), the fact that these ultimate benefits exist is not. Agreement on this issue is based on an extensive body of research, dating at least to the mid-1990s (Schlamadinger and Marland 1996, Marland and Schlamadinger 1997), and reinforced by many more recent studies and reviews. Two types of substitution effects have been the most researched: forest-based energy as a substitute for fossil fuels (Nabuurs et al. 2007, Kirkinen et al. 2008, Nicholls et al. 2008, Bauen et al. 2009, Cherubini et al. 2009, Jones et al. 2010, Malmsheimer et al. 2011, McKechnie et al. 2011, Daigneault et al. 2012, Gaudreault et al. 2012, IPCC 2012, Lippke et al. 2012, Mitchell et al. 2012, Nepal et al. 2012, 2014, Repo et al. 2012, Zanchi et al. 2012, Agostini et al. 2013, Gaudreault and Miner 2013, Lamars

ED_000419-0007908

and Junginger 2013, White et al. 2013, Dwivedi et al. 2014, Smith et al. 2014) and the use of wood-based building materials in place of alternatives (Perez-Garcia et al. 2005, Nabuurs et al. 2007, Upton et al. 2008, Oneil and Lippke 2010, Sathre and O'Connor 2010, Malmsheimer et al. 2011, Smith et al. 2014).

In considering the timing of fossil fuel substitution benefits, the International Energy Agency observed that

> Land suitable for producing biomass for energy can also be used for the creation of biospheric carbon sinks. Several factors determine the relative attractiveness of these two options [i.e., creating sinks or producing biomass energy], in particular land productivity, including co-products, and fossil fuel replacement efficiency.... A further influencing factor is the time scale that is used for the evaluation of the carbon reduction potential: a short time scale tends to favor the sink option, while a longer time scale offers larger savings as biomass production is not limited by saturation but can repeatedly (from harvest to harvest) deliver GHG emission reductions by substituting for fossil fuels (Bauen et al. 2009, p. 14)

Scientific consensus on the long-term benefits of managed forests and of sustainably produced forest products and fuels led the IPCC to highlight, as noted above, the sustained GHG mitigation benefits from using sustainably produced forest biomass (Nabuurs et al. 2007, p. 543). More recently, this conclusion has been echoed in the findings of Ryan et al. (2010). Based on an extensive literature review, they concluded that

> strategies that combine increased use of forest products to offset fossil fuel use (such as use of forest biomass energy and substitution [of wood products for steel and concrete building products]), in conjunction with increasing carbon storage on forested landscapes, are likely to produce the most sustainable forest carbon benefits (Ryan et al. 2010, p. 14)

Research Insight 2

The demand for wood keeps land in forest, provides incentives for expanding forests and improving forest productivity, and supports investments in sustainable forest management that can help offset the forest carbon impacts of increased demand.

Historical Context. The impacts of forest harvesting on carbon emissions are important yet counterintuitive. The history of US forests shows that increased demand can be met without reducing forested area or forest carbon stocks. The amount of forested area in the United States has been essentially constant since 1900 (Alvarez 2007, Smith et al. 2009) (Figure 1). Over this period, land use has not been static, but losses of forest in one place have been offset by increases elsewhere. Where forest has been lost, it has been due primarily to suburban and urban development (Smith et al. 2009).

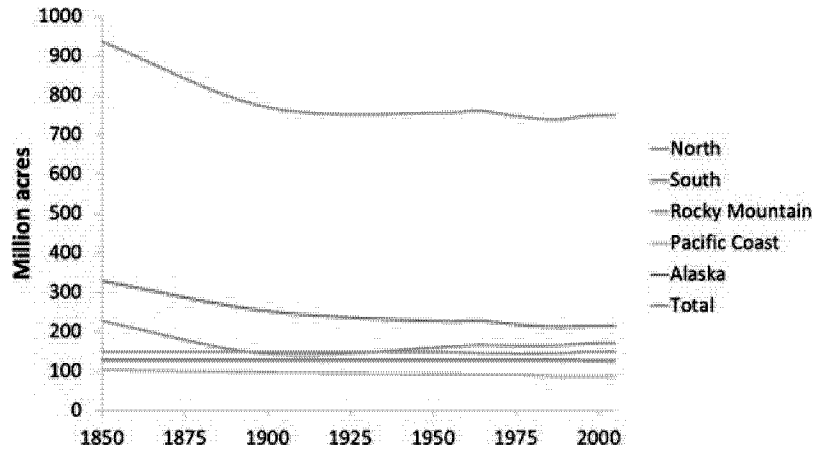


Figure 1. Forest area in the United States has been stable since about 1900. (Data from Alvarez 2007.)

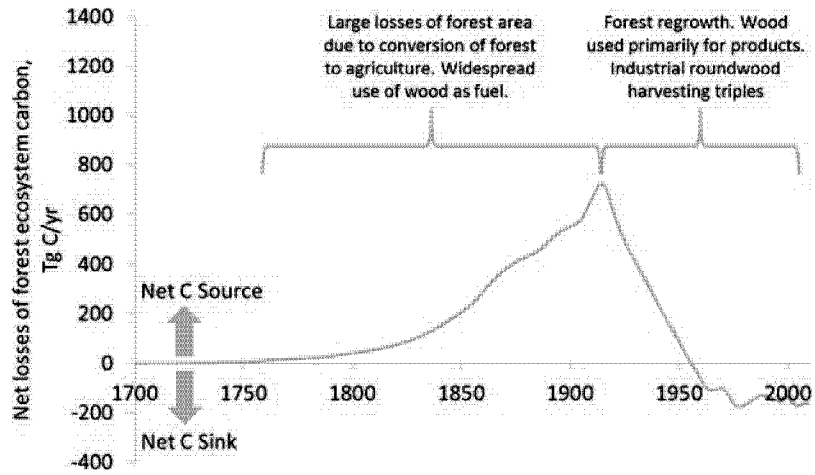


Figure 2. US forest ecosystems are now a net sink for carbon, having rebounded from over a century of deforestation.[2]

Forests in the United States currently function as a carbon sink (Figure 2). This is attributable to a stable forest area for more than 100 years and a long history of net forest growth in excess of mortality and removals at least since 1952 (Birdsey et al. 2006, Smith et al. 2009). Strong markets for forest products, evidenced by a near tripling of industrial roundwood harvests between 1900 and 1998, are also a factor as are improvements in forest management practices (Ince 2000, Birdsey and Lewis 2003, Birdsey et al. 2006).

Currently the net carbon sink in the United States is large enough to offset 14–15% of total annual CO_2 emissions in the United States (US Environmental Protection Agency [EPA] 2013). Approximately 91% of this sink is attributable to increases in carbon stored in forest ecosystems, and the remaining 9% is due to increased quantities of carbon stored in products in use (e.g., wood used in construction) and in landfills (US EPA 2013). Land clearing before the early 1900s and subsequent forest regrowth coupled with improved forest management and increased output of harvested wood products (resulting in increases in carbon stocks in products-in-use and in landfills) created the US forest carbon sink (Figure 2). Although forest carbon stocks have increased considerably since 1950s, it is unlikely that forest area or forest carbon stocks will return to precolonial levels due to the need for productive agricultural land and urban expansion.

Threats to Forest Area and Carbon Stocks. Looking ahead, the strength of the US forest carbon sink is expected to decline

ED_000419-0007909

Table 1. Land-use choice elasticities for the United States: percent change in probability of land changing (a) from forest to other land use categories and (b) from other land use categories to forest given a 1% change in net returns in the final use.

(a) Land starting in forest but ending in another category				(b) Land starting in a different category but ending in forest			
Final land use	1982–1987	1987–1992	1992–1997	Starting land use	1982–1987	1987–1992	1992–1997
Crops	0.21* (0.07)	0.28* (0.05)	0.29* (0.06)	Crops	0.88* (0.05)	0.75* (0.07)	0.31* (0.04)
Pasture	0.10 (0.06)	0.04 (0.09)	−0.01 (0.06)	Pasture	0.22* (0.03)	0.08 (0.05)	0.00 (0.03)
Range	0.28 (0.23)	−0.56 (3.46)	0.23 (0.33)	Range	0.08 (0.36)	0.03 (0.42)	0.13 (0.91)
Urban	0.23* (0.02)	0.30* (0.07)	0.80* (0.06)	Urban	Essentially no land converted to forest		

Adapted from Table 3 in Lubowski et al. (2008). Standard errors are in parentheses.
* Statistical significance at the 1% level. Effects were also tested at the 5% level, but this did not reveal any additional statistically significant effects.

as forests growing on previously cleared land mature and forested land is lost to development and other uses (Birdsey et al. 2006, USDA 2012). In Europe, there are already signs that the forest sink is becoming weaker (Nabuurs et al. 2013). Because of urbanization trends in the US South through 2060,

> total forest losses are forecasted to range from 11 million to 23 million acres, depending on the rate of population growth and the future of timber markets—low population growth with strong timber markets would yield the smallest losses. At 7–13 percent of current forest area, these losses would still equal nearly all the forests in Kentucky or South Carolina at the low end of the range, and nearly all the forests in Georgia or Alabama at the high end (Wear and Greis 2012, p. 23)

Climate change may increase damage caused to forests (Joyce et al. 2014) by wildfire (US Department of Agriculture/US Department of the Interior/National Association of State Foresters 2009, Anderegg et al. 2013), insect outbreaks (Bentz et al. 2010), and hurricanes (McNulty 2002, Negrón-Juárez et al. 2010). The net sink could also be affected by changes in wood production and landowner responses to changes in demand for wood (Hardie et al. 2000, Lubowski et al. 2008, Abt et al. 2010, 2012, Daigneault et al. 2012, Nepal et al. 2012, 2014, USDA Forest Service 2012, Wear and Greis 2012, Joyce et al. 2014) as well as public policies (Perez-Garcia et al. 2001, Beach et al. 2005, Langpap 2006, Zobrist and Lippke 2007, Zhang and Flick 2010, Van Deusen et al. 2012, Joyce et al. 2014). Continued increases in atmospheric CO_2 and other plant nutrients will probably increase forest growth and associated CO_2 removals from the atmosphere, although there is considerable uncertainty regarding the factors influencing this growth response (e.g., as regards nitrogen availability and genetic limitations) (Luo et al. 2004, Reich et al. 2006, Denman et al. 2007, Norby et al. 2010).

Table 2. Despite the large increases in harvesting, carbon stocks on private softwood timberland in the US South have remained essentially constant, due to expanded acreage of planted pine and improved management practices.

	Harvesting, carbon stocks, and planted acreage on privately owned softwood timberland in the South		
Year	Harvest (10^6 ft^3)*	Carbon (10^6 metric tons)†	Planted pine (acres)‡
1952	2,840	923	1.8
1999	5,522	883	32
Change, 1952–1999 (%)	+94	−4	+1,678

* Data are from Adams et al. (2006).
† 1999 values were assumed to be equal to the 1997 values shown in Mickler et al. (2004) for privately owned longleaf-slash, loblolly-shortleaf, and miscellaneous conifer forest. Values for 1952 were back-calculated from data in Mickler et al. (2004) showing the mean annual metric ton/year changes for carbon on each of these areas from 1953 to 1997.
‡ Data are from Fox et al. (2004).

The Role of Markets in Protecting Forest Area and Forest Carbon. Against this backdrop of concerns regarding forest area and loss of forest carbon stocks, research shows that demand for wood in the United States results in investments in forestry that help to prevent loss of forest and incentivize afforestation (Hardie et al. 2000, Lubowski et al. 2008). Forest area loss in the United States is caused primarily by urbanization and development, not demand for wood (Lubowski et al. 2008, USDA Forest Service 2012, Wear and Greis 2012). In the face of pressures to convert land to other uses, increased wood demand in the United States can slow the loss of forested area (USDA Forest Service 2012, Nepal et al. 2014). Empirical studies examining the economic factors affecting land-use change (e.g., Table 1) indicate that changes in economic returns to cropland and forestry affect the movement of land between these two uses (Lubowski et al. 2008). Table 1 illustrates, using land-use elasticities, how changes in net economic returns to different land-use categories result in more or less land in forest. Land constantly moves into and out of forest cover. Approximately 4.6% of the forest on nonfederal land in the lower 48 states in 1982 was converted to other uses by 1997. Over the same period, conversion of nonforest land to forest offset these losses by an amount equivalent to about 5.7% of the 1982 forest area (not considering federal land), resulting in a small net gain in forest area (based on data in Lubowski et al. 2008).

The benefits of investments in working forests due to markets for wood vary regionally and are especially clear in the southern United States (Nepal et al. 2014), where the amount of softwood harvested from private pine forests almost doubled between the early 1950s and the late 1990s (Adams et al. 2006) while carbon stocks in these forests remained essentially constant (Mickler et al. 2004) (Table 2). This was made possible, in part, by investments in working forests that greatly increased productivity and expanded the planted pine area from 1.8 million acres in the early 1950s to almost 32 million acres in the late 1990s. Some of this occurred on land not previously forested, but trends in natural pine acreage suggest that much of the planting of pine took place on land converted from natural pine (Fox et al. 2004, Wear and Greis 2012). Whereas the carbon implications of this conversion are relatively well understood, the ecological attributes of planted forests are a matter of ongoing study

ED_000419-0007910

and debate (e.g., see Loehle et al. 2009, Evans et al. 2013b).

Market-related impacts have been the focus of a number of recent studies, some looking at a range of factors affecting land use and some looking specifically at the projected effects of an increase in demand for forest biomass for energy. A study of factors affecting land use in the US South found that "forestland share responds positively to increases in pine stumpage prices and negatively to increases in timber production costs" (Hardie et al. 2000, p. 670). Another study of land-use change in the United States found that "…the rise in timber net returns [was] the most important factor driving the increase in forest areas between 1982 and 1997" (Lubowski et al. 2008, p. 545). A study of the impacts of increased wood demand for bioenergy in Alabama, Florida and Georgia found that

> …in scenarios in which prices increase, there is more timberland area than occurs under the baseline scenario without bioenergy demand. This, in turn, leads to a higher level of carbon sequestration in the standing forest than occurs with the baseline scenario (Abt et al. 2012, p. 536)

Another study of land-use impacts attributable to increased use of wood for energy found that "[h]igher timber prices lead to new investments in forestry, and in particular in new forestlands in the unconstrained land scenario" (Daigneault et al. 2012, p. 5669). This same study projected that, as a result of increased wood demand for energy, US forest area could expand by 4 to 8.6 million acres by 2015 and 11.9 to 26.9 million acres by 2030 (Daigneault et al. 2012).

A recent assessment by the USDA Forest Service predicted losses in US forest area through 2060 due primarily to urbanization, noting that

> [f]orest area losses are most pronounced under…scenarios, in which population- and income-driven urbanization consumes rural lands at the highest rate. The acceleration of forest loss for [an historical bioenergy demand scenario] relative to [a comparable high bioenergy demand scenario] reflects the role that strong wood products markets can have on retaining or even expanding forestland in parts of the United States (USDA Forest Service 2012, p. 59)

The connection between markets for wood and keeping land in forest is also evident in an assessment of the global patterns of deforestation:

> in general, the data show that the global regions with the highest levels of industrial timber harvest and forest product output are also regions with the lowest rates of deforestation (Ince 2010, p. 32)

Such information led IPCC to observe that

> the anticipation of future bioenergy markets may promote optimized forest management practices or afforestation of marginal land areas to establish managed plantations, so contributing to increased forest carbon stocks. Rather than leading to wide-scale loss of forestlands, growing markets for tree products can provide incentives for maintaining or increasing forest stocks and land cover, and improving forest health through management (Smith et al. 2014)

Although these and other studies provide strong evidence that increased demand for wood leads to increased forested area, the impacts on forest carbon can vary, especially over periods of decades. For instance, the USDA Forest Service (2012) assessment discussed above found that at the end of the study period (2060) projected carbon stocks were likely to be lower in the high biomass demand scenario even while the forest area was likely to be greater. This was due to increased harvesting and more intensive forest management.

Other studies, however, have found that where the investment response to increased demand is strong, it can increase both forest area and forest carbon stocks, especially where investments are made in anticipation of increased demand (Daigneault et al. 2012, Sedjo and Tian 2012, Nepal et al. 2014). Market response varies by region and is especially strong in the US South, where one study found that the investment response would be adequate to offset essentially all of the projected drawdown in forest carbon stocks associated with more than a 4-fold increase in the amounts of forest-derived energy (Nepal et al. 2014). The investment response and the associated carbon impacts can also be affected by policies that constrain market participation (Latta et al. 2013). These varying findings highlight the need for those studying forest bioenergy to consider the many complex ways in which market forces impact forest-related activities and investments.

Landowner responses to increased demand and the carbon impacts of those responses are affected by many things besides markets. This is especially true in the case of small private nonindustrial forest owners, now more commonly referred to as family forest owners (Butler 2008). These landowners supply more than one-half of the wood harvested in the United States (Haynes et al. 2007). A robust body of research shows that these landowners respond to price signals, public policies, and various incentives and disincentives to producing wood. For instance, a meta-analysis of forest management practices of family forest owners found that among the drivers typically studied, policy variables are most likely to be identified as drivers of landowner behavior, followed by plot/resource conditions, owners' characteristics, and market drivers, although the differences in the importance of the various drivers are small (Beach et al. 2005). This and many other studies make it clear that in addition to markets, public policies and other nonmarket factors are important drivers of landowner behavior (Perez-Garcia et al. 2001, Langpap 2006, Zobrist and Lippke 2007, Zhang and Flick 2010, Joshi and Mehmood 2011, Miller et al. 2012, Van Deusen et al. 2012, Aguilar et al. 2013, Becker et al. 2013, Latta et al. 2013, Rozance and Rabotyagov 2014). Research on factors that influence landowner behavior suggests substantial potential for affecting landowner behavior in ways that could have important carbon implications. Policies that provide incentives for landowners to expand forest area, make forests more productive, and store more carbon could have important carbon benefits. On the other hand, policies that increase transaction costs to landowners or devalue forest biomass could have negative carbon consequences, by reducing incentives for investments in working forests, reducing biomass supplies, limiting afforestation activities, and leading to increased conversion of forests to other land uses. The potential for landowner response to disincentives could be especially important in the case of materials collected for energy due to their low value, as revealed in a survey of loggers and landowners in North Carolina (Fielding et al. 2012).

Markets and landowner behavior are often ignored in studies of the carbon impacts of increased use of forest-derived bioenergy, even though many studies have shown that landowners are responsive to forest policies, incentives, and disincentives. Although there are uncertainties associated with studies that provide an integrated analysis of the dynamic interactions between forests, other land uses, and markets for traditional forest products as well as biomass energy, these integrated assessments provide important insights into the carbon implica-

ED_000419-0007911

tions of different policies. There are many examples of such integrated assessments (see Abt et al. 2010, 2012, Ince et al. 2011, Daigneault et al. 2012, Nepal et al. 2012, 2014, Sedjo and Tian 2012, USDA 2012, Abt and Abt 2013, Latta et al. 2013, White et al. 2013, Nepal et al. 2014).

Research Insight 3

Although forest bioenergy systems sometimes produce near-term increases in CO_2, they typically result in lower cumulative CO_2 emissions over time, and cumulative CO_2 emissions, according to the IPCC, are the best predictor of future peak global temperatures.

The time required for biomass energy systems to show net GHG benefits relative to that for alternative systems has received considerable attention (Vaughan et al. 2009, Cherubini et al. 2011, McKechnie et al. 2011, BERC 2012, Mitchell et al. 2012, US EPA 2012, Agostini et al. 2013, Helin et al. 2013, Lamars and Junginger 2013, Walker et al. 2013). Some of the focus on timing stems from concern about "tipping points" and "abrupt changes."

IPCC defines a tipping point as "a hypothesized critical threshold when global or regional climate changes from one stable state to another stable state" (IPCC 2013, p. 1463). In its most recent analysis, IPCC reports that

> A small number of studies using simplified models find evidence for global-scale 'tipping points'; however, there is no evidence for global-scale tipping points in any of the most comprehensive models evaluated to date in studies of climate evolution in the 21st century. There is evidence for threshold behavior in certain aspects of the climate system, such as ocean circulation and ice sheets, on multi-centennial-to-millennial timescales. There are also arguments for the existence of regional tipping points, most notably in the Arctic although aspects of this are contested (IPCC 2013, p. 129)

IPCC defines an "abrupt change" as

> a large-scale change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades, and causes substantial disruptions in human and natural systems (IPCC 2013, p. 1448)

In summarizing the research on abrupt changes IPCC concludes that

> Several components or phenomena in the climate system could potentially exhibit abrupt or nonlinear changes, and some are known to have done so in the past.... For some events, there is information on potential consequences, but in general there is low confidence and little consensus on the likelihood of such events over the 21st century (IPCC 2013, p. 1033)

Whereas the science on tipping points and abrupt changes continues to advance, a consensus has developed on the importance of *cumulative* CO_2 emissions as a predictor of peak global temperatures (Allen et al. 2009, Meinshausen et al. 2009, IPCC 2013). For instance, IPCC (2013) indicates that although there is evidence that short-lived, non-CO_2 GHGs such as aerosols and methane may have near-term temperature impacts within several decades, CO_2 appears to be different:

> taking into account the available information from multiple lines of evidence (observations, models and process understanding), the near linear relationship between cumulative CO_2 emissions and peak global mean temperature is well established in the literature and robust for cumulative total CO_2 emissions up to about 2000 PgC [petagrams of carbon]. It is consistent with the relationship inferred from past cumulative CO_2 emissions and observed warming, is supported by process understanding of the carbon cycle and global energy balance, and emerges as a robust result from the entire hierarchy of models (IPCC 2013, p. 102)

IPCC suggests that for warming to be limited to 2° C at the time net CO_2 emissions are reduced to zero, total cumulative emissions from all anthropogenic sources over the entire industrial era would need to be limited to about 1 trillion tonnes of carbon (IPCC 2013, p. 927). As of 2011, cumulative anthropogenic emissions of CO_2 during the industrial era were estimated to be 555 billion tonnes of carbon (IPCC 2013, p. 467).

IPCC specifically addresses the issue of emissions timing in the context of cumulative emissions, noting that

> The concept of cumulative carbon also implies that higher initial emissions can be compensated by a faster decline in emissions later or by negative emissions. However, in the real world short-term and long-term goals are not independent and mitigation rates are limited by economic constraints and existing infrastructure (IPCC 2013, p. 1113)

Thus, IPCC's concern with higher CO_2 emissions in the near-term reflects concern about what these near-term increases mean about the likelihood of meeting cumulative CO_2 emissions targets in the longer term, especially given economic and infrastructure constraints to making large reductions in the future if emissions are allowed to increase unabated in the near term. In the words of one of the studies cited by IPCC in its most recent assessment

> ... the relationship between cumulative emissions and peak warming is remarkably insensitive to the emission pathway (timing of emissions or peak emission rate). Hence policy targets based on limiting cumulative emissions of carbon dioxide are likely to be more robust to scientific uncertainty than emission-rate or concentration targets (Allen et al. 2009, p. 1163)

Elsewhere, IPCC's Fifth Assessment Report addresses the "relationship between short-term action and long-term targets" (Bruckner et al. 2014, p. 67). The IPCC report states that

> Unlike short-lived species (e.g., CH_4 [methane], CO [carbon monoxide], NOx [nitrogen oxides], and SO_2 [sulfur dioxide]) for which stable concentrations are associated with stable emissions, stable concentrations of CO_2 ultimately in the long-term require net emissions to decline to zero. Two important implications follow from this observation. First, it is cumulative emissions over the entire century that to a first approximation determines the CO_2 concentration at the end of the century, and therefore no individual year's emissions are critical.... Second, minimization of global social cost implies an immediate initiation of global emissions mitigation, relative to a reference, no-climate-policy scenario.... (Bruckner et al. 2014, p. 67–68)

The IPCC text reveals that the primary concern about not meeting near-term limits is related to "lock-in" of high GHG technology and infrastructure that fail to accomplish any significant change in terms of the low-carbon energy share and therefore fail to reduce long-term cumulative emissions (Bruckner et al. 2014, p. 68). IPCC's concern about lock-in is focused on conventional fossil fuel energy systems, not energy systems that yield significant long-term reductions in cumulative emissions, such as energy systems supplied with forest biomass from land that remains in forest. Indeed, bioenergy is among the "low-carbon primary energy" sources included in IPCC's energy sector transformation pathways (Clark et al. 2014, p. 40).

These various findings are directly relevant to the discussions about the timing of emissions and benefits associated with the use of forest-derived fuels. When systems using forest biomass are compared with those using fossil fuels for energy, forest-based energy systems can sometimes show higher near-term emissions of CO_2, incurring a carbon debt (Fargione et al. 2008, Gibbs et al. 2008, Jones et al. 2010, McKechnie et al. 2011, Mitchell et al. 2012, US EPA 2012,

ED_000419-0007912

Zanchi et al. 2012, Agostini et al. 2013, Lamars and Junginger 2013). As discussed above, however, in the case of forest-derived fuels, as long as wood-producing land remains in forest, this short-term increase in emissions is reversed in essentially all cases, and in the long-term, the use of forest-based systems provides lower cumulative CO_2 emissions than fossil fuel-based alternatives (see Research Insight 1). Research Insight 4 (below) elaborates on the times required to achieve lower cumulative emissions from forest biomass fuels. Given the consensus on the importance of reducing long-term cumulative emissions, near-term increases in CO_2 emissions should not be judged in isolation. Forest bioenergy systems may sometimes produce higher near-term CO_2 emissions, but they typically produce lower cumulative CO_2 emissions, making their climate impact fundamentally different from that of fossil fuel systems that increase near-term CO_2 emissions without reducing cumulative emissions.

Research Insight 4

The net warming impacts of biogenic CO_2 should be assessed using a framework that is consistent with that used for other GHGs and, especially in the case of biogenic CO_2 from roundwood, reflects the effects of market-induced investments and forest growth dynamics. When assessed in such a framework, the types of forest-derived biomass likely to be used for energy in the US typically have low (sometimes less than zero) warming impacts.

The GHG impacts of forest-derived energy should be calculated with a metric for biogenic CO_2 that is consistent with the approach used for other GHGs. The impacts of other GHGs are commonly examined on the basis of global warming potentials (GWPs) derived from the 100-year time-integrated global mean radiative forcing of a pulse emission (Forster et al. 2007). Radiative forcing is

> the change in the…radiative flux (expressed in W m^{-2}) at the tropopause or top of atmosphere due to a change in an external driver of climate change, such as…a change in the concentration of carbon dioxide… (IPCC 2013, p. 1460)

Cumulative radiative forcing from a pulse emission of a GHG is determined by calculating the radiative forcing each year, attributable to the amount of GHG remaining in the atmosphere, and summing the annual values over a period, often 100 years. A 100-year GWP for a GHG is equal to the cumulative radiative forcing of a pulse emission of the GHG over 100 years divided by the cumulative radiative forcing of a pulse emission of CO_2 over 100 years. GHGs with higher cumulative radiative forcing than CO_2 have GWPs greater than 1, whereas those with cumulative radiative forcing less than CO_2 will have GPWs less than 1. The impacts of biogenic CO_2 can likewise be characterized by taking net CO_2 fluxes, including removal of CO_2 from the atmosphere by growing trees, and cumulative radiative forcing into account. Several approaches for accomplishing this have been suggested.

Cherubini et al. (2011), for instance, suggest using GWP_{bio} which is a global warming potential for biogenic CO_2. It is comparable to GWPs for other gases in that it reflects the net radiative forcing associated with the release of a pulse emission of a GHG, in this case, biogenic CO_2, relative to a pulse emission of fossil fuel CO_2. It differs from other GWPs only in that it also considers the removal of a pulse emission of biogenic CO_2 from the atmosphere by regrowth of the harvested vegetation. This metric characterizes the emissions from the system in isolation, not considering foregone carbon storage and, in the case of trees, foregone sequestration attributable to tree growth. The Cherubini et al. (2011) GWP for biogenic CO_2 will be equal to 1.0 if there is no regrowth to offset the emissions, between 0.0 and 1.0 if a portion of the biogenic CO_2 is removed from the atmosphere by regrowth, and 0.0 if all of the CO_2 is removed via regrowth instantaneously after harvest.

Helin et al. (2013) suggested an approach that differs from that of Cherubini et al. (2011) in that it also considers foregone storage and sequestration, i.e., the removals of CO_2 from the atmosphere and incremental carbon storage that would have occurred had the biomass not been used. As a result, GWPs for biogenic CO_2 developed using the Helin et al. (2013) approach are larger than those developed using the Cherubini et al. (2011) approach. At a given point in time, the Helin et al. (2013) GWP for biogenic CO_2 will be equal to 1.0 if the amount of CO_2 removed by regrowth after harvest is exactly the same as the foregone CO_2 removals attributable to additional growth that would have occurred had the wood not been harvested. It will be greater than 1.0 if the CO_2 removed by regrowth over time is less than the foregone CO_2 removals attributable to the additional growth lost by harvesting and less than 1.0 if the CO_2 removed by regrowth over time is greater than the foregone CO_2 removals.

The Cherubini et al. (2011) approach is appropriate if the objective is to characterize the biogenic CO_2 emissions from the biomass energy system in isolation, without considering foregone carbon storage and sequestration. The approach of Helin et al. (2013) is appropriate where the objective is to assess the net change in biogenic CO_2 emissions associated with an increase in the use of biomass for energy relative to a scenario where this energy demand is met without increasing the use of biomass.[S] Table 3 compares results from the two approaches when applied to planted loblolly pine on a 20-year rotation. The results from both methods and the differences between them vary from one situation to another, depending primarily on growth rates.

In either case, if these metrics are developed for 100-year periods, they can be used in studies in which other gases are characterized using 100-year GWPs, recognizing that

Table 3. Development of 100-year global warming potentials for biogenic CO_2 using methods comparable to those used for other GHGs.

	Cherubini et al. (2011) approach*	Helin et al. (2013) approach*
20-yr GWP for biomass energy CO_2 emission	0.54	0.85
100-yr GWP for biomass energy CO_2 emission	0.12	0.26

Two approaches for calculating global warming potentials for biogenic CO_2 (not considering investment-related responses to increased demand) are shown. The example is based on increased production of bioenergy from planted loblolly pine on a 20-year rotation (based on growth curves developed from planted pine data in Smith et al. 2006).
* Calculations are contained in Supplemental Spreadsheet S1.

[S] Supplementary data are available with this article at http://dx.doi.org/10.5849/jof.14-009.

ED_000419-0007913

the investment response is not accounted for. Increasingly, however, the impacts of biogenic CO_2 are being judged over periods of less than 100 years in analyses in which other GHGs are examined using 100-year GWPs. Using a time horizon of less than 100 years to judge the significance of emissions of biogenic CO_2 implies that wood energy emissions are more damaging than fossil fuel-derived CO_2 and other GHGs, which has no scientific basis. If the time horizon for judging impacts from biogenic CO_2 is less than 100 years, then logically it should be less than 100 years for all GHGs. In other words, consistent time horizons should be used for judging the radiative forcing of all GHGs. IPCC has developed 20-year GWPs (Forster et al. 2007, IPCC 2013), which can be used to judge the cumulative radiative forcing of a pulse emission of many GHGs over a 20-year period. Because these values are static, however, their use can be problematic in systems involving more than pulse emissions of CO_2 at time zero (e.g., see Levasseur et al. 2010, Gaudreault and Miner 2013). For example, because methane has a relatively short lifetime in the atmosphere, methane leaks from natural gas systems exert most of their warming impacts in the years immediately after their release (Alvarez et al. 2012). This dynamic process is important to understanding the timing of impacts involving methane, but it is ignored when using GWPs because GWPs represent cumulative warming impacts over a specific period, usually 100 years. In such cases, dynamic modeling of radiative forcing may be necessary, as suggested by Levasseur et al. (2010), Cherubini et al. (2011), and Helin et al. (2013).

Insights into the GHG attributes of biomass energy can be gained by using the metrics described above. Although these metrics address the direct impacts of using biomass, they miss potentially important indirect impacts, such as market-related impacts on forestry, including investment responses that expand forest area or increase forest productivity, as described in Research Insight 2 above, and the impacts of natural disturbances that might be affected by a decision to increase forest output. The inclusion of impacts related to market-induced investments that expand forest area and improve forest management provides a more robust assessment of the effects of using forest biomass (Daigneault et al. 2012, Galik and Abt 2012). If indirect market-related effects, such as landowner responses to increased demand, are excluded, one can overlook carbon impacts associated with private landowner responses to increased demand that in most cases tend to increase supplies of forest biomass, improve forest management, and offset carbon losses associated with increased harvesting (Daigneault et al. 2012, Nepal et al. 2014).

With an understanding of the importance of using consistent metrics and consideration of the effects of the investment response, it is possible to examine the GHG impacts associated with increased use of specific types of forest-derived biomass. This is done in the following sections addressing logging residue, roundwood from private land, wood from federal land in the West, mill residues, and large trees.

Logging Residue from Private and Public Land. To sustain ecological functions and site productivity, it may be appropriate to retain a portion of logging residues on site, as recognized by various biomass harvesting guidelines (Evans et al. 2013a). Within these constraints, using some of these residues to displace fossil fuel reduces atmospheric GHGs (Lippke et al. 2012, Zanchi et al. 2012, Smith et al. 2014). To estimate the CO_2 reductions associated with increased use of logging residues and their timing, one compares a system in which increased amounts of logging residues are used for energy and an alternative system in which they are not. In cases in which the alternative to using these residues for energy is burning them on site, as is the practice in many US locations, the carbon returns to the atmosphere at the same time for the two systems, so the net impact on biogenic carbon emissions is zero or less than zero if methane and nitrous oxide emissions from pile burning are higher than those from boilers (Jones et al. 2010). In these cases, the benefits of using residues for energy are observed immediately. Where the alternative to using logging residues for energy is leaving them on site to decay, net emissions of biogenic CO_2 may be temporarily higher for the case in which residues are used for energy and substitution benefits may be delayed for a period that depends primarily on the expected decay rate of forest residues (Lamars and Junginger 2013). Although decay half-lives of 100 years or longer have been reported, the majority of United States logging residue half-lives are less than 50 years and generally less than 20 years under warm conditions, with hardwoods generally decomposing more rapidly than softwoods (Zimmerman 2004, Radtke et al. 2009, Russell et al. 2014).

With use of the biogenic CO_2 impact metric developed by Helin et al. (2013) and two assumptions (that slash would have been left on site to decay, with an avoided decay half-life of 20 or 50 years, had it not been burned for energy, and that carbon released by decomposition enters the atmosphere as CO_2), the estimated 100-year GWPs for biogenic CO_2 from increased use of logging slash for energy are 0.30 and 0.56, respectively, not considering avoided fossil fuel emissions (calculations are shown in Supplemental Spreadsheet S2), meaning that the biogenic CO_2 from these sources exerts 30 and 56% of the net radiative forcing of fossil fuel CO_2 over 100 years. In circumstances representative of the eastern United States, where most logging residues are produced and residue decay half-lives are generally 20 years or less (Zimmerman 2004, Russell et al. 2014), the use of forest residues that otherwise would have been left to decay typically accomplishes net GHG benefits within a decade when displacing coal-based electricity and within two decades when displacing natural gas-based electricity, even though wood energy systems usually have somewhat lower efficiencies than fossil fuel systems (Zanchi et al. 2012, Lamars and Junginger 2013, Walker et al. 2013). Longer times to see net benefits can occur in situations in which residues are normally left to decay, and the decay rates are lower (McKechnie et al. 2011, Repo et al. 2012, Lamars and Junginger 2013). Residue decay rates appear to be lower in parts of the Northwest than in the eastern United States, and burning of logging residues onsite is most common in the Northwest, followed by the North, the Southwest, and the South (Cleaves et al. 1999, Zimmerman 2004).

Roundwood from Private Land. The biogenic CO_2 metric developed by Helin et al. (2013), described above, yields an estimated 100-year GWP for biogenic CO_2 from roundwood produced from forests evaluated by the Manomet Center (Walker et al. 2013) and used in accordance with Massachusetts biomass regulations,[3] of 0.68 (calculations are contained in Supplemental Spreadsheet S2), meaning that this biogenic CO_2 has 68% of the cumulative 100-year radiative forcing of fossil fuel CO_2. Lower GWPs are likely where the forest is faster growing (e.g., see Table 3 for a case involv-

ED_000419-0007914

ing 20-year rotation loblolly pine). Although the GWPs for biogenic CO_2 from old or slow-growing forest are likely to be higher (Marland and Schlamadinger 1997), it is important to consider the extent to which such trees are likely to be used for energy, a topic discussed in more detail below.

In many cases, to correctly characterize net emissions associated with using roundwood, indirect impacts related to market-induced investments must also be analyzed (e.g., see Daigneault et al. 2012, Galik and Abt 2012, Nepal et al. 2014). This can be a complex undertaking, however, and most studies ignore these indirect impacts and instead assume that forest management within a supply area will not change in response to increased demand for forest biomass; i.e., management practices, the amount of forested area, and the impacts of natural disturbances do not change (e.g., see McKechnie et al. 2011, BERC 2012, Mitchell et al. 2012, Zanchi et al. 2012, Walker et al. 2013). Historical evidence indicates, however, that increased demand for roundwood for products and energy from sustainably managed private forestland will increase revenue to landowners and often affect carbon stocks as landowners respond by retaining or expanding forest and intensifying forest management (Fox et al. 2004, Lubowski et al. 2008, Daigneault et al. 2012, Nepal et al. 2014). Because of the time needed to produce wood, studies examining landowner responses to increased demand for wood often look at the role of anticipatory investments made in expectation of future demand (Sedjo and Tian 2012). These anticipatory investments help prevent forest carbon stocks from declining, especially on private land, as the historical record in the southern United States demonstrates (Table 2) and recent research reinforces (Nepal et al. 2014). Empirical studies show that landowners have converted agricultural land to forest and refrained from converting forestland to other uses in response to higher revenues from forestland (Hardie et al. 2000, Lubowski et al. 2008).

The largest demand for wood biomass for energy from private lands is likely to occur where the investment response to increased demand for wood has been the strongest—the US South (Nepal et al. 2014). Research suggests that the impact of the investment response on forest carbon stocks is less significant in other regions of the country (Nepal et al. 2014). In the Pacific Northwest, another major wood-producing region, landownership patterns and economic forces, among other factors, have limited the extent to which investments in forestry result in increased forest area. In this region, essentially all land-use change has involved converting undeveloped agricultural and forestland into developed uses (Lettman et al. 2002, Bradley et al. 2007). Family forest owners in areas with strong development pressures in the Northwest and elsewhere are relatively unlikely to keep land in forest simply for the income from wood production (e.g., see Table 1 and Rozance and Rabotyagov 2014). In places with less development pressure such as eastern Washington state, however, higher forest values can lower the likelihood of development (Rozance and Rabotyagov 2014).

The impacts of roundwood harvesting on soil carbon are complex. Soil carbon can be affected by management treatments that impact site productivity or cause soil disturbance (Johnson et al. 2002, Jandl et al. 2007, Nabuurs et al. 2007). Conversion of nonforested land to forest generally increases soil carbon stocks, although decreases have been observed in some grassland ecosystems with very high initial soil carbon and in situations where peatland has been drained to allow plantations to be established (Nabuurs et al. 2007). However, in temperate forests, as long as land remains in forest, mineral soil carbon levels generally remain stable even though forest floor carbon levels may be affected by harvesting with the effects being related to changes in species composition and soil taxonomic order (Nave et al. 2010).

A general increase in the demand for biomass for energy could cause a reduction in biomass carbon stocks on the land if the new demand induces forest landowners to convert lands to produce annual or short-rotation biomass energy crops (White et al. 2013). Healthy markets for higher value-added forest products (e.g., lumber, panels, and paper), produced in parallel with wood biomass coproducts (e.g., thinnings and logging slash) that are sources of energy, can help minimize such losses. Munsell and Fox (2010), for instance, found that

> providing biomass for energy from pine plantations on cutover sites is most profitable when intensive management is used to produce a mixture of traditional forest products and biomass for energy

The economic benefit of integrated production of traditional products that help make removal of small diameter trees and other low-value biomass feasible for bioenergy or other purposes is also highlighted in works by Barbour et al. (2008), Evans (2008), Lowell et al. (2008), Nicholls et al. (2008), Abbas et al. (2013), and Aguilar et al. (2013). Although not examined in this review, the effects of changes in forest management on impacts of natural disturbances can also affect the net benefits of biomass energy, although important information gaps in some situations limit the extent to which this can be dealt with quantitatively (Gunn et al. 2014).

Obtaining GHG benefits from use of trees for energy requires retaining wood-producing land in forest. The timing of net CO_2 emissions from forest bioenergy systems and the time required to see net GHG benefits from increased use of trees for energy will depend on many factors including tree size and growth rate, displaced fossil fuel, life cycle GHG emissions from transport, processing and other activities, and the rate at which demand increases and the investment response to that demand. Where large trees are involved, the investment response is weak or not considered and the calculations include foregone sequestration, the net radiative forcing associated with biogenic CO_2 attributable to increased use of trees for energy may be close to that of fossil fuel CO_2 (e.g., estimated 100-year GWP of ≥ 0.9 for slow-growing trees), and in these cases many decades may be required to see net GHG benefits (McKechnie et al. 2011, Mitchell et al. 2012, Lamars and Junginger 2013, Walker et al. 2013). Where tree growth rates are relatively fast and there is a history of landowners responding to increased demand by expanding forest area and improving forest productivity, the net radiative forcing of biogenic CO_2 is far less than that of fossil fuel CO_2. For instance, the estimated 100-year GWP of biogenic CO_2 resulting from increased use of 20-year rotation pine is 0.26 if foregone sequestration is included in the calculation and 0.12 if it is not (Table 3). This does not consider the investment response to increased demand that would be expected to reduce this further. Where the investment response is strong and fast-growing trees are involved, the increased production of energy from a mix of forest biomass that includes trees can produce net GHG benefits within a decade or two, with shorter times being associated with studies that assume investments occur in anticipation of increased demand (Abt et al. 2010, 2012, Daigneault et al. 2012, Nepal et al. 2014).

ED_000419-0007915

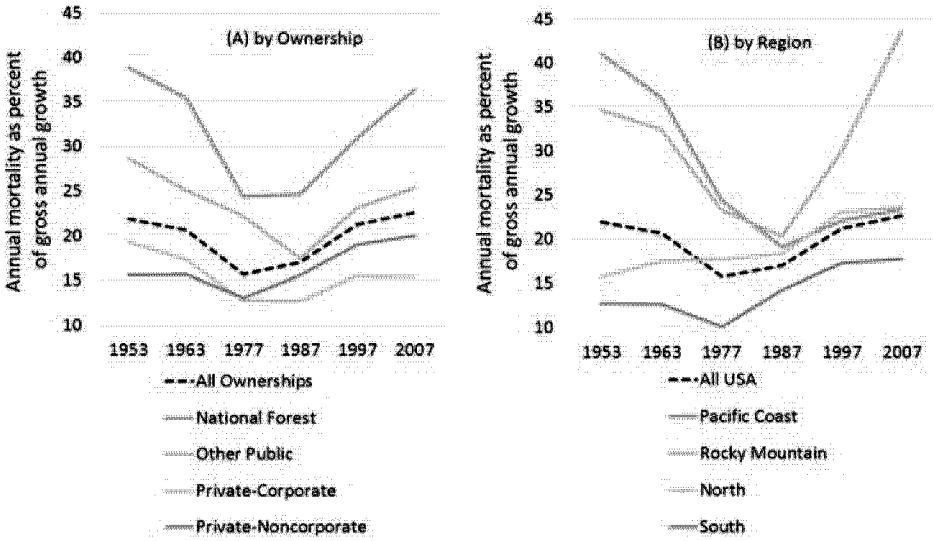


Figure 3. Mortality trends in US forests highlight the need for forest restoration on (A) national forest and other public ownerships, especially (B) in the Rocky Mountain region. The differences in mortality between public and private forests, as well as the regional differences, are probably related, in part, to different levels of investment in working forests which are known to be greater on private land and in the South (data from Smith et al. 2009).[4]

Wood from Federal Land in the West

Tree mortality rates in public forests are higher than the nationwide average (Figure 3A), especially in the Rocky Mountain region (Figure 3B). In the West, the wildfire threat involves more land than is threatened by insects, disease, and development (Kline et al. 2013). As a result of the increasing mortality trend since 1987 and the corresponding potential for large-scale intensive wildfires, there is considerable interest in improving forest conditions on public lands in the West by fuel reduction treatments, particularly thinning (Finkral and Evans 2008, Ager et al. 2010, Coleman et al. 2010, Jones et al. 2010, Oneil and Lippke 2010, Reinhardt and Holsinger 2010).

Because economic returns are a lower priority for public land, revenues from periodic harvesting in public forests are unlikely to influence either the scheduling of treatments to enhance growth or the conversion of forest to other land-use categories. However, markets for timber and biomass may facilitate or accelerate silvicultural treatments to produce conditions that reduce the risks of catastrophic fire, disease, or insect outbreaks. Although thinning treatments for fuel reduction reduce carbon on the landscape, they also reduce the threats of carbon loss from fire, especially in fire-prone areas, as well as from insects and disease (Hurteau et al. 2008, Hurteau and North 2009). The net carbon benefits of fuel reduction treatments are highly site-specific with benefits unlikely in forests that are not fire prone (Mitchell et al. 2009, Ager et al. 2010, Coleman et al. 2010, Jones et al. 2010, Oneil and Lippke 2010). The net carbon benefits of fuel reduction treatments can be enhanced by using the wood to make products or fuels that reduce fossil fuel-related carbon emissions via substitution effects (see references in Research Insight 1). For purposes of carbon accounting, however, if the goal of treatments is viewed as forest restoration then any wood that is not used for timber products can be viewed as logging residue and would have net GHG emissions similar to those of other logging residues, as discussed above.

Mill Residues. The use of biomass manufacturing residues for energy results in very low net impacts from biogenic GHGs. Almost all of these materials are now used for energy. This was not always the case, however. At one time, for instance, teepee or beehive burners were used to dispose of much of the residues produced by saw mills, but by 1992, or earlier, these became "essentially obsolete" (US EPA 1992). History suggests, therefore, that if mill residues were not used for energy, most of these materials would be wastes that would be either incinerated, in which case the atmosphere would see the same biogenic CO_2 emissions as if the material had been burned for energy, or disposed in landfills.

If the alternative to using mill residues for energy is disposing of these materials in landfills, then the net impact of burning for energy on biogenic emissions, in terms of warming (i.e., CO_2 equivalents), can actually be less than zero because of the warming potency of the methane generated in landfills (Gaudreault and Miner 2013). Methane is a far more potent GHG than CO_2, exerting 28 times the radiative forcing of CO_2 over 100 years (IPCC 2013). In some cases, the methane emissions from piles used to store residuals at bioenergy facilities may also need to be considered, and these may reduce the net benefits of using these materials for energy. These emissions appear to be small, however, compared with those from landfills (Pier and Kelly 1997). When assessment is extended to consider all GHGs and fossil fuel substitution, the overall benefits of using manufacturing residuals for energy are large and become evident in short periods (Gaudreault and Miner 2013, Lamars and Junginger 2013).

Large Trees and Bioenergy. Mature forests are important reservoirs of stored carbon (Mackey et al. 2013), and carbon debts associated with using large trees as sources of energy would be expected to be large and require considerable time to overcome (Mitchell et al. 2012). The use of large trees (i.e., those of a size suitable for use as sawtimber), however, is unlikely because of market and economic considerations. Studies have shown that even with substantial demand for forest biomass and conservative supply assumptions, larger and higher valued materials, such as sawtimber, are not likely to be used for energy even if smaller diameter trees, such as those used for pulpwood, may be diverted to the biomass energy market (Abt et al. 2010, Ince et al. 2011).

For instance, a recent forward-looking assessment examining a range of wood energy scenarios included one wherein the use of wood for energy increased by a factor of 3.7 by 2060 to a level at which wood fuel feedstock consumption was slightly greater than all other commercial uses. Even under these conditions, projected sawtimber prices remained above those of nonsawtimber. Only when the use of wood for energy far exceeded all other uses did projected sawtimber and nonsawtimber prices converge (USDA Forest Service 2012, p. 26 and Figure 83). Looking specifically at the southern United States, studies have found that increased demand for biomass energy is un-

ED_000419-0007916

likely to increase the price of small diameter roundwood to even half that of typical prices for sawtimber (Abt et al. 2012, Abt and Abt 2013). Many factors combine to keep prices for biomass used for energy well below prices that would lead to harvest of sawtimber-size material for energy, including the small roundwood supply, the potential for increased utilization of residues, the complementary effect of forest biomass harvest on other products, and the probable supply and management response to higher prices. These factors make it very unlikely that wood suitable as sawtimber, in the southern United States or elsewhere, would be harvested for energy as long as a market for sawtimber is available.

Summary and Conclusions

It has been known for at least 25 years that there are substantial long-term CO_2 reduction benefits from forest bioenergy as long as wood-producing land remains in forest. It has also been known that, in some cases, increased use of forest bioenergy can result in higher near-term CO_2 emissions, causing delays in seeing net benefits. The length of this delay varies considerably, based on physical and biophysical factors, differences in biomass characteristics, and reference conditions.

Recently, researchers have examined forest bioenergy in a broader, integrated framework that also addresses market impacts. Based both on empirical data and modeling, these studies have determined that increased demand often leads to investments in forestry that increase forest area and incentivize improvements in forest management that, depending on circumstances, can also increase forest carbon stocks. This investment response has been found to be especially important in places such as the US South, where economic returns to land have been shown to directly affect gains and losses in forest area.

Recently researchers have also examined metrics for characterizing the impacts from biogenic CO_2 in ways consistent with those used for other GHGs. The research has produced several metrics for calculating 100-year GWPs for biogenic CO_2, reflecting net cumulative radiative forcing. The use of these metrics reveals that as long as land remains in forest, emissions of biogenic CO_2 associated with increased production of forest bioenergy have smaller, and often far smaller, net warming impacts than comparable emissions of CO_2 from fossil fuel.

The logic behind the selection of time horizons for judging the impacts of biogenic CO_2 has been clarified by IPCC, which has found that in the case of CO_2, there is a near linear relationship between cumulative emissions and projected peak global temperatures. The emphasis on near-term reductions in CO_2 emissions primarily reflects concern about the "lock-in" of technologies that do not help reduce cumulative emissions of CO_2 in the longer term. The near-term increases in CO_2 emissions sometimes caused by forest bioenergy are associated with energy systems that *reduce* cumulative emissions in the longer term, something that clearly differentiates them from fossil fuel systems that increase near-term emissions without reducing cumulative emissions.

The research described above provides the basis for a number of generalizations about the GHG impacts to be expected from increased use of different types of forest biomass for energy:

- Under almost all circumstances, the use of biomass residuals from manufacturing has been found to yield low to negative emissions of biogenic GHGs in relatively short times and essentially instantaneous benefits when displacing fossil fuels.
- Net biogenic CO_2 emissions from increased use of forest harvest residues for energy are highly dependent on whether harvest residues would have been burned in the forest or left to decay. When the alternative to using residuals for energy is burning them in the forest, the net emissions of biogenic CO_2 associated with using forest residues for energy are essentially zero, and benefits from displacing fossil fuel occur instantaneously. If the alternative is leaving the material to decay under conditions representative of the eastern United States, the net warming caused by biogenic CO_2 emissions is likely to be in the range of one-third to one-half of that associated with a pulse emission of an equal amount of fossil fuel CO_2. Under these conditions, GHG benefits from using forest residues to produce electricity are generally observed in less than a decade or two. Where decay rates are slower, as appears to be the case in the Pacific Northwest, longer times may be required to see net benefits.
- Considering the economic disincentives to using large trees for energy and the regions expected to provide wood for energy, the types of roundwood anticipated to be used to meet increased demand for bioenergy in the United States are likely to be associated with relatively low net biogenic CO_2 emissions impacts. Where growth rates are relatively high and the investment response is strong, net GHG benefits from increased use of trees for energy can be realized within a decade or two, depending on the fossil fuel being displaced and the timing of the investment response. Where tree growth is slow and the investment response is lacking, many decades may be required to see the net benefits from using roundwood for energy.

Legal, policy, and practical considerations, beyond the scope of this science- and economics-focused review, will affect how biogenic CO_2 is characterized under different laws, regulations, and forest management guidelines. Those working to understand the GHG impacts of increased reliance on forest bioenergy, however, need to consider the following: the relatively low net cumulative emissions impacts associated with increased use of the types of forest biomass most likely to be used for energy in the United States; the importance of the investment response in contributing to these low net emissions; and the possible effect on these investments of policies that attach an emissions liability to biogenic CO_2.

Endnotes

1. IPCC was established by the United Nations Environment Programme and the World Meteorological Organization in 1988 to provide scientific analysis of climate change, including its potential environmental and socioeconomic impacts. IPCC relies on a network of government-nominated scientists from around the world, operates under the auspices of the United Nations, and has a Secretariat located in Geneva, Switzerland.
2. The following sources of data were used to construct Figure 2. The history of changes in US forest carbon stocks is modeled after a similar figure in Birdsey et al. (2006): plotted data do not include below ground carbon; 1630–1930 data and conversion factors are from Birdsey et al. (2006), plotted data are 10-year averages; 1931–1961 data are interpolated; 1962–1987 data are from Birdsey and Heath (1995); and 1990–2010 data are from Table A240, Annex Section 3.13 in US EPA (2013). The statement on industrial roundwood harvesting is based on Ince (2000). Estimates developed before the beginning of the U.S. forest inventory program in the 1930s are likely to be less reliable than those developed since then. Data are available on request.
3. Information about the Massachusetts renewable energy portfolio standards is available online at www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/biomass/renewable-portfolio-standard-biomass-policy.html; last accessed May 24, 2014.

ED_000419-0007917

4. The following are notes on the data in Figure 3. Although annual mortality is often expressed as a percentage of growing stock volume, mortality as a percentage of gross growth is a more useful health indicator (O'Laughlin 1996) because stands can be considered healthy when growth and mortality are appropriately balanced (Norris et al. 1993). Missing from the literature are judgments on appropriate balance, which would vary by stand type and age. However, the mortality/growth rate depicted in Figure 3 is correlated to stand density (significant at the 0.01 level); thus, within any ownership class or region, higher mortality/growth rates can be attributed to denser stands (O'Laughlin and Cook 2003).

Literature Cited

Abbas, D., R. Handler, D. Dykstra, B. Hartsough, and P. Lautala. 2013. Cost analysis of forest biomass supply chain logistics. *J. For.* 111:271–281.

Abt, K.L., R.C. Abt, and C. Galik. 2012. Effect of bioenergy demands and supply response on markets, carbon, and land use. *For. Sci.* 58: 523–539.

Abt, R.C., and K.L. Abt. 2013. Potential impact of bioenergy demand on the sustainability of the southern forest resource. *J. Sustain. For.* 32:175–194.

Abt, R.C., C.S. Galik, and J.D. Henderson. 2010. *The near-term market and greenhouse gas implications of forest biomass utilization in the southeastern United States.* Nicholas School of the Environment, Working Pap. CCPP 10-01, Duke University, Durham, NC. 34 p.

Adams, D.M., R.W. Haynes, and A.J. Daigneault. 2006. *Estimated timber harvest by US region and ownership, 1950–2000.* USDA For. Serv., Gen. Tech. Rep. PNW-GTR-659, Pacific Northwest Research Station, Portland, OR. 64 p.

Ager, A.A., M.A. Finney, A. McMahan, and J. Cathcart. 2010. Measuring the effect of fuel treatments on forest carbon using landscape risk analysis. *Nat. Hazards Earth Syst. Sci.* 10: 2515–2526.

Agostini, A., J. Giuntoli, and A. Boulamanti. 2013. *Carbon accounting for forest bioenergy: Conclusions and recommendations from a critical literature review.* Joint Research Centre Institute for Energy and Transport, Scientific and Policy Rep. EUR 25354, European Commission, Luxembourg, Belgium. 85 p.

Aguilar, F.X., M.J. Daniel, and L.L. Narine. 2013. Opportunities and challenges to the supply of woody biomass for energy from Missouri nonindustrial privately owned forestlands. *J. For.* 111:249–260.

Allen, M.R., D.J. Frame, C. Huntingford, C.D. Jones, J.A. Lowe, M. Meinshausen, and N. Meinshausen. 2009. Letter: Warming caused by cumulative carbon emissions towards the trillionth tonne. *Nature* 458:1163–1166.

Alvarez, M. 2007. *The state of America's forests.* Society of American Foresters, Bethesda, MD. 68 p.

Alvarez, R.A., S.W. Pacala, J.J. Winebrake, W.L. Chameides, and S.P. Hamburg. 2012. Greater focus needed on methane leakage from natural gas infrastructure. *Proc. Natl. Acad. Sci. USA* 109:6435–6440.

Anderegg, W.R.L., J.M. Kane, and L.D.L. Anderegg. 2013. Consequences of widespread tree mortality triggered by drought and temperature stress. *Nat. Clim. Change* 3:30–36.

Barbour, R.J., X. Zhou, and J.P. Prestemon. 2008. Timber product output implications of a program of mechanical fuel treatments applied on public timberland in the western United States. *For. Policy Econ.* 10:373–385.

Bauen, A., G. Berndes, M. Junginger, M. Londo, and F. Vuille. 2009. *Bioenergy—A sustainable and reliable energy source: A review of status and prospects.* International Energy Agency IEA Bioenergy, Rotorua, New Zealand. 108 p.

Beach, R., S. Pattanayak, J. Yang, B. Murray, and R. Abt. 2005. Economic studies of nonindustrial private forest management: A review and synthesis. *For. Policy Econ.* 7:261–281.

Becker, D., D. Erylimaz, J. Klapperich, and M. Kilgore. 2013. Social availability of residual woody biomass from nonindustrial private woodland owners in Minnesota and Wisconsin. *Biomass Bioenergy* 56:82–91.

Bentz, B.J., J. Régniere, C.J. Fettig, E.M. Hansen, J.L. Hayes, J.A. Hicke, R.G. Kelsey, et al. 2010. Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. *Bioscience* 60:602–613.

Berger, A., B. Palik, A. D'Amato, S. Fraver, J. Bradford, K. Nislow, D. King, and R. Brooks. 2013. Ecological impacts of energywood harvests: Lessons from whole-tree harvesting and natural disturbance. *J. For.* 111: 139–153.

Biomass Energy Resource Center. 2012. *Biomass supply and carbon accounting for southeastern forests.* Biomass Energy Resource Center, Montpelier, VT. 123 p. + appendices.

Birdsey, R.A., and L.S. Heath. 1995. Carbon changes in US forests. P. 56–70 in *Productivity of America's forests and climate change,* Joyce, L.A. (ed.). USDA For. Serv., Gen. Tech. Rep. RM-GTR-271, Rocky Mountain Research Station, Fort Collins, CO. 70 p.

Birdsey, R.A., and G.M. Lewis. 2003. Current and historical trends in use, management, and disturbance of US forestlands. P. 15–33 in *The potential of US forest soils to sequester carbon and mitigate the greenhouse effect,* Kimble, J.M., L. Heath, R.A. Birdsey, and R. Lal (eds.). CRC Press, New York.

Birdsey, R., K. Pregitzer, and A. Lucier. 2006. Forest carbon management in the United States: 1600–2100. *J. Environ. Qual.* 35: 1461–1469.

Bradley, G., A. Erickson, A. Robbins, G. Smith, L. Malone, L. Rogers, M. Connor. 2007. Forest land conversion in Washington State. P. 238–302 in *Future of Washington's forest and forest industries study,* Edmonds, R., B. Boyle, B. Lippke, J. Perez-Garcia, I. Eastin, and G. Bradley (principal investigators). College of Forest Resources, University of Washington, Seattle, WA. 406 p.

Bruckner, T., I.A. Bashmakov, Y. Mulugetta, H. Chum, A.D. Navarro, J. Edmonds, A. Faaij, et al. 2014. Energy systems. Chapter 7 in *Climate change 2014: Mitigation of climate change.* Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Edenhofer, O., et al. (eds.). Available online at report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_chapter7.pdf; last accessed August 22, 2014.

Butler, B.J. 2008. *Family forest owners of the United States, 2006.* USDA For. Serv., Gen. Tech. Rep. NRS-27, Northern Research Station, Newtown Square, PA. 72 p.

Clark, L., K. Jiang, K. Akimoto, M. Babiker, G. Blanford, K. Fisher, J. Vanden, J.C. Hourcade, V. Krey, et al. 2014. Assessing transformation pathways. Chapter 6 in *Climate change 2014: Mitigation of climate change.* Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Edenhofer, O., et al. (eds.). Available online at report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_chapter6.pdf; last accessed August 20, 2014.

Confederation of European Paper Industries. 2007. *Bio-energy and the European pulp and paper industry—An impact assessment: A summary of the conclusions of the report.* Confederation of European Paper Industries, Brussels, Belgium. 4 p.

Cherubini, F., N. Bird, A. Cowie, G. Jungmeier, B. Schlamadinger, and S. Woess-Gallasch. 2009. Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. *Res. Conserv. Recycling* 53:434–447.

Cherubini, F., G. Peters, T. Berntsen, A. Strømman, and E. Hertwich. 2011. CO_2 emissions from biomass combustion for bioenergy: Atmospheric decay and contribution to global warming. *Glob. Change Biol. Bioenergy* 3:413–426.

Cleaves, D., T. Haines, and J. Martinez. 1999. Prescribed burning costs: Trends and influences in the National Forest System. P. 277–287 in *Proc. of the Symposium on fire economics, planning, and policy: Bottom lines,* González-Cabán, A., and P. Omi (eds.). USDA For. Serv., Gen. Tech. Rep. PSW-GTR-173, Pacific Southwest Research Station, Albany, CA. 332 p.

Coleman, M., D. Page-Dumroese, J. Archuleta, P. Badger, W. Chung, T. Venn, D. Loeffler, et al. 2010. Can portable pyrolysis units make biomass utilization affordable while using bio-char to enhance soil productivity and sequester carbon? P. 159–168 in *Integrated management of carbon sequestration and biomass utilization opportunities in a changing climate: Proc. of the 2009 National Silviculture Workshop,* Jain, T.B., R. Graham, and J. Sandquist (eds.). USDA For. Serv.,

ED_000419-0007918

Proc. RMRS-P-61, Rocky Mountain Research Station, Ogden, UT. 351 p.

DAIGNEAULT, A., B. SOHNGEN, AND R. SEDJO. 2012. Economic approach to assess the forest carbon implications of biomass energy. *Environ. Sci. Technol.* 46:5664–5671.

DENMAN, K.L., G. BRASSEUR, A. CHIDTHAISONG, P. CIAIS, P.M. COX, R.E. DICKINSON, D. HAUGLUSTAINE, ET AL. 2007. Couplings between changes in the climate system and biogeochemistry. Chapter 7 in *Climate change 2007: The physical science basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Cambridge University Press, Cambridge, UK. 587 p.

DWIVEDI, P., M. KHANNA, R. BAILLIS, AND A. GHILARDI. 2014. Potential greenhouse gas benefits of transatlantic wood pellet trade. *Environ. Res. Lett.* 9(2014):024007. 11 p. Available online at iopscience.iop.org/1748-9326/9/2/024007/pdf/1748-9326_9_2_024007.pdf; last accessed May 13, 2014.

EVANS, A.M. 2008. *Synthesis of knowledge from woody biomass removal case studies: A summary of knowledge from the Joint Fire Science Program.* USDA For. Serv. and Forest Guild, Santa Fe, NM. 39 p.

EVANS, A.M., R.T. PERSCHEL, AND B.A. KITTLER. 2013a. Overview of forest biomass harvesting guidelines. *J. Sustain. For.* 32:89–107.

EVANS, J.M., R.J. FLETCHER JR., J.R.R. ALAVALAPATI, A.L. SMITH, D. GELLER, P. LAL, D. VASUDEV, M. ACEVEDO, J. CALABRIA, AND T. UPADHYAY. 2013b. *Forestry bioenergy in the Southeast United States: Implications for wildlife habitat and biodiversity.* National Wildlife Federation, Merrifield, VA. 275 p.

EUROPEAN UNION. 2009. Directive 2009/28/EC of the European Parliament and of the Council [of the European Union] on the promotion of the use of energy from renewable sources. *Official J. Eur. Union* 5.6.2009. 47 p.

FARGIONE, J., J. HILL, D. TILMAN, S. POLASKY, AND P. HAWTHORNE. 2008. Land clearing and the biofuel carbon debt. *Science* 319:1235–1238.

FIELDING, D., F. CUBBAGE, M.N. PETERSON, D. HAZEL, B. GUGELMANN, AND C. MOORMAN. 2012. Opinions of forest managers, loggers and forest landowners in North Carolina regarding biomass harvesting guidelines. *Int. J. For. Res.* 2012:256141. 15 p. Available online at dx.doi.org/10.1155/2012/256141; last accessed May 13, 2014.

FINKRAL, A.J., AND A.M. EVANS. 2008. Effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest. *For. Ecol. Manage.* 255:2743–2750.

FORSTER, P., V. RAMASWAMY, P. ARTAXO, T. BERNTSEN, R. BETTS, D.W. FAHEY, J. HAYWOOD, ET AL. 2007. Changes in atmospheric constituents and in radiative forcing. Chapter 2 in *Climate change 2007: The physical science basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Cambridge University Press, Cambridge, UK. 234 p.

FOX, T.R., E.J. JOKELA, AND H.L. ALLEN. 2004. The evolution of pine plantation silviculture in the southern United States. P. 63–82 in *Southern forest science: Past, present, and future*, Rauscher, H.M., and K. Johnsen (eds.). USDA For. Serv., Gen. Tech. Rep. SRS-75, Southern Research Station, Asheville, NC. 394 p.

GALIK, C.S., AND R.C. ABT. 2012. The effect of assessment scale and metric selection on the greenhouse gas benefits of woody biomass. *Biomass Bioenergy* 44:1–7.

GAUDREAULT, C., B. MALMBERG, B. UPTON, AND R. MINER. 2012. Life cycle greenhouse gases and non-renewable energy benefits of kraft black liquor recovery. *Biomass Bioenergy* 46:683–692.

GAUDREAULT, C., AND R. MINER. 2013. *Greenhouse gas and fossil fuel reduction benefits of using biomass manufacturing residues for energy production in forest products manufacturing facilities.* National Council for Air and Stream Improvement, Inc., Tech. Bull. 1016, Research Triangle Park, NC. 74 p.

GIBBS, H., M. JOHNSTON, J. FOLEY, T. HOLLOWAY, C. MONFREDA, N. RAMANKUTTY, AND D. ZAKS. 2008. Carbon payback times for crop-based biofuel expansion in the tropics: The effects of changing yield and technology. *Environ. Res. Lett.* 3(2008):034001. 10 p. Available online at iopscience.iop.org/1748-9326/3/3/034001/pdf/1748-9326_3_3_034001.pdf; last accessed May 13, 2014.

GUNN, J.S., M.J. DUCEY, AND A.A. WHITMAN. 2014. Late-successional and old-growth forest carbon temporal dynamics in the Northern Forest (Northeastern USA). *For. Ecol. Manage.* 312:40–46.

HARDIE, I., P. PARKS, P. GOTTLEIB, AND D. WEAR. 2000. Responsiveness of rural and urban land uses to land rent determinants in the US South. *Land Econ.* 76:659–673.

HAYNES, R.W., D.M. ADAMS, R.J. ALIG, P.J. INCE, J.R. MILLS, AND X. ZHOU. 2007. *The 2005 RPA timber assessment update.* USDA For. Serv., Gen. Tech. Rep. PNW-GTR-699, Pacific Northwest Research Station, Portland, OR. 212 p.

HELIN, T., L. SOKKA, S. SOIMAKALLIO, K. PINGOUD, AND T. PAJULA. 2013. Approaches for inclusion of forest carbon cycle in life cycle assessment—A review. *Glob. Change Biol. Bioenergy* 5:475–486.

HURTEAU, M., AND M. NORTH. 2009. Fuel treatment effects on tree-based forest carbon storage and emissions under modeled wildfire scenarios. *Front. Ecol. Environ.* 7:409–414.

HURTEAU, M.D., G.W KOCH, AND B.A. HUNGATE. 2008. Carbon protection and fire risk reduction: Toward a full accounting of forest carbon offsets. *Front. Ecol. Environ.* 6:493–498.

INCE, P. 2000. *Industrial wood productivity in the United States, 1900–1998.* USDA For. Serv., Res. Note FPL-RN-0272, Madison, WI. 14 p.

INCE, P.J. 2010. Global sustainable timber supply and demand. P. 29–41 in *Sustainable development in the forest products industry*, Rowell, R.M., F. Caldeira, and J.K. Rowell (eds.). Universidade Fernando Pessoa, Portal, Portugal. 281 p.

INCE, P.J., A.D. KRAMP, K.E. SKOG, D. YOO, AND V.A. SAMPLE. 2011. Modeling future US forest sector market and trade impacts of expansion in wood energy consumption. *J. For. Econ.* 17:142–156.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). 1990. *Climate change: The IPCC response strategies.* Contribution of Working Group III of the Intergovernmental Panel on Climate Change, Bernthal, F.M. (chmn.). Intergovernmental Panel on Climate Change, Geneva, Switzerland. 269 p.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). 2012. *Renewable energy sources and climate change mitigation.* Special report prepared by Working Group III of the Intergovernmental Panel on Climate Change, Edenhofer, O., R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, et al. (eds.). Cambridge University Press, Cambridge, UK. 1075 p.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). 2013. *Climate change 2013: The physical science basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, et al. (eds.). Cambridge University Press, Cambridge, UK and New York. 1535 p.

INTERNATIONAL ENERGY ASSOCIATION. 2014. *United Kingdom renewables obligation 2002, last amended 2009.* IEA/IRENA Joint Policies and Measures database. Available online at www.iea.org/policiesandmeasures/renewableenergy/?country=United Kingdom; last accessed May 15, 2014.

JANDL, R., M. LINDNER, L. VESTERDAL, B. BAUWENS, R. BARITZ, F. HAGEDORN, D. JOHNSON, ET AL. 2007. How strongly can forest management influence soil carbon sequestration? *Geoderma* 137:253–268.

JOHNSON, D., J. KNOEPP, W. SWANK, J. SHAN, L. MORRIS, D. VANLEAR, AND P. KAPELUCK. 2002. Effects of forest management on soil carbon: Results of some long-term sampling studies. *Environ. Pollut.* 116(Suppl. 1):S201–S208.

JONES, G., D. LOEFFLER, D. CALKIN, AND W. CHUNG. 2010. Forest treatment residues for thermal energy compared with disposal by on-site burning: Emissions and energy return. *Biomass Bioenergy* 34:737–746.

JOSHI, O., AND S. MEHMOOD. 2011. Factors affecting nonindustrial private forest landowners' willingness to supply woody biomass for bioenergy. *Biomass Bioenergy* 35:186–192.

JOYCE, L.A., S.W. RUNNING, D.D. BRESHEARS, V.H. DALE, R.W. MALMSHEIMER, R.N. SAMPSON, B. SOHNGEN, AND C.W. WOODALL. 2014. Forests. P. 175–194 in *Climate change impacts in the United States: The third national climate assessment*, Melillo, J.M., T.C. Richmond, and G.W. Yohe (eds.). US Global

ED_000419-0007919

Change Research Program, Washington, DC. 829 p.

KIRKINEN, J., T. PALOSUO, K. HOLMGREN, AND I. SAVOLAINEN. 2008. Greenhouse impact due to the use of combustible fuels: Life cycle viewpoint and relative radiative forcing commitment. *Environ. Manage.* 42:458–469.

KLINE, J.D., B.K. KERNS, M.A. DAY, AND R.B. HAMMER. 2013. Mapping multiple forest threats in the Northwestern United States. *J. For.* 111:206–213.

LAMARS, P., AND M. JUNGINGER. 2013. The 'debt' is in the detail: A synthesis of recent temporal forest carbon analyses on woody biomass for energy. *Biofuels Bioproducts Biorefining* 7:373–385.

LANGPAP, C. 2006. Conservation of endangered species: Can incentives work for private landowners? *Ecol. Econ.* 57:558–572.

LATTA, G., J. BAKER, R. BEACH, S. ROSE, AND B. MCCARL. 2013. A multi-sector intertemporal optimization approach to assess the GHG implications of US forest and agricultural biomass electricity expansion. *J. For. Econ.* 19: 361–383.

LEBLANC, S. 2010. *Mass. study: Wood worse polluter than coal.* Associated Press, Boston, MA, June 11. Available online at www.boston.com/yourtown/cambridge/articles/2010/06/11/mass_study_wood_power_worse_polluter_than_coal/; last accessed May 13, 2014.

LETTMAN, G., D.L. AZUMA, K.R. BIRCH, A.A. HERSTROM, AND J.D. KLINE. 2002. *Land use change on non-federal land in western Oregon, 1973–2000.* Oregon Department of Forestry, Salem, OR. 48 p.

LEVASSEUR, A., P. LESAGE, M. MARGNI, L. DESCHENES, AND R. SAMSON. 2010. Considering time in LCA: Dynamic LCA and its application to global warming impact assessments. *Environ. Sci. Technol.* 44:3169–3174.

LIPPKE, B., R. GUSTAFSON, R. VENDITTI, P. STEELE, T.A. VOLK, E. ONEIL, L. JOHNSON, M.E. PUETTMANN, AND K. SKOG. 2012. Comparing life-cycle carbon and energy impacts for biofuel, wood product, and forest management alternatives. *For. Prod. J.* 62:247–257.

LOEHLE, C., T.B. WIGLEY, E. SCHILLING, V. TATUM, J. BEEBE, E. VANCE, P. VAN DEUSEN, AND P. WEATHERFORD. 2009. Achieving conservation goals in managed forests of the Southeastern Coastal Plain. *Environ. Manage.* 44:1136–1148.

LOWELL, E.C., D.R. BECKER, D. LARSON, R. RUMMER, AND L. WADLEIGH. 2008. An integrated approach to evaluating the economic costs of wildfire hazard reduction through wood utilization opportunities in the southwestern United States. *For. Sci.* 54:273–283.

LUBOWSKI, R.N., A.J. PLANTINGA, AND R.N. STAVINS. 2008. What drives land-use change in the United States? A national analysis of landowner decisions. *Land Econ.* 84:529–550.

LUO, Y., B. SU, W.S. CURRIE, J.S. DUKES, A. FINZI, U. HARTWIG, B. HUNGATE, ET AL. 2004. Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. *Bioscience* 54:731–739.

MACKEY, B., I.C. PRENTICE, W. STEFFEN, J.I. HOUSE, D. LINDENMAYER, H. KEITH, AND S. BERRY. 2013. Untangling the confusion around land carbon science and climate change mitigation policy. *Nat. Clim. Change* 3:552–557.

MALMSHEIMER, R.W., J.L. BOWYER, J.S. FRIED, E. GEE, R.L. IZLAR, R.A. MINER, I.A. MUNN, E. ONEIL, AND W.C. STEWART. 2011. Managing forests because carbon matters: Integrating energy, products, and land management policy. *J. For.* 109(7S):S7–S50.

MARLAND, G. 1989. The role of forests in addressing CO_2 greenhouse. P. 199–212 in *Global climate change linkages: Acid rain, air quality, and stratospheric ozone*, White, J.C., W.R. Wagner, and C.N. Beal (eds.). Elsevier, New York. 272 p.

MARLAND, G., AND B. SCHLAMADINGER. 1997. Forests for carbon sequestration or fossil fuel substitution? A sensitivity analysis. *Biomass Bioenergy* 13:389–397.

MCKECHNIE, J., S. COLOMBO, J. CHEN, W. MABEE, AND H. MACLEAN. 2011. Forest bioenergy or forest carbon? Assessing the trade-offs in greenhouse gas mitigation with wood-based fuels. *Environ. Sci. Technol.* 2011:789–795.

MCNULTY, S.G. 2002. Hurricane impacts on US forest carbon sequestration. *Environ. Pollut.* 116:S17–S24.

MEINSHAUSEN, M., N. MEINSHAUSEN, W. HARE, S.C.B. RAPER, K. FRIELER, R. KNUTTI, D.J. FRAME, AND M.R. ALLEN. 2009. Letter: Greenhouse-gas emission targets for limiting global warming to 2° C. *Nature* 458:1158–1162.

MICKLER, R.A., J.E. SMITH, AND L.S. HEATH. 2004. Forest carbon trends in the southern United States. P. 383–394 in *Southern forest science: Past, present, and future*, Rauscher, H.M., and K. Johnsen (eds.). USDA For. Serv., Gen. Tech. Rep. SRS-75, Southern Research Station, Asheville, NC. 394 p.

MILLER, K., S. SNYDER, AND M. KILGORE. 2012. An assessment of forest landowner interest in selling forest carbon credits in the Lake States, USA. *For. Policy Econ.* 25:113–122.

MITCHELL, S.R., M.E. HARMON, AND K.E.B. O'CONNELL. 2009. Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems. *Ecol. Appl.* 19:643–655.

MITCHELL, S.R., M.E. HARMON, AND K.E.B. O'CONNELL. 2012. Carbon debt and carbon sequestration parity in forest bioenergy production. *Glob. Change Biol. Bioenergy* 4:818–827.

MUNSELL, J., AND T. FOX. 2010. An analysis of the feasibility for increasing woody biomass production from pine plantations in the southern United States. *Biomass Bioenergy* 34:1631–1642.

NABUURS, G.J., O. MASERA, K. ANDRASKO, P. BENITEZ-PONCE, R. BOER, M. DUTSCHKE, E. ELSIDDIG, ET AL. 2007. Forestry. Chapter 9 in *Climate change 2007: Mitigation.* Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds.). Cambridge University Press, Cambridge, UK. 584 p.

NABUURS, G.J., M. LINDNER, P.J. VERKERK, K. GUNIA, P. DEDA, R. MICHALAK, AND G. GRASSI. 2013. First signs of carbon sink saturation in European forest biomass. *Nat. Clim. Change* 3:792–796.

NAVE, L., E. VANCE, C. SWANSTON, AND P. CURTIS. 2010. Harvest impacts on soil carbon storage in temperate forests. *For. Ecol. Manage.* 259:857–866.

NEGRÓN-JUÁREZ, R., D.B. BAKER, H.C. ZENG, T.K. HENKEL, AND J.Q. CHAMBERS. 2010. Assessing hurricane-induced tree mortality in US Gulf Coast forest ecosystems. *J. Geophys. Res. Biogeosci.* 115:1–11.

NEPAL, P., P.J. INCE, K.E. SKOG, AND S.J. CHANG. 2012. Projection of US forest sector carbon sequestration under US and global timber market and wood energy consumption scenarios, 2010–2060. *Biomass Bioenergy* 45:251–264.

NEPAL, P., D. WEAR, AND K. SKOG. 2014. Net change in carbon emissions with increased wood energy use in the United States. *Glob. Change Biol. Bioenergy.* doi: 10.1111/gcbb.12193.

NICHOLLS, D.L., R.A. MONSERUD, AND D.P. DYKSTRA. 2008. *A synthesis of biomass utilization for bioenergy production in the western states.* USDA For. Serv., Gen. Tech. Rep. PNW-GTR-753, Pacific Northwest Research Station, Portland, OR. 48 p.

NORBY, R.J., J.M. WARREN, C.M. IVERSEN, B.E. MEDLYN, AND R.E. MCMURTRIE. 2010. CO_2 enhancement of forest productivity constrained by limited nitrogen availability. *Proc. Natl. Acad. Sci. USA* 107:19368–19373.

NORRIS, L.A., H. CORTNER, M.R. CUTLER, S.G. HAINES, J.E. HUBBARD, M.A. KERRICK, W.B. KESSLER, ET AL. 1993. *Sustaining long-term forest health and productivity.* Task Force Rep. Society of American Foresters, Bethesda, MD. 83 p.

O'LAUGHLIN, J. 1996. Forest ecosystem health assessment: Definition, measurement and management implications. *Ecosyst. Health* 2(1):19–39.

O'LAUGHLIN, J., AND P.S. COOK. 2003. Inventory-based forest health indicators: Implications for national forest management. *J. For.* 101(2):11–17.

ONEIL, E.E., AND B.R. LIPPKE. 2010. Integrating products, emissions offsets, and wildfire into carbon assessments of inland northwest forests. *Wood Fiber Sci.* 42:144–164.

PEREZ-GARCIA, J.M., J. EDELSON, AND K. ZOBRIST. 2001. *New proposed forest practices rules small business economic cost statement.* Washington State Department of Natural Resources, Olympia, WA. 37 p. + appendices.

PEREZ-GARCIA, J., B. LIPPKE, J. COMNICK, AND C. MANRIQUEZ. 2005. An assessment of carbon pools, storage, and products market substitution using life-cycle results. *Wood Fiber Sci.* 37: 140–148.

PIER, P., AND J. KELLY. 1997. Measured and estimated methane and carbon dioxide emissions from sawdust waste in the Tennessee Valley

ED_000419-0007920

under alternative management strategies. *Bioresour. Technol.* 61:213–220.

RADTKE, P., R. AMATEIS, S. PRISLEY, C. COPENHEAVER, D. CHOJNACKY, J. PITTMAN, AND H. BURKHART. 2009. Modeling production and decay of coarse woody debris in loblolly pine plantations. *For. Ecol. Manage.* 257:790–799.

REICH, P.B., B.A. HUNGATE, AND Y. LUO. 2006. Carbon-nitrogen interactions in terrestrial ecosystems in response to rising atmospheric carbon dioxide. *Annu. Rev. Ecol. Evol. Syst.* 37: 611–636.

REINHARDT, E., AND L. HOLSINGER. 2010. Effects of fuel treatments on carbon-disturbance relationships in forests of the northern Rocky Mountains. *For. Ecol. Manage.* 259:1427–1435.

REPO, A., R. KANKANEN, J. TUOVINEN, R. ANTIKAINEN, M. TUOMI, P. VANHALA, AND J. LISKI. 2012. Forest bioenergy climate impact can be improved by allocating forest residue removal. *GCB Bioenergy* 4:202–212.

ROZANCE, M.A., AND S.S. RABOTYAGOV. 2014. Washington State small forest landowners: Who intends to develop their forestlands and when? *J. For.* doi: http://dx.doi.org/10.5849/jof.12-103.

RUSSELL, M., C. WOODALL, S. FRAVER, A. D'AMATO, G. DOMKE, AND K. SKOG. 2014. Residence times and decay rates of downed woody debris biomass/carbon in eastern US forests. *Ecosystems* 17:765–777.

RYAN, M.G., M.E. HARMON, R.A. BIRDSEY, C.P. GIARDINA, L.S. HEATH, R.A. HOUGHTON, R.B. JACKSON, ET AL. 2010. A synthesis of the science on forests and carbon for US forests. *Issues Ecol.* 13:1–16.

SATHRE, R., AND J. O'CONNOR. 2010. Meta-analysis of greenhouse gas displacement factors of wood product substitution. *Environ. Sci. Policy* 13:104–114.

SCHLAMADINGER, B., AND G. MARLAND. 1996. The role of forest and bioenergy strategies in the global carbon cycle. *Biomass Bioenergy* 10: 275–300.

SEARCHINGER, T., S.P. HAMBURG, J. MELILLO, W. CHAMEIDES, P. HAVLIK, D.M. KAMMEN, G.E. LIKENS, ET AL. 2009. Policy forum: Fixing a critical climate accounting error. *Science* 326: 527–528.

SEDJO, R., AND X. TIAN. 2012. Does wood bioenergy increase carbon stocks in forests? *J. For.* 110:304–311.

SMITH, J., L. HEATH, K. SKOG, AND R. BIRDSEY. 2006. *Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States.* USDA For. Serv., Gen. Tech. Rep. NE-343, Northeastern Research Station, Newtown Square, PA. 216 p.

SMITH, P., M. BUSTAMANTE, H. AHAMMAD, H. CLARK, H. DONG, E.A. ELSIDDIG, H. HABERL, R. HARPER, ET AL. 2014. Agriculture, forestry and other land use (AFOLU). Chapter 11 in *Climate change 2014: Mitigation of climate change.* Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Edenhofer, O., et al. (eds.). Available online at report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_chapter11.pdf; last accessed August 22, 2014.

SMITH, W.B., P.D. MILES, C.H. PERRY, AND S.A. PUGH. 2009. *Forest resources of the United States, 2007.* USDA For. Serv., Gen. Tech. Rep. WO-78, Washington, DC. 336 p.

SPELTER, H., AND D. TOTH. 2009. *North America's wood pellet sector.* USDA For. Serv., Res. Pap. FPL-RP-656, Forest Products Laboratory, Madison, WI. 21 p.

UPTON, B., R. MINER, M. SPINNEY, AND L. SMITH. 2008. The greenhouse gas and energy impacts of using wood instead of alternatives in residential construction in the United States. *Biomass Bioenergy* 32:1–10.

USDA FOREST SERVICE. 2012. *Future of America's forest and rangelands: Forest Service 2010 Resources Planning Act assessment.* USDA For. Serv., Gen. Tech. Rep. WO-87, Washington, DC. 198 p.

US ENVIRONMENTAL PROTECTION AGENCY. 1992. Emission factors for waste incineration in conical burners without controls. In *Compilation of air pollutant emission factors, AP-42.* 3 p. Available online at www.epa.gov/ttnchie1/ap42/ch02/final/c02s07.pdf; last accessed May 15, 2014.

US ENVIRONMENTAL PROTECTION AGENCY. 2012. *SAB review of EPA's accounting framework for biogenic CO_2 emissions from stationary sources: Report to the EPA administrator.* US Environmental Protection Agency Science Advisory Board, Washington, DC. 49 p. + appendices.

US ENVIRONMENTAL PROTECTION AGENCY. 2013. *Inventory of US greenhouse gas emissions and sinks: 1990–2011.* EPA 430-R-13-001, Washington, DC.

US DEPARTMENT OF AGRICULTURE/US DEPARTMENT OF THE INTERIOR/NATIONAL ASSOCIATION OF STATE FORESTERS. 2009. *Quadrennial fire review 2009.* Washington, DC. 44 p. + appendices.

VAN DEUSEN, P., T. WIGLEY, AND A. LUCIER. 2012. Cumulative effects of constraints on forest management. *J. For.* 110:123–128.

VAUGHAN, N.E., T.M. LENTON, AND J.G. SHEPHERD. 2009. Climate change mitigation: Trade-offs between delay and strength of action required. *Clim. Change* 96:29–43.

WALKER, T., P. CARDELLICHIO, J.S. GUNN, D.S. SAAHD, AND J.M. HAGAN. 2013. Carbon accounting for woody biomass from Massachusetts (USA) managed forests: A framework for determining the temporal impacts of wood biomass energy on atmospheric greenhouse gas levels. *J. Sustain. For.* 32:130–158.

WEAR, D.N., AND J.G. GREIS. 2012. *The Southern Forest Futures Project: Summary report.* USDA For. Serv., Gen. Tech. Rep. SRS-GTR-168, Southern Research Station, Asheville, NC. 54 p.

WHITE, E., G. LATTA, R. ALIG, K. SKOG, AND D. ADAMS. 2013. Biomass production from the US forest and agriculture sectors in support of a renewable electricity standard. *Energy Policy* 58:64–74.

WISER, R., C. NAMOVICZ, M. GIELECKI, AND R. SMITH. 2007. *Renewables portfolio standards: A factual introduction to experience from the United States.* US Department of Energy, Rep. LBNL-63569, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA. 15 p.

WOOD RESOURCES INTERNATIONAL. 2014. North American wood pellet exports to Europe double in two years. *Biomass Mag.* May 6. Available online at biomassmagazine.com/articles/10311/north-american-wood-pellet-exports-to-europe-double-in-2-years; last accessed May 15, 2014.

ZANCHI, G., N. PENA, AND N. BIRD. 2012. Is woody bioenergy carbon neutral? A comparative assessment of emissions from consumption of woody bioenergy and fossil fuel. *Glob. Change Biol. Bioenergy* 4:761–772.

ZHANG, D., AND W.A. FLICK. 2010. Sticks, carrots, and reforestation investment. *Land Econ.* 77:443–456.

ZIMMERMAN, G. 2004. *Dynamics of coarse woody debris in North American forests: A literature review.* National Council for Air and Stream Improvement, Inc., Tech. Bull. No. 877, Research Triangle Park, NC. 55 p.

ZOBRIST, K.W., AND B.R. LIPPKE. 2007. Economic costs of different riparian management regulations in the Pacific Northwest. *West. J. Appl. For.* 22:36–41.

ED_000419-0007921

Wood Bioenergy Markets and Forestland Owner Decisions: 2010 - 2013

Commissioned by:

National Alliance of Forest Owners
Washington, D.C. 20001
www.nafoalliance.org

Conducted by:

Forisk Consulting
Athens, GA 30604
www.forisk.com

Principal investigators:
Brooks Mendell, Ph.D.,
bmendell@forisk.com
Amanda Hamsley Lang,
ahlang@forisk.com

ED_000419-0007922

Executive Summary

This research spotlights how U.S. wood bioenergy markets evolved relative to the existing forest products industry since 2010. Observers worry about wood feedstock competition, unintended consequences from bioenergy-related policies and changing forest landowner behaviors. However, the data finds wood bioenergy markets evolving slowly with failures outnumbering successes since 2010, and traditional forestland management strategies seemingly unchanged. The U.S. biopower sector in particular is relatively "fragile" given low natural gas prices, financing challenges resulting from the recession, and regulatory uncertainty.

Key findings in this white paper include:

- Woody feedstock consumed by bioenergy projects
  - Wood bioenergy, currently and as projected, accounts for a small portion of wood use. U.S. forest industry mills consume ~500 million tons per year of logs and wood chips from forestry operations. In 2023, pulpwood and logging residue use from viable bioenergy applications could range from 4% to 9% of the total wood use of the forestry sector. Of this 9%, pellets bound offshore represent 3% and other domestic bioenergy applications represent 6%.
- Forest management and landowner decisions
  - Analysis suggests that landowners will continue current forest management strategies, which target higher-valued sawtimber products, rather than managing for pure pulpwood plantations.
  - Breakeven analysis indicates that South-wide average pine pulpwood prices in 2018 need to exceed $17.67 per ton for landowners to be economically indifferent between managing purely for pulpwood versus a traditional sawtimber strategy. This price will vary across local markets as it relies on the relative difference between prices for pulpwood and higher-valued products such as chip-n-saw and sawtimber.
  - This level of pine pulpwood price requires projected demand of wood for energy to double from ~24 million green tons of pulpwood in 2018 (as currently projected by Forisk) to ~48 million green tons.
- Wood bioenergy market development and renewable energy policies
  - Since 2010, more wood bioenergy projects were cancelled or delayed in the U.S. than were successfully built and operated. Most failures and project delays resulted from unfavorable project economics due to cheap natural gas, unavailable financing, and legislative uncertainties.
  - At the state level, wood bioenergy represents a small portion of total energy generation. Federal or state policies treating biomass emissions the same as fossil fuel emissions could impede the already slowly developing wood bioenergy markets by perpetuating uncertainty and further restricting available financing.

About Forisk Consulting

Forisk provides research and educational services to executives and analysts in the forest industry, wood bioenergy and timberland investing sectors. Forisk specializes in understanding and quantifying local wood and timber markets throughout the United States.

About the National Alliance of Forest Owners (NAFO)

NAFO is an organization of private forest owners committed to advancing national policies that promote the economic and environmental benefits of privately-owned forests. NAFO membership encompasses more than 80 million acres of private forestland in 47 states.

Introduction

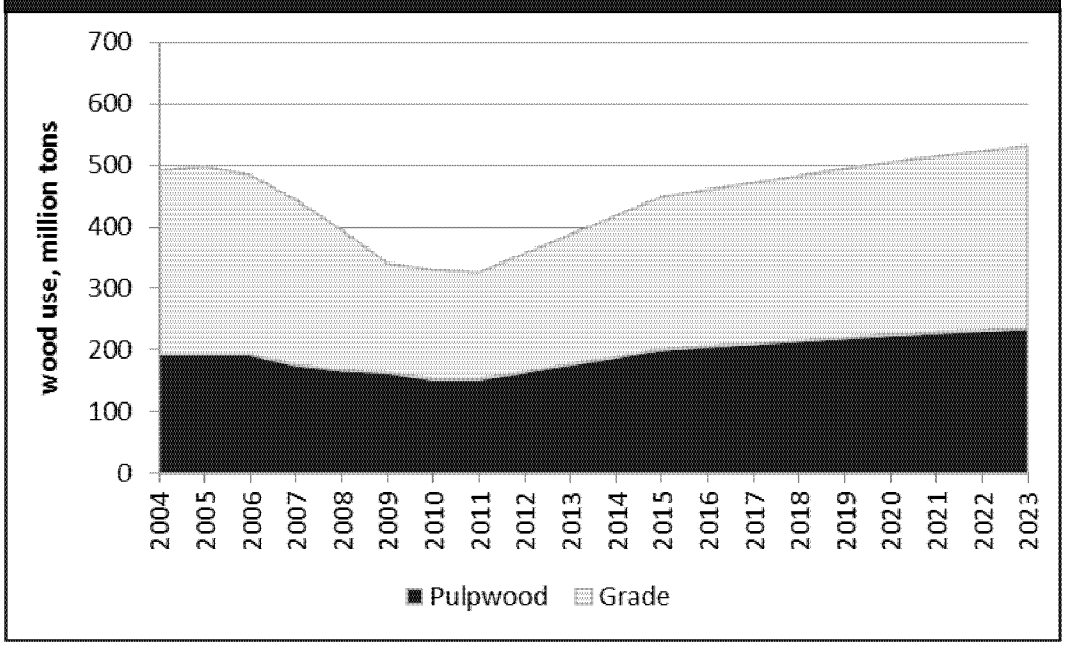
In this white paper, we evaluate the progress of U.S. wood bioenergy markets and update previous analysis of forest landowner behaviors in response to growing wood demand from bioenergy.

The research spotlights how U.S. wood bioenergy markets actually evolved relative to the existing forest products industry since 2010. Bioenergy market observers worry about wood feedstock competition, unintended consequences from bioenergy-related policies and changing forest landowner behaviors. However, the data finds wood bioenergy markets evolving slowly with failures outnumbering successes since 2010, and traditional forestland management strategies seemingly unchanged. Overall, wood bioenergy will advance as a small, but important, component of total wood consumption in the United States.

Wood Use Trends in Bioenergy Markets

Private forest owners have long-established forest industry customers for the trees grown on their lands. These include manufacturers of pulp and paper, lumber and other wood-based building products. During "normal" economic conditions, the U.S. forest products industry harvests and consumes ~500 million green tons of wood per year[1]. Figure 1 shows the 34% decline from 2005 to 2010 during the economic recession and housing market collapse, and the subsequent 17% increase in wood use since 2010 through 2013. Projections estimate that wood use in the U.S. forest industry return and exceed 2005 levels between 2018 and 2020.

Figure 1. Forest Industry Wood Use, 2004 – 2023, green tons



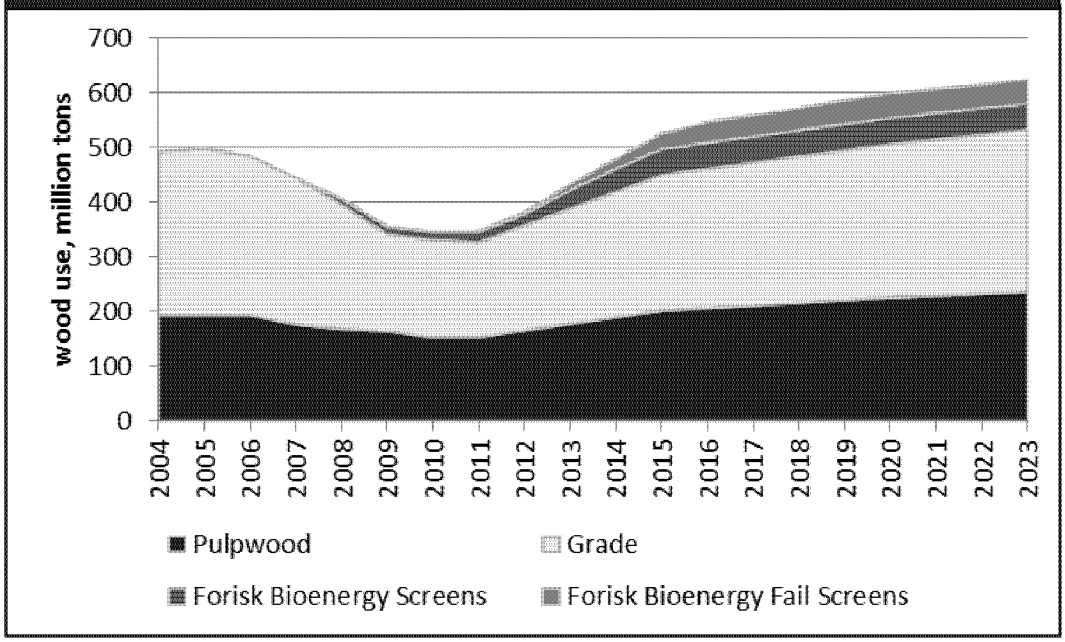
Sources: U.S. Forest Service, Forisk Consulting
Note: "grade" includes chip-n-saw and sawtimber

[1] Wood volumes in this report are in green U.S. short tons. See Appendix 1 for guidance to convert green tons to dry tons.

ED_000419-0007924

Developing bioenergy markets are not significantly affecting the use and demand for wood in the U.S. Since 2010, wood use for bioenergy relative to the forest products industry has been modest as multiple projects opened, closed or advanced towards becoming viable operations. Of the 442 operating biomass plants and announced projects in the U.S. as of December 2013, 290 (66%) pass basic viability screens and development milestones.[2] Figure 2 shows the projected marginal increase in wood use from bioenergy projects that pass Forisk screens (in green) and the total potential wood use relative to traditional forest industry use if every known, announced project succeeded (gray).

Figure 2. Forest Industry and Bioenergy Wood Use Projections, 2004 – 2023, green tons*



Sources: U.S. Forest Service, Forisk Consulting (*Wood Bioenergy US*)
*Wood use specific to raw material "from the forest" (i.e. pulpwood and logging residues).
Note: "grade" includes chip-n-saw and sawtimber

By 2023, wood use from bioenergy (primarily forest residuals and pulpwood) could range from 4% to 9% of total forest materials use in the U.S. Currently announced or operating export pellet facilities could use 15 million green tons of pulpwood by 2023, or 3% of total forest industry consumption, while other domestic bioenergy plants could use 37 million tons of pulpwood and forest residuals, or 6% of industry use.

In addition to wood raw material "from the forest", some forest products and bioenergy firms use manufacturing residuals – such as chips, sawdust and bark – for their own manufacturing or energy generation purposes. Manufacturing residuals flow into three primary end uses:

1) **Paper and paperboard manufacturing**, which includes all paper, containerboard and cardboard types produced in the U.S.

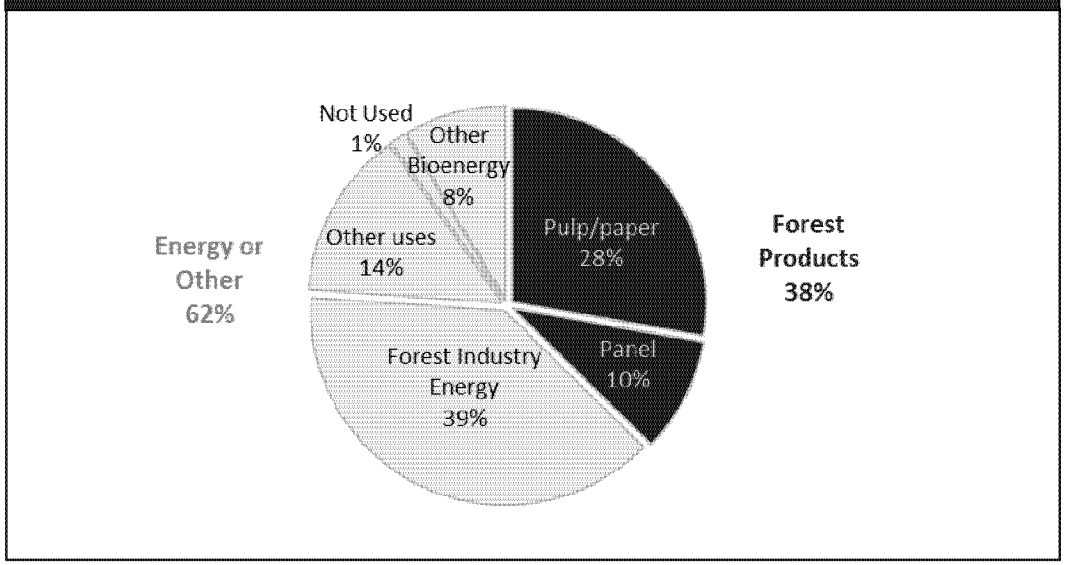
[2] Forisk tracks and screens all operating and announced wood bioenergy projects in the U.S. to assess project viability, and documented the methodology in a NAFO white paper (Mendell and Lang 2010). The method relies on two criteria: technology (does the project employ currently viable technology?) and status (does the project satisfy basic milestones requires for construction?).

ED_000419-0007925

2) **Composite panels production (particleboard, MDF)**, and other types of engineered structural panels that rely primarily on manufacturing residuals for raw material.
3) **Wood use for bioenergy,** at both forest industry and bioenergy plants, including the production of electricity directly and the production of wood pellets as a fuel.

Just as wood for bioenergy reflects a small percentage of the total use of wood and forest residuals in the forest industry (Figure 2), the use of manufacturing residuals by wood bioenergy firms represents a small portion of the total use of manufacturing residuals in forest industry manufacturing and energy applications (Figure 3). Of the mill residues used today, the forest industry uses 28% to make pulp or chip products, and 10% to manufacture composite panels. 39% of the residues are used as fuel to generate energy at forest industry manufacturing facilities, while another 8% of the residues go to other bioenergy uses, largely wood pellet production. In addition to the volumes in Figure 3, proposed bioenergy plants that pass Forisk screens would only use an additional 2% of mill residues by 2023.

Figure 3. Relative Use of Mill Residues for Manufacturing and Bioenergy



Sources: U.S. Forest Service, Forisk Consulting, Composite Panel Association
Note: other bioenergy includes stand-alone electricity facilities, co-firing at power plants, CHP plants other than forest industry, and pellet plants.

A portion of wood bioenergy and pellet generation rely on mill residuals; however, pulpwood, clean chips and logging residuals remain the primary feedstocks for wood bioenergy projects.

Forest Management and Landowner Decisions

Given the potential role of pulpwood in bioenergy markets, it is important to understand the relationship between pulpwood demand for bioenergy and the extent to which wood bioenergy markets might affect landowner behavior and current private forestland management.

Forestland owners consistently make management decisions with respect to long-term economics. Current owners manage forests to grow sawtimber; a high-valued product from large, straight trees used to make lumber and plywood. Pulpwood is a lower-valued product from small or deformed trees used to make pulp, paper, or engineered building materials such as OSB panels. Typically, pulpwood is produced when landowners cull smaller trees from the

forest during a treatment called a forest thinning. Given bioenergy project announcements, there is an interest in how landowners may change management strategies to produce more pulpwood to sell to bioenergy firms.

In 2010, Clutter et al. modeled forest owner behavior in light of evolving bioenergy markets and concluded, "…landowner responses clearly increase supply and decrease raw materials costs in the long-run…" In a 2011 NAFO white paper, Mendell et al. evaluated how wood biomass markets in the South must grow to affect forest management decisions. The study found that average pine pulpwood prices needed to increase 49% for landowners to be economically indifferent between pulpwood and sawtimber forest management.[3] Based on the South-wide increase for wood bioenergy required to realize this price increase, the authors concluded "that a significant shift from sawtimber to pulpwood rotations in the South is highly improbable."

Here we update the 2011 forest management research to gauge concerns over long-term forest management changes. This analysis includes growth-and-yield modeling by Forest Resource Consultants (FRC) of Macon, Georgia to support the breakeven assessment of prices paid to landowners for wood and for forestland values. FRC estimated alternative price scenarios with a forest growth model to calculate bare land values (BLV) for management regimes using a range of harvest rotations. The BLV analysis assumes constant forest management on the same property forever. Appendix 2 details the assumptions used in this analysis.

SIDEBAR: What is BLV and how is it useful when evaluating forest management?

BLV is a special application of net present value (NPV). It uses assumed timber prices, forest management costs and interest rates to determine the optimal economic forest rotation (age) that maximizes the value of the land when growing trees. BLV remains a standard model for analyzing forest management alternatives and decisions.

BLV is useful for evaluating forest management strategies, such as managing for sawtimber versus managing for pulpwood, because it allows us to compare forestry investments of different rotation lengths. This addresses a practical issue when comparing forest investments, or investments of any type, that last for different lengths of time. How does a forestland owner compare the costs and benefits of managing an 18-year rotation forest to a 31-year rotation forest? In finance, this 13-year gap between 18 and 31 creates a problem for apples-to-apples analysis which BLV neatly solves by assuming you manage the forest "in perpetuity" under different strategies.

BLV provides a "theoretically" appropriate measure for valuing bare land managed exclusively for timber production. In practice, the estimated BLV may not correspond to current market values for the land. Investors may have alternative uses for the land, in which case the forestry-centric BLV may not be competitive. As such, BLV helps (1) identify the optimal rotation length for a forest; (2) schedule forest management activities; and (3) determine whether or not to invest in specific silvicultural activities (Mendell 2013).

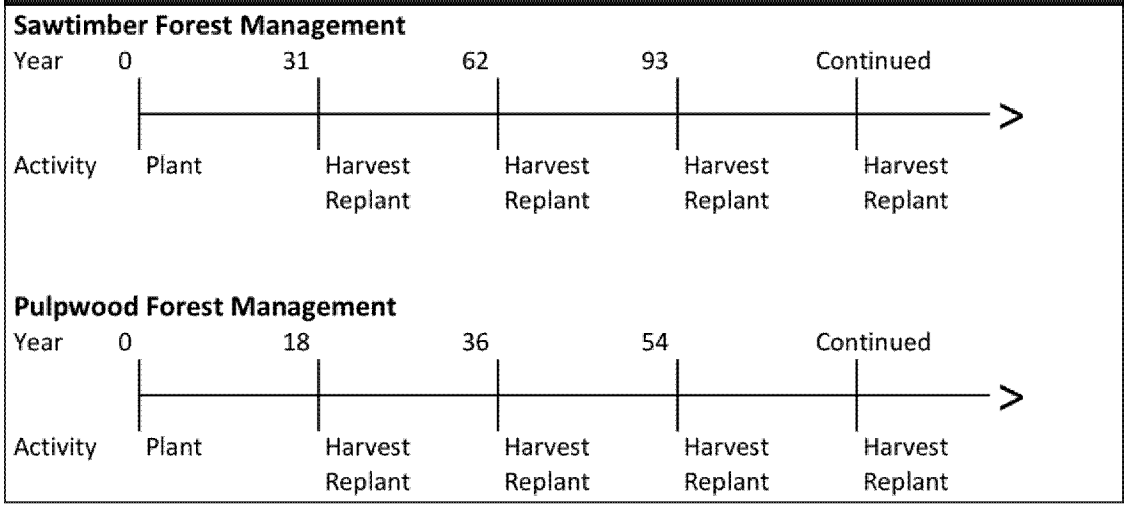
Figure 4 shows timelines for the two forest management strategies being compared in the BLV analysis. In the Sawtimber Forest Management strategy, trees are grown longer into larger,

[3] Reflects increasing a South-wide pine pulpwood price of $11.47 per ton to $17.09 per ton.

ED_000419-0007927

more valuable products used to produce lumber and plywood. In the Pulpwood Forest Management strategy, trees are grown exclusively for lower-valued pulpwood products used to produce paper, energy, and some engineered building materials.

Figure 4. Final Harvests in Sawtimber and Pulpwood Forest Management Strategies



Note: in between the "final harvests" each 31 years in the sawtimber strategy, forest managers would thin the forest twice to cull lower valued trees, mostly pulpwood.

The summary BLV results in Figure 5 show the added value to forest owners from implementing a forest management strategy focused on growing sawtimber for sawmills rather than focusing on pulpwood for paper mills and bioenergy. The results say "for the same acre, given our assumptions, implementing a sawtimber strategy in perpetuity creates over $200 more present value to the landowner than implementing a pulpwood strategy in perpetuity." In short, managing for sawtimber makes more economic sense because it generates better returns.

Figure 5. BLV Analysis for Sawtimber and Pulpwood Forest Management Strategies[4]

	Traditional Sawtimber Rotation	Pulpwood Maximizing Rotation
Max BLV	$584 per acre	$382 per acre
Max BLV rotation age	31 years	18 years

It is true, however, that if pulpwood prices were consistently high enough, then landowners might be indifferent between sawtimber and pulpwood management. To determine the pine pulpwood price at which landowners would be indifferent, we increased pine pulpwood prices to the point at which landowners would receive the same economic return from harvest rotations producing pulpwood and sawtimber (Figure 6). The pulpwood price that pushes up BLV to $584 per acre, making it "breakeven" to the sawtimber rotation, is $17.67 per ton.

The breakeven analysis reflects a South-wide average pine pulpwood price with no associated change in sawtimber and chip-n-saw (i.e. small sawtimber) markets. We assumed constant sawtimber and chip-n-saw prices to test the effect of increased pulpwood prices. In practice, this price will vary widely in local markets as it relies on the relative difference between prices for pulpwood and higher-valued chip-n-saw and sawtimber products.

ED_000419-0007928

Figure 6. BLV Breakeven Analysis for Two Forest Management Strategies	
	Pulpwood Maximizing Rotation
Target BLV	$584 per acre
Starting pulpwood price	$13.82
Pulpwood price to hit target BLV	$17.67
Rotation age	18
Key assumption	Growing 100% pulpwood

Forest product supplies and demand affect prices. For average South-wide pine pulpwood prices to achieve a "new normal" of $17.67 per ton by 2018 requires 48.2 million green tons of bioenergy demand for pulpwood, a 96% increase on the expected 24.6 million green tons projected by Forisk. We highlight that "48 million green tons" of demand is easier said than realized. Bioenergy markets would need to identify, access and procure this level of demand in enough viable wood baskets with sufficient accessible supplies to make this work.

The forest industry in the South used approximately 111 million green tons of pulpwood in 2013[4]. Forisk projects this volume to increase by about 8 million tons (~7%) by 2018 due primarily to increased production of OSB and panels for greater demand from housing.[5] By comparison, bioenergy projects in the South used less than 15 million green tons of pulpwood and logging residues in 2013. Forisk projects the volume from bioenergy plants to be 24.6 million green tons by 2018. The analysis described above indicates that total pulpwood use would, in theory, have to increase an additional 16% to 17% to over 188 million tons to drive the average price increase to incent large scale management shifts from sawtimber to pulpwood.

The analysis highlights that a South-wide shift from sawtimber to pulpwood rotations remains unlikely. The analysis assessed whether or not the economic incentives existed to drive large shifts in management. As usual, assumptions matter. The BLV method used to compare management regimes and price levels is a conservative approach that assumes constant prices in perpetuity. The BLV method also assumes that landowners employ the same forest management strategies forever. So a shift from sawtimber to pulpwood management, in this model, reflects a permanent shift. This does not account for one-time changes in management in response to spot prices.

Landowners can, and do, respond to short-term increases in price. In some local timber markets, pulpwood prices increased temporarily to high enough prices that landowners have harvested stands younger than 18 years of age to take advantage of short-term prices. These opportunistic sales are a normal part of private forestland management and occur today in traditional pulpwood and sawtimber markets. Ultimately, landowners replant stands with the intention to grow sawtimber. While they may take advantage of high spot prices, forestland owners avoid sweeping changes in their strategies until new pricing regimes are proven.

[4] Estimated from the Wood Demand Report, Q3 2013, published by the Wood Demand Research Program at the Center for Forest Business, University of Georgia.
[5] *2013 Forisk Forecast Mid-Year Update*, September 2013.

ED_000419-0007929

Policy Uncertainty and Wood Bioenergy Development

In the U.S., the future of wood bioenergy could hinge on near-term policy signals and choices. Since the U.S. lacks a federal mandate or renewable energy standard (RES) for electricity, wood biopower projects must stand on their own economic feasibility or state-level renewable portfolio standards (RPSs).

Policies that create uncertainty for potential projects can impede the development of wood bioenergy markets. For example, Georgia Power announced in January 2014 that it cancelled the coal-to-biomass conversion of Unit 3 at Plant Mitchell in Albany, GA[6]. Georgia Power cited higher capital costs and expenses related to environmental compliance, the economic recession, and lower natural gas prices as factors in the decision. In another case, Duke Energy plans to retire all units at the W.C. Beckjord coal-fired power station in New Richmond, OH by 2015[7]. Duke cited expected EPA actions "to implement new environmental regulation that would require cost-prohibitive equipment upgrades and retrofits to the plant." Previously, the utility planned to co-fire with biomass at the plant. In addition, Russell Biomass cancelled plans for a 50 MW wood-fired electricity plant in Massachusetts, citing the state's restrictive efficiency requirements along with high fuel costs given the restrictions[8]. The project also failed to secure long-term thermal contracts to make a more efficient plant economical.

In 2010, NAFO published research (Mendell et al 2010) that assessed potential economic impacts to meeting renewable energy targets and developing wood biomass markets associated with the Tailoring Rule. Since 2010, 167 wood bioenergy projects of all types were cancelled or delayed for reasons related and unrelated to policies such as the Tailoring Rule. Reasons include cheap natural gas, lack of financing, and the absence of regulatory certainty. Factors specific to biopower development emphasize project economics and financing: limited access to investment funds during the economic recession squashed many projects, coupled with the relative high cost of biomass feedstocks compared with natural gas. Overall, the biopower sector remains relatively "fragile" given these developments.

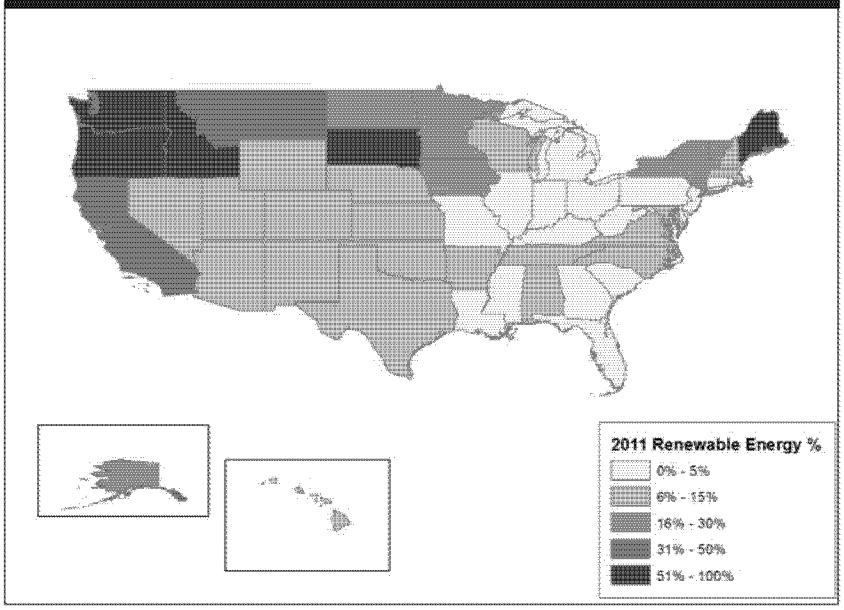
Despite these developments, some projects advanced, particularly electricity projects in states with renewable portfolio standards (RPSs) or related goals and CHP projects at manufacturing facilities. These project types are vulnerable to policies that create uncertainty or increase construction or operating costs. For example, a Tailoring Rule decision that disfavors biomass can hinder the development of current projects and also discourage the consideration or development of future biopower projects. A neutral federal policy allows biomass to evolve in markets and times that work for forest owners and project developers.

Data from the Energy Information Administration (EIA) reveals that five states currently generate over 50% of their electricity from renewable sources: Maine, Washington, Oregon, South Dakota, and Idaho (Figure 7). The primary renewable energy source in these states is hydroelectric. Maine also utilizes wood energy and South Dakota utilizes wind in addition to hydroelectric. Most states generate less than 15% of their electricity from renewable sources; 20 states generate 5% or less while 17 states generate 6 to 15% from renewable sources.

[6] http://www.prnewswire.com/news-releases/georgia-power-to-file-decertification-request-for-plant-mitchell-unit-3-239645661.html
[7] http://www.duke-energy.com/beckjord/default.asp
[8] http://www.masslive.com/news/index.ssf/2012/10/russell_biomass_llc_drops_plan.html

ED_000419-0007930

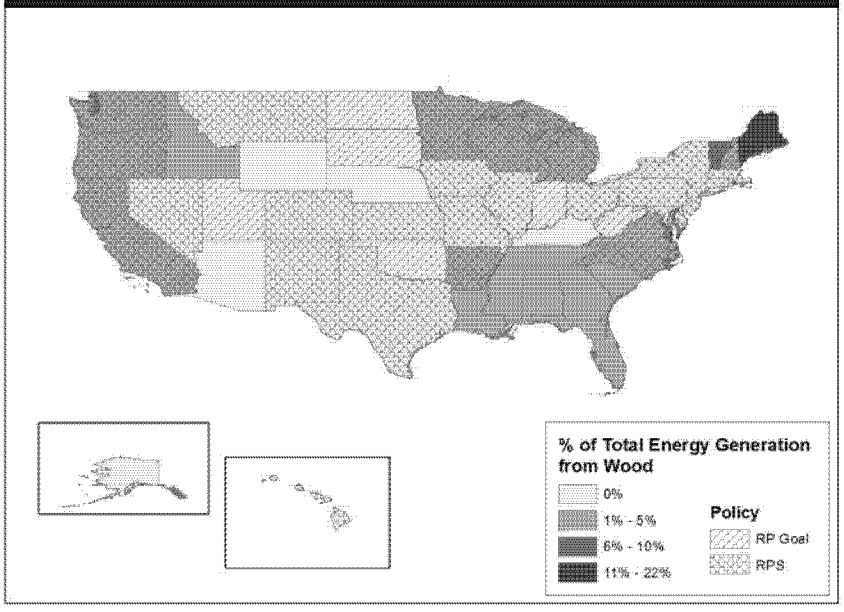
Figure 7. Renewable Energy Generation in 2011



Source: Energy Information Administration.

RPS policies require a certain portion of a state's electricity originate from renewable sources, such as wind, solar, geothermal, biomass, and to some degree hydro. Twenty-nine states have RPSs; eight more have renewable portfolio goals[9] (Figure 8). Most states in the South and Kentucky, Idaho, Wyoming, and Nebraska currently have no RPS policies. The ability of states to meet these targets relies on developing new capacity from renewables, such as wood.

Figure 8. State Energy Generation from Wood Biopower, 2011



Sources: Energy Information Administration; DSIRE.

[9] NC State University, U.S. DOE, DSIRE Database of State Incentives for Renewables and Efficiency. March 2013.

ED_000419-0007931

We assessed current levels of wood biopower at the state level to provide context for potential wood bioenergy growth. As of 2011, 20 states had measurable – 1% or higher – energy generation from wood. Of these, three states, all in the Northeast, had energy generation from wood of 5% or higher: Maine, New Hampshire and Vermont. The other 17 states, each with 1% to 5% of their total energy coming from wood, were clustered as expected near the nation's forest resources in the U.S. South, Northwest and Lake States.

Regionally, the U.S. South has the highest levels of potential wood bioenergy growth, as measured in announced projects and recent wood use. Most states in the South already produce up to 5% of total energy generation from wood without policies requiring them to do so. Any current or future policy that is unfavorable to wood bioenergy, including, potentially, the Tailoring rule, could jeopardize this renewable energy production.

Conclusions

The outlook for the next ten years shows slow, gradual growth in wood bioenergy. Currently and as projected to 2023, pulpwood and logging residue use from viable bioenergy applications will range from 4% to 9% of forest materials used by the U.S. forestry sector.

The gradual growth in wood demand from bioenergy corresponds to a continuation of current forest management regimes. Projected demand of wood for energy must double for landowners to consider permanent changes in management regimes from sawtimber to pulpwood plantations. The analysis highlights that a South-wide shift from sawtimber to pulpwood management by forest owners remains unlikely.

Since 2010, more wood bioenergy projects were cancelled or delayed in the U.S. than were successfully built and operated. Most failures and project delays resulted from unfavorable project economics due to cheap natural gas, unavailable financing, and legislative uncertainties. Federal or state policies treating biomass emissions the same as fossil fuel emissions could impede the already slowly developing wood bioenergy markets by perpetuating uncertainty and further restricting available financing.

ED_000419-0007932

Literature Cited

Clutter, M., R. Abt, D. Greene, and J. Siry. 2010. A developing bioenergy market and its implications on forests and forest products markets in the United States: economic considerations. *National Alliance of Forest Owners White Paper*. April: 1-10.

Composite Panel Association. 2013. 2013 North American Capacity Report. 19 pages.

Energy Information Administration. 2012. State historical tables for 2011. Retrieved November 1, 2013 from http://www.eia.gov/electricity/data/state/annual_generation_state.xls.

Forisk Consulting, 2013. *Forisk Forecast Mid-Year Update*, September.

Forisk Consulting, 2013. *Wood Bioenergy US* database.

Ince, Peter J.; Nepal, Prakash 2012. Effects on U.S. Timber Outlook of Recent Economic Recession, Collapse in Housing Construction, and Wood Energy Trends. USDA Forest Service, Forest Products Laboratory, General Technical Report, FPL-GTR-219, 2012: 21 p.

Mendell, B.C. 2013. *Forest Finance Simplified, 4th Edition*. Forisk Press, 82 pages.

Mendell, B.C. and A.H. Lang. 2012. Wood for Bioenergy: Forests as a Resource for Biomass and Biofuels. Forest History Society, 77 pages.

Mendell, B., A.H. Lang and T. Sydor. 2011. Woody biomass as a forest product: wood supply and market implications. *National Alliance of Forest Owners White Paper*. October: 1-19.

Mendell, B., A.H. Lang and T. Sydor. 2010. Economic and regional impact analysis of the treatment of biomass energy under the EPA greenhouse gas Tailoring Rule. *National Alliance of Forest Owners White Paper*. December: 1-32.

Mendell, B. and A.H. Lang. 2010. A practical guide for tracking wood-using bioenergy markets. *National Alliance of Forest Owners White Paper*. April: 1-10.

Smith, W. Brad, tech. coord.; Miles, Patrick D., data coord.; Perry, Charles H., map coord.; Pugh, Scott A., Data CD coord. 2009. Forest Resources of the United States, 2007. Gen. Tech. Rep. WO-78. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. xxx p.

USDA Forest Service. 2012. Future of America's Forest and Rangelands: Forest Service 2010 Resources Planning Act Assessment. Gen. Tech. Rep. WO-87. Washington, DC. 198 p.

Glossary

Chips: small pieces of wood used for fuel or to make pulp or certain engineered wood products. Chips are produced either as a residual by-product from wood waste in sawmills or plywood mils, or produced from pulpwood at pulp mills or chip mills specifically for the purpose of pulp or other manufacturing processes.

Chip-n-saw: timber product from mid-sized trees (9-13 inches at DBH) that makes small dimension lumber and chips for fuel or paper production. A rectangular piece is cut from the center of a chip-n-saw log for lumber while the outer slabs are chipped.

Composite panels: type of engineered structural panel consisting of a veneer face and backing with a particleboard core.

Lumber: wood products sawn to a standard thickness by cutting a log on two or four sides. In North America, softwood lumber is classified as boards, dimension, or timbers based on thickness categories.

MDF, medium density fiberboard: panel product made from wood fibers compressed with resins or other binders.

OSB, oriented strand board: a type of engineered structural panel made from low-value wood raw material; strands, or long chips, of wood are glued together in a specific orientation to form panels. OSB is used in construction and directly competes with plywood.

Particleboard: generic term used to describe wood panel products such as MDF and OSB.

Pulpwood: timber product from small diameter (6-9 inches DBH) and/or low quality trees used for fuel or paper production.

Renewable Portfolio Standard (RPS): state-level mandates that require a certain percentage of electricity generated in a state to be from renewable sources.

Residues: bark and woody materials that are generated in primary wood-using mills when roundwood products converted to other forest products. Examples of residues include edgings, sawdust, shavings and pulp screenings. Also includes bark residues and wood residues (both coarse and fine materials), but excludes logging residues.

Roundwood: a segment of a felled tree of no particular length that has a round cross-section. The term usually refers to raw material cut logs or tree-length logs being delivered to a forest products mill.

Sawtimber: timber product from large diameter trees (12-14 inches at DBH and up) of good quality used to make lumber.

Stumpage: value of standing trees “on the stump”; price of the trees that a landowner receives from a timber sale.

Timberland: forestland that is growing or can grow trees at a rate of twenty cubic feet per acre per year for industrial use.

ED_000419-0007934

Appendix 1: Green Tons or Dry Tons?

A common error in evaluating raw material supplies for announced bioenergy projects is confusion of green-versus-dry tons. Moisture content of wood affects each end use differently. Traditional forest industry users prefer, on balance, fresh "green" wood. Potential bioenergy users prefer dry wood with minimal moisture. While forestry operators and managers think in green tons, bioenergy project engineers and users of feasibility studies often think in dry tons. Confusing green and dry tons distorts contents and injects an additional error of 50 to 100% with respect to forest and wood raw materials volumes.

A rule of thumb conversion is 2:1 green-to-dry. To visualize this in terms of actual wood, 1 (bone) dry ton at 0% moisture content equals 2 freshly harvested green tons, assuming 50% moisture content.[10] These estimates depend critically on the wood's actual moisture content.

Moisture content also affects the value of wood to potential users, suppliers and forestland owners. A payment scheme based on weight, for example, encourages the seller to sell heavier trees. Since trees contain approximately 50% moisture, payment on a green ton basis benefits the sellers. A payment scheme based on energy content incents the seller to sell wood on a dry ton basis, since the water in the wood reduces its energy value.[11] That, in turn, could change the way wood is processed and hauled.

Today in the U.S. South, a single logging crew can harvest, process, and transport timber in succession; in this "hot" logging scenario, wood has no time to dry. If wood is sold in dry tons, harvesters could switch to "cold" logging, in which harvested wood is left stacked at roadside for several months before being processed and hauled to market (Mendell and Lang 2012).

[10] Another rule of thumb related to energy generation per unit of wood: 1 dry ton = 1MW/hour = 2 green tons.
[11] General value formula: $ per dry ton = $ per green ton/(1-Moisture Content/100); general volume formula: green tons = dry tons/(1-Moisture Content/100).

ED_000419-0007935

Appendix 2: Assumptions Used in Bare Land Value (BLV) Analysis

Forest Resource Consultants (FRC) of Macon, Georgia applied alternative price scenarios from Forisk to a forest growth and yield model to estimate bare land values (BLV) for management regimes using a range of harvest rotations. To simplify the analysis, the model set aside common miscellaneous expenses associated with annual ad valorem taxes and supplementary hunting lease income, as they normally cancel each other out.

Mendell (2013) outlines the methodology with a simplified version of the BLV formula:

$$\text{BLV} = \frac{\text{Harvest Value at Rotation Age - Regen Costs} * (1 + \text{Rate})^{\text{Rotation Age}}}{(1 + \text{Rate})^{\text{Rotation Age}} - 1}$$

Where "Regen" = regeneration (costs associated with site prep and planting)
"Rate" = discount rate

"Harvest Value" refers to the volume harvested at final harvest times the appropriate stumpage values. "Regeneration Costs" refer to the investment made at the beginning of the rotation to get trees in the ground. The math in the BLV formula has two basic steps. First, it carries (compounds) each revenue and cost to the end of the rotation. Second, it applies a version of the NPV formula to calculate value on a perpetual periodic basis.

The key assumptions associated with using BLV include:
1. BLV assumes that costs and revenues for all future rotations remain identical.
2. BLV assumes that the land will be reforested in perpetuity.
3. BLV assumes that regeneration costs occur at the beginning of each rotation.

The modeling incorporated the following assumptions, including prices forecasted to 2018 to reflect "post-recession" timber markets.

Assumptions and Data Sources for BLV Modeling[12]

Variable	Assumption	Notes	Source
Region	Lower Coastal Plain	i.e. SE Georgia	FRC
Planting density	605	trees per acre	FRC
Site index	68	regional average	FRC
Site prep/planting costs	$225 per acre	one year after harvest	FRC
Discount rate	5.50%	real	Forisk
Pine sawtimber price	$33.12 per ton	South-wide, 2018	*Forisk Forecast*
Pine chip-n-saw	$21.95 per ton	South-wide, 2018	*Forisk Forecast*
Pine pulpwood	$13.82 per ton	South-wide, 2018	*Forisk Forecast*

Based on the forest modeling by FRC and assumptions above, we determined the maximum potential BLV for two forest management strategies and the associated rotation ages.

ED_000419-0007936

From: Ohrel, Sara
To: Justin Baker (justinbaker@rti.org)
Sent: 11/15/2014 8:27:48 AM
Subject: some possibly useful lit
Attachments: BiogenicGeologic August 2011 gunn.pdf; gtr_srs178_213 Abt Wear 2013.pdf; ja_2012_K abt_002.pdf; tb1016revised.pdf

Some of the conclusions sections are interesting

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

GLOBAL CHANGE BIOLOGY
BIOENERGY

GCB Bioenergy (2012) 4, 239–242, doi: 10.1111/j.1757-1707.2011.01127.x

OPINION

Biogenic vs. geologic carbon emissions and forest biomass energy production

JOHN S. GUNN*, DAVID J. GANZ† and WILLIAM S. KEETON‡

*Natural Capital Initiative, Manomet Center for Conservation Sciences, 14 Maine St., Suite 410, Brunswick, ME, 04011, USA, †Lowering Emissions in Asia's Forests (LEAF), Liberty Square, Suite 2002 287 Silom Road Bang Rak, Bangkok, 10500, Thailand, ‡The Rubenstein School of Environment and Natural Resources, University of Vermont, 209 Hills Building, 81 Carrigan Drive, Burlington, VT, 05405, USA

Abstract

In the current debate over the CO_2 emissions implications of switching from fossil fuel energy sources to include a substantial amount of woody biomass energy, many scientists and policy makers hold the view that emissions from the two sources should not be equated. Their rationale is that the combustion or decay of woody biomass is simply part of the global cycle of biogenic carbon and does not increase the amount of carbon in circulation. This view is frequently presented as justification to implement policies that encourage the substitution of fossil fuel energy sources with biomass. We present the opinion that this is an inappropriate conceptual basis to assess the atmospheric greenhouse gas (GHG) accounting of woody biomass energy generation. While there are many other environmental, social, and economic reasons to move to woody biomass energy, we argue that the inferred benefits of biogenic emissions over fossil fuel emissions should be reconsidered.

Keywords: bioenergy emissions, biogenic carbon, carbon debt, forest biomass, greenhouse gas accounting

Received 20 April 2011; revised version received 14 July 2011 and accepted 3 August 2011

A recent letter to US House of Representatives Natural Resource and Energy and Commerce Committees signed by more than 100 academics from American universities articulated a concern over equating biogenic carbon (C) emissions with fossil fuel emissions in emerging state and federal legislation and rule making (Lippke *et al.*, 2010). They stated that 'the combustion or decay of woody biomass is part of the global cycle of biogenic carbon and does not increase the amount of carbon in circulation. In contrast, carbon dioxide released from fossil fuels increases the amount of carbon in the cycle'. This view recently has been reiterated by many (e.g. Hale, 2010; Lucier, 2010; Strauch *et al.*, 2010; Sedjo, 2011) as justification to promote policies that encourage the substitution of fossil fuel energy sources with biomass. This position ignores the inherent complexities associated with atmospheric greenhouse gas (GHG) accounting of woody biomass energy generation, including the consideration of the system boundaries used in net emissions calculations and the indirect effects associated with land-use change. According to some calculations, switching from fossil fuels to wood energy could actually result in increased levels of atmospheric GHGs, at least over a period of decades (e.g. Searchinger *et al.*, 2009; Walker *et al.*, 2010; McKechnie *et al.*, 2011). This recent scientific approach to the issue has come about through the recognition by many in the scientific community that GHG accounting must consider explicitly the carbon dynamics of the woody biomass feedstock source and not dismiss it as immediately 'carbon neutral.' Though our comments below are driven by the US policy debate over how to treat biomass energy emissions, this desire to dismiss these important biogenic emissions is echoed internationally. In particular, the current Intergovernmental Panel on Climate Change (IPCC, 2006) GHG accounting approach accounts for feedstock carbon stock change, but does not attribute biogenic emissions to the energy sector. This approach risks creating incentives for bioenergy production that, in some circumstances, may emit more CO_2 than the fossil fuel alternatives over the whole life cycle of the bioenergy chain and considering indirect pay-back effects (Bird *et al.*, 2011).

There are many credible environmental, social and economic reasons to move away from fossil fuels, including: reducing dependence on foreign petroleum, providing economic incentives to maintain forest management infrastructure, and encouraging conservation of working forests. But for the specific goal of mitigating

Correspondence: John S. Gunn, tel. + 207 721 9040, fax + 207 721 9144, e-mail: jgunn@manomet.org

© 2011 Blackwell Publishing Ltd

ED_000419-0007938

climate change, the critical question to answer is 'what will the atmosphere see and over what timescale?' as a result of switching from geologic to biogenic fuel sources. The physics of the greenhouse effect is indifferent as to the origin of the pollutant. Once a molecule of CO_2 is in the atmosphere its heating capacity is the same regardless of its source. It is the overall C budget and the net atmospheric concentration of greenhouses gases that are of concern. If greater use of wood energy has the unintended consequence of contributing to an increase in atmospheric CO_2 concentrations, then decisions to switch to biogenic fuels should be guided by careful accounting to determine net carbon fluxes to and from the atmosphere.

An earlier letter to the US House of Representatives and US Senate (Schlesinger *et al.*, 2010) from 90 American scientists stated that 'Although fossil fuel emissions are reduced or eliminated, the combustion of biomass replaces fossil emissions with its own emissions (which may even be higher per unit of energy because of the lower energy to carbon ratio of biomass)'. More research is needed to determine which biomass energy technology scenarios and forest ecosystems are most likely to result in greater biogenic emissions than the equivalent fossil fuel energy source. But recent work in the United States and Europe supports the Schlesinger *et al.* (2010) statement (e.g. Walker *et al.*, 2010; Bird *et al.*, 2011; McKechnie *et al.*, 2011). In addition, if biomass harvests involve living trees that would otherwise have remained alive and growing, the short-term net impact on the atmosphere will be greater than if logging residue or waste wood were used. All wood is not equal in terms of temporal impact to atmospheric GHG levels. Therefore, the use of wood for energy needs a strong quantitative basis ensuring policy based on evidence rather than opinion.

Wood energy harvests encompass a wide range of silvicultural treatments, but have the potential to increase the overall intensity and frequency of harvesting. This can reduce the net amount of carbon stored in forest biomass at any moment in time at landscape scales, particularly in natural forest systems with low risk of catastrophic disturbances and relatively slow growth rates. If overall harvesting intensity increases to meet new demand for wood energy, carbon stocks on the landscape can be depressed to a lower equilibrium storage condition therefore increasing overall atmospheric CO_2 even when considering the substitution benefits (Harmon *et al.*, 1990; Smithwick *et al.*, 2006; McKechnie *et al.*, 2011). In addition, when biomass energy is produced from land converted to nonforest uses; regrowth of forests and the associated uptake of C will not occur. As long as the world continues to experience net loss of forest cover (deforestation) and harvest intensity increases, the residence time period for biogenic C in the atmosphere is likely longer than what is assumed by many scientists. Moreover, most sequestration of this biogenic C in the atmosphere will likely occur beyond the critical timeframe for addressing climate change (e.g. the next 50 years). When we also consider the amount of biogenic C remaining in the atmosphere as a result of historical global conversion of forests, prairies, peatlands and wetlands (Birdsey *et al.*, 2006; Rhemtulla *et al.*, 2009; van der Werf *et al.*, 2009), it becomes clear that all sources of additional C emissions should be evaluated based upon their near term contribution to the atmosphere and their potential for re-sequestration by new biological growth. This historical debt also negates the argument that biogenic carbon can be banked in advance of consumption for energy (e.g. Sedjo, 2011). Again, what matters is the amount of CO_2 in the atmosphere, regardless of the source.

One rationale for increasing the use of forest biomass for energy is that the biogenic carbon cycle is in balance as long as trees are growing and sequestering carbon somewhere else within other forests (Lucier, 2010). While this argument makes sense when considering the sustained yield of wood products, it fails to consider the complete basis for calculating net GHG effect on the atmosphere of switching from fossil fuels to biomass. Moreover, when applied to carbon, this approach implies that the biogenic carbon cycle is separate from a global carbon cycle. It is indisputable that emissions from fossil fuels contribute to the atmospheric pool by releasing carbon from the geologic pool and are therefore new emissions to the atmosphere. However, the same is functionally true, in terms of climate implications, for any biological carbon emission with a low likelihood or a delayed return (>50 years) to the biogenic or oceanic pools. If alternatives to fossil fuels include use of forests where C is emitted and resides in the atmosphere for long periods of time (e.g. decades or longer), a reduction of atmospheric concentrations of CO_2 (e.g. to 350 ppm; Hansen *et al.*, 2008) will be difficult to achieve and may contribute to some degree of irreversible climate change (Solomon *et al.*, 2009). With this in mind, we must continue to ask ourselves whether we are truly using forests to their greatest atmospheric benefit.

What matters most in our climate change mitigation efforts is the movement of C from any pool into and out of the atmosphere (i.e. the net effect on atmospheric carbon concentrations). Consider the five major global pools of C in decreasing order of volume: oceanic; geologic; pedologic; atmospheric; and biogenic (Morgan *et al.*, 2010). The flow of C among these pools operates at varying temporal scales. It may take millions of years for C to move from the biogenic pool

ED_000419-0007939

to the geologic pool, while fluxes between the atmospheric and biogenic pools are continuous. Humans influence movement among pools by burning fossil fuels and releasing C to the atmospheric pool. Likewise, we burn and clear forests from the biogenic pool to convert land to agriculture, development, and other nonforest uses, leading essentially in many cases to a permanent loss of biogenic C (van der Werf *et al.*, 2009; Hansen *et al.*, 2010). Movement of biogenic C from the atmosphere back into the biogenic pool cannot be automatically assumed. Biogenic C released from activities such as permanent deforestation, or the combustion of forest biomass for energy, must be replaced through photosynthesis and sequestration to maintain flow from the atmosphere back into the biogenic pool. In the context of climate change mitigation efforts, activities that generate emissions from biogenic or geologic C pools should be evaluated for the contribution it makes to the atmospheric pool and the timing of residence.

There is an immediate need to deal with the complexity of carbon accounting as it relates to wood-derived bioenergy. Scientists are studying the benefits and tradeoffs associated with different carbon management scenarios in a variety of forest types around the world (Harmon & Marks, 2002; Seidl *et al.*, 2007; Mitchell *et al.*, 2009; North *et al.*, 2009; Swanson, 2009; Hurteau *et al.*, 2010; Nunery & Keeton, 2010; Gunn *et al.*, 2011). As our understanding of this complexity improves, we need to carefully consider the role of forests as both a potential C sink and source (Ray *et al.*, 2009). If forests are going to be used to reduce our dependence on fossil fuels, we will need to determine where and when to provide the economic incentives to maintain the forest management infrastructure and our working forests. Independently verified sustainable forestry standards that conserve our forest resources in perpetuity provide one existing mechanism to prevent degradation and promote forest practices with C sequestration benefits. The opportunities to use our forests and maintain them as forests with their embedded ecosystem service values is worthy of balancing the carbon accounting issues mentioned here with the other management objectives (water, biodiversity, human livelihoods, recreation, energy, etc.). Ideally, balancing the flow of ecosystem service values from forests will benefit from global policies such as Reducing Emissions from Deforestation and Forest Degradation (REDD) that consider the whole suite of ecosystem goods and services including atmospheric benefits (Canadell & Raupach, 2008; Ebeling & Yasue, 2008; FAO UNDP, 2008). But first, we must be confident that our climate policies designed to reduce atmospheric GHGs in a time frame that matters actually *do* reduce GHG levels, and not unwittingly increase them.

References

Bird DN, Zanchi G, Pena N, Havlik P, Frieden D (2011) Analysis of the Potential of Sustainable Forest-Based Bioenergy for Climate Change Mitigation, Working Paper No. 59, CIFOR, Bogor, Indonesia.

Birdsey R, Pregitzer K, Lucier A (2006) Forest Carbon Management in the United States: 1600 2100. *Journal of Environmental Quality*, **35**, 1461 1469.

Canadell JG, Raupach MR (2008) Managing forests for climate change mitigation. *Science*, **320**, 1456 1457.

Ebeling J, Yasue M (2008) Generating carbon finance through avoided deforestation and its potential to create climatic, conservation and human development benefits. *Philosophical Transactions of the Royal Society B*, **363**, 1917 1924.

FAO UNDP (2008) *UN-REDD: UN Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD)*. FAO, UNDP, UNEP Framework Document. Available at: http://www.un-redd.org/Publications/tabid/587/Default.aspx (accessed 7 September 2011).

Gunn JS, Saah D, Fernholz K, Ganz D (2011) Carbon credit eligibility under area regulation of harvest levels in Northern Minnesota. *Forest Science*, (in press).

Hale R (2010) American Forest & Paper Association Comments on Massachusetts Department of Energy Resources (DOER) Manomet Biomass Sustainability and Carbon Policy Study, Carbon Accounting and Biomass/RPS Policy Directions, August 12, 2010. Available at: http://www.mass.gov/Eoeea/docs/doer/renewables/biomass/study comments/American%20Forest%20&%20Paper%20Association,%20Rhea%20Hale.pdf (accessed 20 April 2011).

Hansen J, Sato M, Kharecha P *et al.* (2008) Target atmospheric CO_2: where should humanity aim? *Open Atmospheric Science Journal*, **2**, 217 231.

Hansen MC, Stehman SV, Potapov PV (2010) Quantification of global gross forest cover loss. *Proceedings of the National Academy of Sciences USA*, **107**, 8650 8655.

Harmon ME, Marks B (2002) Effects of silvicultural practices on carbon stores in Douglas-fir-western hemlock forests in the Pacific Northwest, USA: results from a simulation model. *Canadian Journal of Forest Research*, **32**, 863 877.

Harmon ME, Ferrell WK, Franklin JF (1990) Effects on carbon storage of conversion of old-growth forests to young forests. *Science*, **247**, 699 702.

Hurteau MD, Stoddard MT, Fule PZ (2010) The carbon costs of mitigating high-severity wildfire in southwestern ponderosa pine. *Global Change Biology*, **17**, 1516 1521.

IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National Greenhouse Gas Inventories Programme (eds Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K), IGES, Japan.

Lippke B, Oneil E, Winistorfer PM *et al.* (2010) Letter to US House of Representatives Energy & Commerce Committee and US House of Representatives Natural Resource Committee, 20 July 2010.

Lucier A (2010) A Fatal Flaw in Manomet's Biomass Study. *The Forestry Source*, **15**, p. 4.

McKechnie J, Colombo S, Chen J, Mabee W, MacLean HL (2011) Forest bioenergy or forest carbon? Assessing trade-offs in greenhouse gas mitigation with wood-based fuels. *Environmental Science & Technology*, **45**, 789 795.

Mitchell SR, Harmon ME, O'Connell KEB (2009) Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems. *Ecological Applications*, **19**, 643 655.

Morgan JA, Follett RF, Allen LH Jr (2010) Carbon sequestration in agricultural lands of the United States. *Journal of Soil and Water Conservation*, **65**, 6A 13A.

North M, Hurteau M, Innes J (2009) Fire suppression and fuels treatment effects on mixed-conifer carbon stocks and emissions. *Ecological Applications*, **19**, 1385 1396.

Nunery JS, Keeton WS (2010) Forest carbon storage in the northeastern United States: net effects of harvesting frequency, post-harvest retention, and wood products. *Forest Ecology and Management*, **259**, 1363 1375.

Ray DG, Seymour RS, Scott NS, Keeton WS (2009) Mitigating climate change with managed forests: balancing expectations, opportunity, and risk. *Journal of Forestry*, **107**, 50 51.

Rhemtulla J, Mladenoff D, Clayton M (2009) Historical forest baselines reveal potential for continued carbon sequestration. *Proceedings of the National Academy of Sciences USA*, **106**, 6082 6087.

Schlesinger WH, Allen M, Aneja VP *et al.* (2010) Letter to Nancy Pelosi, US House of Representatives and Harry Reid, US Senate 17 May 2010.

ED_000419-0007940

Searchinger T, Hamburg SP, Melillo J *et al.* (2009) Fixing a critical climate accounting error. *Science*, **326**, 527 528.

Sedjo RA (2011) *Carbon Neutrality and Bioenergy: A Zero-Sum Game?* Resources for the Future Discussion Paper DP 11-15. Available at: http://www.rff.org/RFF/Documents/RFF-DP-11-15.pdf (accessed 14 July 2011).

Seidl R, Rammer W, Jager D, Currie WS, Lexer MJ (2007) Assessing trade-offs between carbon sequestration and timber production within a framework of multi-purpose forestry in Austria. *Forest Ecology and Management*, **248**, 64 79.

Smithwick EAH, Harmon ME, Domingo JB (2006) Changing temporal patterns of forest carbon stores and net ecosystem carbon balance: the stand to landscape transformation. *Landscape Ecology*, **22**, 77 94.

Solomon S, Plattner GK, Knuttic R, Friedlingstein P (2009) Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences*, **106**, 1704 1709.

Strauch P, Payne JN, Cleaves B (2010) *Maine Voices: Tale of the Tree Turns a New Leaf*, Portland Press Herald, September 5, Op-Ed. Available at: http://www.pressherald.com/opinion/tale-of-the-tree-turns-a-new-leaf_2010-09-05.html (accessed 19 April 2011).

Swanson ME (2009) Modeling the effects of alternative management strategies on forest carbon in the Nothofagus forests of Tierra del Fuego, Chile. *Forest Ecology and Management*, **257**, 1740 1750.

Walker T, Cardellichio P, Colnes A *et al.* (2010) *Biomass Sustainability and Carbon Policy Study. Manomet Center for Conservation Sciences.* NCI-2010-03. 189 pp. Available at: http://www.manomet.org/sites/manomet.org/files/Manomet_Biomass_Report_Full_LoRez.pdf (accessed 19 April 2011).

van der Werf GR, Morton DC, DeFries RS *et al.* (2009) CO_2 emissions from forest loss. *Nature Geoscience*, **2**, 737 738.

ED_000419-0007941

CHAPTER 10. Forest Biomass-Based Energy

Janaki R. R. Alavalapati, Pankaj Lal, Andres Susaeta, Robert C. Abt, and David N. Wear[1]

KEY FINDINGS

- Harvesting woody biomass for use as bioenergy is projected to range from 170 million to 336 million green tons by 2050, an increase of 54 to 113 percent over current levels.
- Consumption projections for forest biomass-based energy, which are based on Energy Information Administration projections, have a high level of uncertainty given the interplay between public policies and the supply and investment decisions of forest landowners.
- It is unlikely that the biomass requirement for energy would be met through harvest residues and urban wood waste alone. As consumption increases, harvested timber (especially pine pulpwood) would quickly become the preferred feedstock.
- The emergence of a new woody biomass-based energy market would potentially lead to price increases for merchantable timber, resulting in increased returns for forest landowners.
- While woody biomass harvest is expected to increase with higher prices, forest inventories would not necessarily decline because of increased plantations of fast growing species, afforestation of agricultural or pasturelands, and intensive management of forest land.
- Because it would allow more output per acre of forest land and dampen potential price increases, forest productivity is a key variable in market futures.
- The impacts that increased use of woody biomass for energy would have on the forest products industry could be mitigated by improved productivity through forest management and/or by increased output from currently unmanaged forests.
- Price volatility associated with increased use of woody biomass for energy is expected to be higher for pulpwood than for sawtimber.
- The impacts of wood-based energy markets tend to be lower for sawtimber industries, although markets for all products would be affected at the highest levels of projected demand.
- Different types of wood-based energy conversion technologies occupy different places on the cost feasibility spectrum. Combined heat and power, co-firing for electricity, and pellet technologies are commercially viable and are already established in the South. Biochemical and thermochemical technologies used to produce liquid fuels from woody biomass are not yet commercially viable.
- Current research does not suggest which woody species and what traits would likely be most successful for energy production. The future of conversion technologies is uncertain.
- In the absence of government support, research, pilot projects, and incentives for production, woody bioenergy markets are unlikely to grow substantially.
- Under a high demand scenario for bioenergy, the resulting intensity of woody biomass harvests could have deleterious effects on stand productivity, biodiversity, soil fertility, and water quality.
- Although research provides some guidelines for the design of management to protect various forest ecosystem services, forest sustainability benchmarks are not well defined for a high bioenergy demand future and existing certification systems may need modifications to address multiple resource values.

INTRODUCTION

The United States is the largest consumer of petroleum products, consuming about 19.5 million barrels per day in 2008 (Energy Information Administration 2009), with a significant portion imported from politically unstable regions of the world. This reliance on imported fossil fuels, coupled with their associated greenhouse gas emissions, has led to economic, social and environmental concerns. Bioenergy may offset fossil fuel use, diversify energy sources, reduce emissions, and provide socioeconomic benefits in the form

[1] Janaki R.R. Alavalapati is a Professor and Department Head of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA 24061. Pankaj Lal is an Assistant Professor, Department of Earth and Environmental Studies, Montclair State University, Montclair, NJ 07043. Andres Susaeta is a Postdoctoral Scholar, Department of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA 24061. Robert C. Abt is a Professor, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695. David N. Wear is the Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695.

of additional income and new jobs. Bioenergy from woody biomass could contribute by increasing U.S. renewable energy resources, reducing competition between agricultural crops destined for food and those for fuel production (Hill and others 2006), and perhaps improving the condition of some forests. Some analysts, for example the Manomet Center of Conservation Sciences (2010) in their analysis of wood-based bioenergy in Massachusetts raise doubts about the greenhouse gas mitigation potential of forest bioenergy. Others, e.g., Lucier (2010) and O'Laughlin (2010), challenge these findings. In the South, some studies, e.g., Dwivedi and others (2011), indicate that southern pine based energy could reduce greenhouse gas emissions as compared to using fossil fuels.

Although historically limited to residues from the production of wood products, biomass could be sourced from logging residues, stands damaged by natural disturbances (such as wildfire, pest outbreaks, and hurricanes), small-diameter trees thinned from plantations and other forests, and energy crops such as eucalyptus and poplar; these sources would likely be tapped as woody bioenergy markets become competitive. At high enough prices, even merchantable timber could be diverted to bioenergy uses. Hughes (2000) suggests that the combination of forest bioenergy plantations and continued use of wood residues from forest product industries could supply 7 to 20 percent of the U.S. electricity generation in the future.

Many pine plantations established to supply pulpwood for paper and engineered wood products are overstocked and therefore susceptible to wildfires and pest attacks (Gan and Mayfield 2007a). For example, nearly half of over 1.1 million acres of nearly pure pine stands are at risk from southern pine beetle in Oklahoma (Oklahoma Department of Agriculture Food And Forestry 2008). Wood-based bioenergy markets could increase thinning and removals, thereby reducing these risks (Belanger and others 1993, Gan and Mayfield 2007a, Neary and Zieroth 2007, Speight 1997). Schmidt and others (2002) estimated that 2.7 billion dry tons of forest biomass needs to be removed through forest fuel reduction treatments in the South, about 20 million dry tons annually. Furthermore, wood-based bioenergy markets would improve profitability for landowners in the South (Nesbit and others 2011, Susaeta and others 2009). Furthermore, southerners appear willing to pay more for cleaner sources of energy such as wood based biofuels (Susaeta and others 2010).

Federal policies such as the 2002 Farm Bill, 2005 Energy Policy Act, 2007 Energy Independence Security Act, and 2008 Farm Bill have specifically encouraged the production of cellulosic biofuels such as those produced from wood, ranging from grants and loans to the establishment of renewable fuel standards (15.5 billion gallons in 2012, and 36 billion gallons by 2022 of which 21 billion gallons must be cellulosic). Federal law provides differing definitions of acceptable forest biomass for bioenergy. For example, under the 2007 Energy Independence Security Act biomass from public lands, municipal solid waste, plantations established after the enactment of the Act, 'old growth' or 'mature' forests, and most other woody biomass (except for slash and pre-commercial thinning) is excluded from private and non-industrial forests (NIPFs) landowners. The 2008 Farm Bill on the other hand is less restrictive, as it allows for biomass derived from Federal lands and other forests (i.e., not tree plantations) as biofuels. The American Clean Energy and Security Act of 2009 (H.R. 2454), as passed by the House of Representatives, sought to create a broadened universal definition of renewable biomass that applies to the Renewable Fuel Standard, and a national Renewable Electricity Standard. We followed a non-restrictive definition of biomass while simulating supply variations and southern forests and considered that aboveground biomass on private forestlands in the South could be used for energy production. This is based on the assumption that policy would not restrict the allocation of forest biomass to bioenergy uses.

This chapter analyzes the potential effects of the emergence of a bioenergy market on southern forests, forest owners, traditional forest product industries, and ecosystem integrity and services; with emphasis on the following key issues:

- How markets for wood for energy production might evolve and potential implications for traditional forest product industries and landowners
- The status of current and potential technologies that can help realize large-scale production of woody bioenergy
- How bioenergy policies could impact forest landowners and forest industry
- Effects of woody bioenergy markets on forest ecosystems health; benchmarks for sustainability

METHODS

We surveyed the literature to address questions about technology development, bioenergy policies, and sustainability, and we developed detailed modeling to project market changes and incorporate an analytical component into the results of the literature survey.

To assess tradeoffs between the traditional forest product industry and the woody bioenergy industry, we evaluated woody biomass supply variation through time and associated price, inventory, and removal responses following Rossi and others (2010). In the face of future competition for raw materials and the potential competitive advantage that policy incentives would provide to woody bioenergy sector, this tradeoff analysis was considered

critical for the future of southern forests (Wear and others 2009). Many authors have explored this issue; what has been lacking is a systematic analysis of regional trends that assesses woody biomass supply in response to variation in future consumption for energy.

We modified the Subregional Timber Supply (SRTS) model (Abt and others 2000), to assess the potential effects of bioenergy consumption on wood products markets. The model provided price, inventory, and removal responses for different wood-for-energy consumption and supply scenarios; and allowed us to estimate impacts on traditional forest industries and landowners.

Of the large-scale macro models available for conducting our analysis (Adams and others 1996; De La Torre Ugarte and Ray 2000; De La Torre Ugarte and others 1998, 2006), the SRTS model is the only one that treats standing timber as a potential supply of bioenergy and defines regions in a way that is congruent with Forest Inventory Analysis (FIA) survey units. Because it incorporates an inventory projection model into a timber market model framework, its projections are based on supply and demand interactions. It allows of larger diameter sawtimber to be downgraded for nonsawtimber (largely pulpwood uses) in response to price signals and is familiar to many forest industry analysts and State forestry agencies, having been used to model timber supply and prices in the Northeast (Sendek and others 2003) as well as the South (Bingham and others 2003, Prestemon and Abt 2002). It has also been used to assess the influence of nonmarket values on timber market decisions by nonindustrial private forest landowners (Pattanayak and others 2005), the effects of wood chip mills on timber supply in North Carolina (Schaberg and others 2005), the impacts of Renewable Energy Standards policy implemented in North Carolina (Galik and others 2009), and bioenergy demands in South (Abt and Abt, in press).

The SRTS model estimates two forest products, sawtimber and pulpwood product allocations for softwoods and hardwoods. Its equations—defined through supply, demand, and inventory elasticity values—are used to project the market-clearing price and quantity levels, which in turn are used to allocate subregional harvesting and to project the next period's inventory values. A Goal Program then categorizes the total wood requirement by management type and age class and makes allocations to subregions, owners, and products.

The separation of products and inventory in terms of sawtimber and pulpwood is based on user-specified definitions that allocate most of the largest diameter wood to saw mills, a percent of the largest diameter and all of the medium diameter wood to pulpwood, and the smallest diameter wood to the forest floor. With these allocations, a product mix is calculated for harvest in any management type and age class with the objective of defining the projected removal mix for the region/owner in a way that follows historical harvest patterns of existing removal-to-inventory intensities. For partial harvests, the model defines a stocking target (volume per acre) for each management type and age class; if the current stocking is greater than the target, the harvest is considered a thinning. After the volume-per-acre target is reached, the harvest considered final and acres are returned to age class zero. Under most circumstances, this approach ensures that average stocking is close to target (historical) levels throughout the projection (Abt and Abt 2010; Abt and others 2000; Abt and others 2009, 2010; Prestemon and Abt 2002; Rossi and others 2010).

We made a number of modifications to the SRTS model (fig. 10.1) to assess the effects of woody bioenergy industry on future prices, harvests, and inventories of four wood product categories—softwood sawtimber, other softwoods, hardwood sawtimber, and other hardwoods—derived from private owners of forest land (public forest lands have been excluded from the study, because public land harvest decisions are not necessarily price-responsive). Appendix B contains descriptions of these products and the allocation of consumption of each for woody bioenergy production. The model allocates woody biomass consumption among product groups based on the price variations. Pine plantations can be harvested for pulpwood as early as 10 years of age. To determine the availability of harvest residuals, we applied utilization percentages that are consistent with timber product output data for the South (Johnson and others 2009).

Alternative runs of the model allowed us to examine how management or genetic improvements would affect productivity. Rather than applying identical responses across the five forest management types (pine plantation, natural pine, oak-pine, upland hardwood, and lowland hardwood), we modified the model so that responses can be disaggregated across them.

Within the SRTS model, the area of timberland will change in response to the relative rents of crop and forest uses. We defined timber rents as weighted averages of sawtimber and nonsawtimber prices, with weighting specified by the present value difference in income between the two products while agricultural rents are held constant. Because woody bioenergy markets are expected to impact the nonsawtimber sector more than the high valued sawtimber sector (Aulisi and others 2007), the model allocates less weight to sawtimber prices.

We used the aggregate demand information gathered from each southern wood-based industry—forest products, woody biomass-based electricity, woody biomass-based liquid fuels, and wood pellets—to project the allocation of harvested

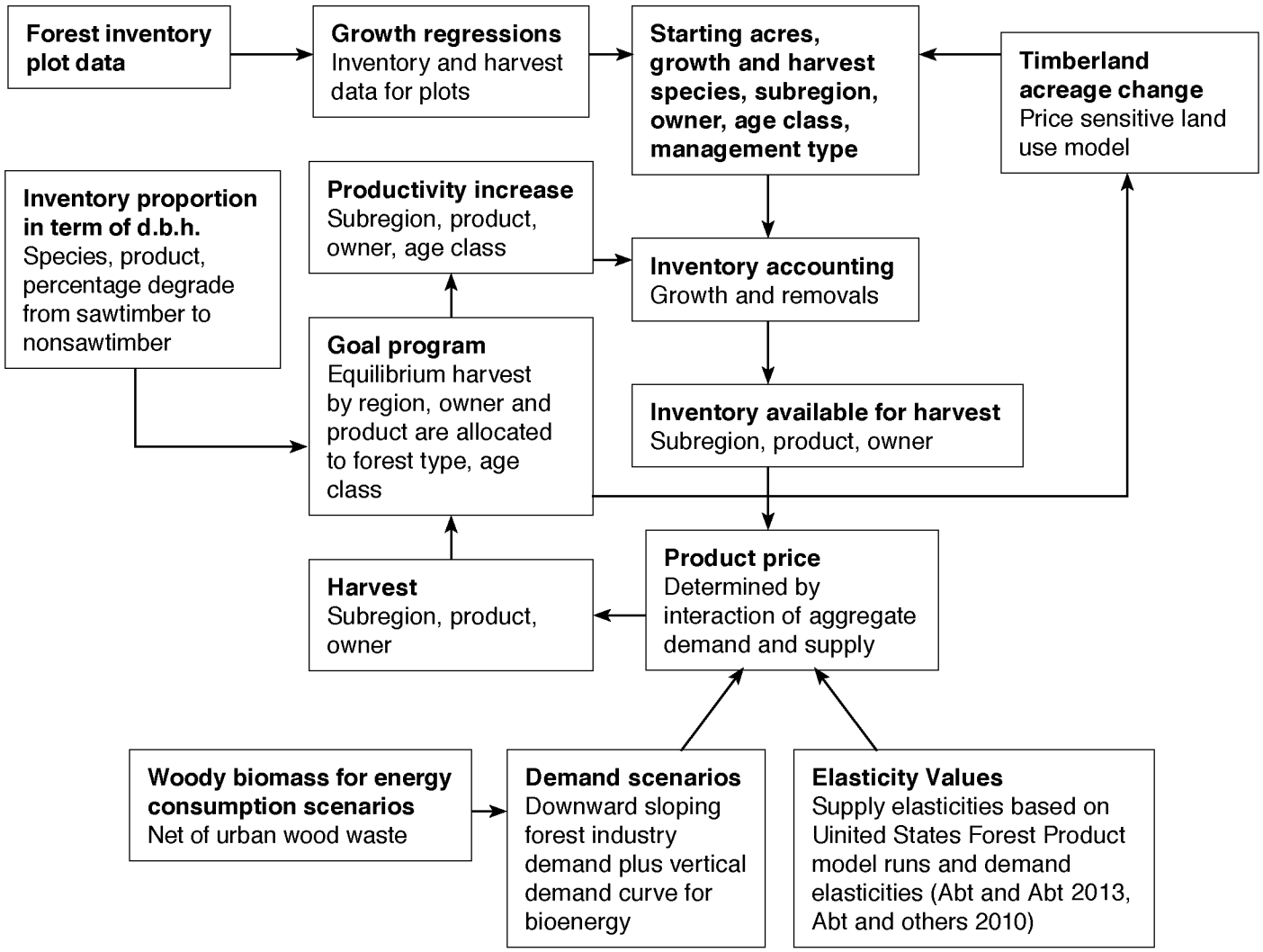


Figure 10.1—Methodology diagram for the modified Subregional Timber Supply model used to project levels and effects of woody biomass consumed for energy for the South.

timber. The modified SRTS model defines a market simulation model based on empirical relationships—demand and supply, price, land use, reforestation and inventory—for woody biomass and traditional forest products. A key assumption is that forest owners are price responsive and decisions to invest or harvest are made accordingly.

Consumption/Demand Scenarios

Our consumption scenarios were based on the three principal uses of woody biomass for energy: as power for electricity generation through combustion or gasification processes, co-firing with coal, or in combined heat and power systems in industrial facilities (Energy Information Administration 2010b); as liquid fuel (cellulosic ethanol) that can be blended with conventional transportation fuels (Energy Information Administration 2010b); and as bioproducts such as highly compact wood pellets used for heating purposes (Spelter and Toth 2009, appendix B).

The amount of wood consumed for electricity, liquid fuels, and pellets defines the total requirement for meeting bioenergy consumption projections. This can be met with wood from additional harvesting or with residuals and other wood waste. Although harvesting unutilized residues (discarded tree tops and limbs generated during the harvesting process) might provide a portion of woody biomass-based energy consumption, recent analysis (Galik and others 2009, Rossi and others 2010) indicates that merchantable timber is also likely to be required. In addition, woody biomass-based energy demand figures need to account for urban wood wastes that could be used for energy production (Rossi and others 2010). Because the SRTS model deals only in harvested wood, we backed urban

waste and other sources of nonharvested woody biomass out of the consumption estimates, and defined the remainder as harvested-wood consumption (including harvesting residues) for woody biomass-based energy; appendix B shows the method used to estimate the harvesting residues and urban wood waste that can be diverted for energy production. Demand price elasticity, which like inventory supply elasticity can vary by product (Liao and Zhang 2008, Pattanayak and others 2002), was assumed to be -0.5 for all four SRTS products (softwood/hardwood sawtimber and nonsawtimber), the same assumption used by Abt and Abt (2010) for their Southwide timber supply analysis.

Demand for woody biomass for energy can also be met with fast-growing short rotation woody crop species, among them yellow-poplar (*Populus* spp.), willow (*Salix* spp.), cottonwood (*Populus fremontii* L.), sweetgum (*Liquidambar styraciflua*), sycamore (*Platanusoccidentalis*), black locust (*Robinia pseudoacacia*), silver maple (*Acer saccharinum* L.), and eucalyptus (*Eucalyptus cinerea*); these species have been identified by the U.S. Department of Energy as potentially viable for energy production. We followed the approach outlined by the Energy Information Administration (2010a) and assumed that short rotation woody crops would grow largely on nonforested lands (agricultural or pasture lands) and partially offset increased future wood requirements. We assumed of the offset to be 10 percent by 2050 and removed this material from woody biomass demands for bioenergy (in effect, treating short rotation woody crops as a part of the agricultural sector).

Although we describe our assumptions as consumption scenarios, it is important to understand that they are not demand projections, as we have not specified price-responsive demand relationships for woody biomass. The consumption projection is essentially a vertical demand curve added to the downward sloping demand curves for traditional forest products for each period using modified Energy Information Administration (2010b) projections. As a counterfactual, we also introduced a constant consumption scenario with no forest biomass-based energy market and ran the SRTS model to define the amount of woody biomass that would be required by traditional forest industry absent a bioenergy market. Subsequent years are held constant at the original 2010 level on the assumption that the traditional forest product industry will not increase wood consumption beyond what would be expected at the constant price level estimated by SRTS.

To account for uncertainty in bioenergy technologies, demands, and policies, we considered three consumption scenarios that we label high, medium, and low. The low-consumption scenario assumes that 7.74 percent of total electricity will derive from renewable sources based on Energy Information Administration (2010b) reference case projections. The medium-and high-consumption scenarios assume that 20 percent of total electricity consumption derives from renewable sources; in the high-consumption scenario, woody biomass is assigned a higher percentage of the total electricity generation from renewable sources (table 10.1).

Biomass Supply

The SRTS model accounts for forest inventory changes and timber removals based on historical forest inventory (FIA) data. However, southern forest productivity has seen a three-fold over the last 50 years from advancements in management and genetic improvements (Fox and others 2007). Siry and others (2001) projected that productivity gains for pine plantations could be as high as 100 percent of empirical FIA data (using data from the late 1990s) over the next 50 years. Prestemon and Abt (2002) assumed a 75-percent productivity gain in southern pine plantations from 2000 to 2040. With strong markets, other forest

Table 10.1—Allocation of woody biomass for energy production under woody biomass consumption scenarios by 2050

Woody biomass consumption scenario	Electricity	Liquid fuels	Wood pellets
Low	Based on Energy Information Administration (2010b) projections	Provides 30 percent of renewable energy sources	Based on Spelter and Toth (2009)
Medium	Increases to 20 percent of renewable energy sources by 2050, with share of total electricity sources remaining the same as in the low-consumption scenario	Increases to 50 percent of renewable energy sources by 2050, with 30 percent of total liquid energy coming from woody sources	Increases by 25 percent, 2015–50
High	Increases to 40 percent of renewable energy sources by 2050, with 20 percent of total electricity coming from woody sources	Increases to 50 percent of renewable energy sources by 2050, with 40 percent of total liquid fuel coming from woody sources	Increases by 50 percent, 2015–50

management types might experience productivity gains due to silvicultural improvements or improvements in management, although not as high as pine plantations.

We developed supply projections to examine alternative trajectories of productivity increases through 2050. In these projections, productivity growth is applied to every acre every year, so that over time the improved silvicultural practices on existing or new forest stands or genetic improvements of new plantations result in an aggregate growth response. For the "pine productivity" strategy, we assumed that pine plantation productivity increases steadily until it reaches 100 percent, while the productivity of other forest management types is held constant. For the "all productivity" strategy, we assumed a 100-percent pine plantation productivity increase and a 25-percent increase for other types. For the "low productivity" strategy, pine plantation productivity increases by 50 percent and the productivity of other types increases to 25 percent (tables 10.2 and 10.3). These assumptions are in line with hardwood field trials that report growth responses between 17 and 33 percent after stem density reduction, herbaceous competition control, and fertilization (Siry and others 2004).

Within SRTS, removals are treated as a function that responds to changes in the product price and the total biomass inventory. The timber supply elasticity with respect to inventory has been assumed to be 1.0 for all products and owners. For own-price elasticities of timber supplies (elasticity of product demand with respect to their own price), we used the average bootstrapped values for A1B and B2 cornerstone futures described in chapter 9, which vary across products and years and range from 0.18 to 0.32.

RESULTS

Market Analysis

By 2050, woody biomass consumption is projected to range from 150.16 million green tons for the low-consumption scenario to 235.88 million for the medium-consumption scenario and 316.12 million for the high-consumption scenario (fig. 10.2). The amount of urban wood waste amounts to about 12.72 million in 2010 and trends slightly upward throughout the projection period to reach 20.08 million by 2050. In contrast, the projection of biomass requirement for the forest products industry (held constant through the projection period) is about 278.46 million. By 2050, the biomass requirement for energy reaches about 54 percent of the forest products requirement for the low-consumption scenario and 85 percent for the medium scenario. For the high-consumption scenario, the bioenergy requirement exceeds the forest products requirement by 2045 and is 13 percent greater than the forest product requirement in 2050.

Adding urban wood waste and the forest biomass consumption requirement in 2050 would bring demand to 170 million tons for the low-consumption scenario, 256 million for the medium scenario, and 336 million for the high scenario. These estimates are comparable to other estimates in the literature if we assume that that supply of wood from the South mirrors the national harvest share—i.e., approximately 57 percent of national harvest as per Hanson and others (2010).

Without accounting for milling residues, Milbrandt (2005) estimated that just 86 million tons of woody biomass is readily available for energy production (roughly half of the projection for the low-consumption scenario). Walsh (2008) estimated that approximately 121 million tons of forest and mill residues could be supplied at a price of $100 per dry short ton, compared to estimates of 154 million tons by Kumarappan and others (2009). The Energy Information Administration (2007) estimated that approximately 414 million tons of wood from South might be required to meet the Federal goal of 25 percent of renewable fuel and electricity standards. Sample (2009) suggested that this demand figure could be much higher, estimating the yearly requirement at 992 million green tons. Perlack and others (2005) estimated that 420 million green tons of wood resources could be annually made available for energy production from southern forests.

Consumption increases of this magnitude (at a minimum, a 54 percent increase in timber harvesting) could imply a structural change in forest products markets. Analysis of traditional wood products markets (chapter 9) indicates that the supply of biomass could grow by about 43 percent under current levels of productivity without increased scarcity, largely because of declining demands for wood products. With plantation productivity growth at about 50 percent by 2060, forest biomass output could expand by as much as 70 percent without substantial impacts on market scarcity.

To identify the market implications of the three consumption scenarios, we ran the SRTS model, which provides projections of the removals from growing stock resulting from timber harvesting but does not distinguish among final products. To deduce the implications of increased woody biomass requirement for the traditional wood products industry, we disaggregated the removals projections into harvesting residues, additional removals that could not have occurred without woody bioenergy markets, and/or displacement from traditional wood product industry.

To ensure that some slash is left on the ground, we constrained the SRTS model so that no more than

Table 10.2—Simulations of supply responses when woody biofuels at three consumption levels are matched with four productivity strategies, 2050

Woody biomass consumption scenario	Productivity strategy	Details
Medium	Only improve pine plantation productivity	Productivity of pine plantations doubles; no change in other forest management types
Medium	Improve productivity on all management types	Productivity of pine plantations doubles by 2050 and productivity of other forest management types increases by 50 percent
High	Only improve pine plantation productivity	Productivity of pine plantations doubles; no change in other forest management types
High	Improve productivity on all management types	Productivity of pine plantations doubles and productivity of other forest management types increases by 50 percent
Short rotation woody crops	Improve productivity on all management types and expand short rotation woody crops	Short rotation woody crops growing on agricultural or pasture land offset 10 percent of wood energy demand; productivity of pine plantations doubles and productivity of other forest management types increases by 25 percent
High	Low productivity	Productivity of pine plantations increases by 50 percent and productivity of other forest management types increases by 25 percent

Table 10.3—Modified subregional timber supply model assumptions

Assumption	Scenario/Strategies	Details
Woody biomass consumption for electricity and biofuels	Low,Medium. High	Demand values in million green tons (Energy Information Administration 2010b)
Urban wood waste	Low,Medium. High	Per capita availability (Carter and others 2007)
Harvest residues	Low,Medium. High	SRTS model run based on Johnson and others (2009) data
Forest industry demand	Low,Medium. High	Auxiliary SRTS run for constant prices
Demand elasticity	Low,Medium. High	-0.5 for all products (Abt and others 2010)
Supply elasticity	Low,Medium. High	Different annual values for products based on RPA storylines[a]
Pine productivity	Pine productivity strategy	Pine productivity increases by 100 percent by 2050
All productivity values	All productivity strategy	Pine productivity increases by 100 percent and other forest type increases by 50 percent by 2050
Low productivity values	Low productivity strategy	Pine productivity increases by 50 percent and other forest type increases by 25 percent by 2050
Short rotation woody crops	Short rotation woody crops	Short rotation woody crops take care of 10 percent of total woody biomass for energy demand by 2050
Forest management type acreage	All scenarios and strategies	Forest land change as compared to agriculture and pasture land, in turn impacting acreage of pine plantations, natural pines, oak-pines, upland hardwoods, and lowland hardwoods (Abt and Abt 2013, Hardie and others 2001)
Timber rent	All scenarios and strategies	Weighted average of pulp and sawtimber prices. Model allocates weights, with pulpwood gaining more weight in total rent calculations
Degradation of sawtimber for pulp use	All scenarios and strategies	Percentage allocation of sawtimber that can be used as pulp (Abt and others 2010)
Pulp diameter range	All scenarios and strategies	<9 inch softwood <13 inch hardwood
Sawtimber diameter range	All scenarios and strategies	>9 inch softwood >13 inch hardwood
Forest products	All scenarios and strategies	Sawtimber softwoods, other softwoods, sawtimber hardwoods, and other hardwoods

[a]Personal communication. 2010. David N. Wear, Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695.

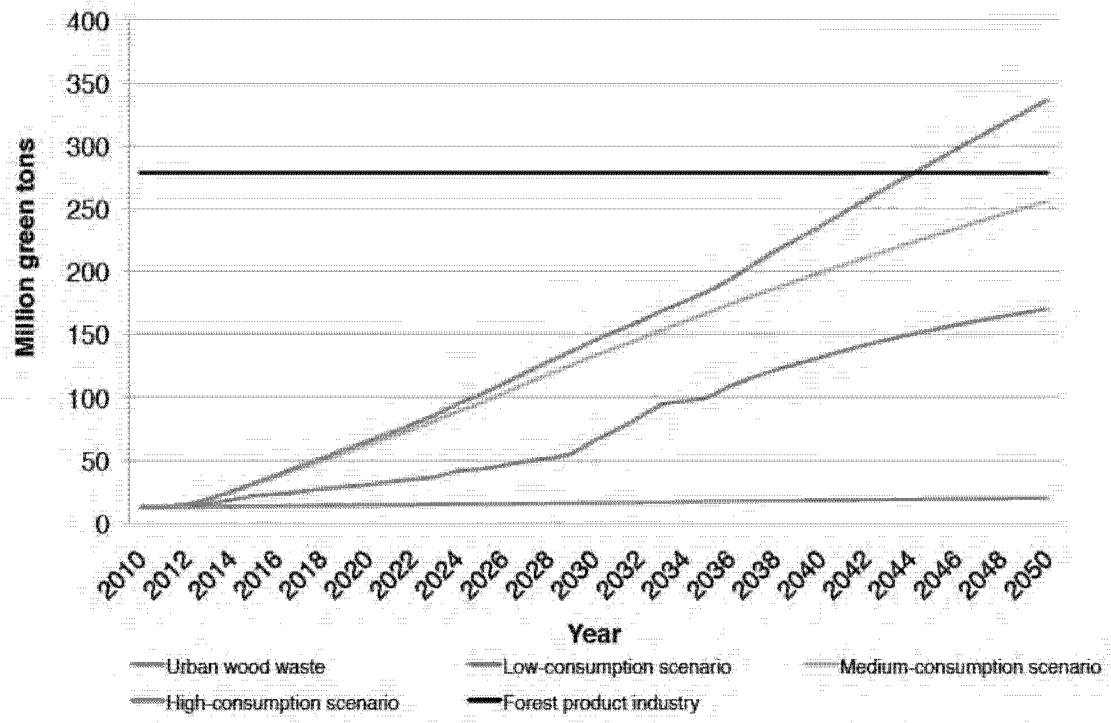


Figure 10.2—Woody biomass demand for energy in the South under low-, medium-, and high-consumption scenarios, with demand from traditional forest industry and availability from urban wood waste, 2010 to 2050.

67 percent of harvesting residues could be diverted for energy production. The constant consumption scenario (with no expanded demand for bioenergy) defines a base harvest projection for the traditional wood products industry. Comparing the SRTS projections for a bioenergy consumption scenario with the base harvest for forest industry defines the additional harvesting associated with the bioenergy scenario (new removals). Comparing new removals with the bioenergy requirement (less harvest residues) provides an estimate of the timber that would be diverted from forest industry for woody biomass-based energy production (displacement). Because the maximum amount of product displacement is constrained by forest product industry consumption, the possible product shortfalls that may arise due to additional biomass demands for bioenergy are met by other softwood and hardwood product removals.

The remaining paragraphs in this section summarize projections that assume a base harvest for forest industry and three bioenergy consumption scenarios without in the absence of supply expansion through productivity growth.

No consumption for bioenergy—Figure 10.3 shows the results of the SRTS model run for four product types (sawtimber softwoods, other softwoods, sawtimber hardwoods, and other hardwoods), expressed in terms of index values for prices, inventory, and removals with respect to 2007 levels. Prices decline, and inventory and removals increase for all hardwoods and for sawtimber softwoods; the reverse is predicted for the other (nonsawtimber) softwoods. This is consistent with a SRTS-based analysis (Abt and Abt 2010) that plays out the implications of a protracted recession. The scenario predicts 10 percent declines in Southern private forest acreage from 2010 to 2050 (fig. 10.4), which is consistent with the maximum projected forest losses described in chapter 4 and with the forest product demand analysis contained in chapter 9, which predicted constant or somewhat expanding harvest levels and declining timber prices.

Low woody biomass consumption—Harvest, inventory, and removals projections for sawtimber under the low-consumption scenario are similar to the no-consumption scenario projections (fig. 10.5), although the price reductions for sawtimber are somewhat lower. Change in prices, inventory, and removals reflect an inelastic market response as price changes more than removals or inventory.

Consistent with Rossi and others (2010), demand for wood energy leads to price increases for other (nonsawtimber) softwoods beginning in about 2016, when supplies of urban wood wastes are unable to meet the extra demand of wood for energy production, and somewhat later for nonsawtimber hardwoods. The associated price increases are more than triple 2007 levels. Substantial timber is diverted away from

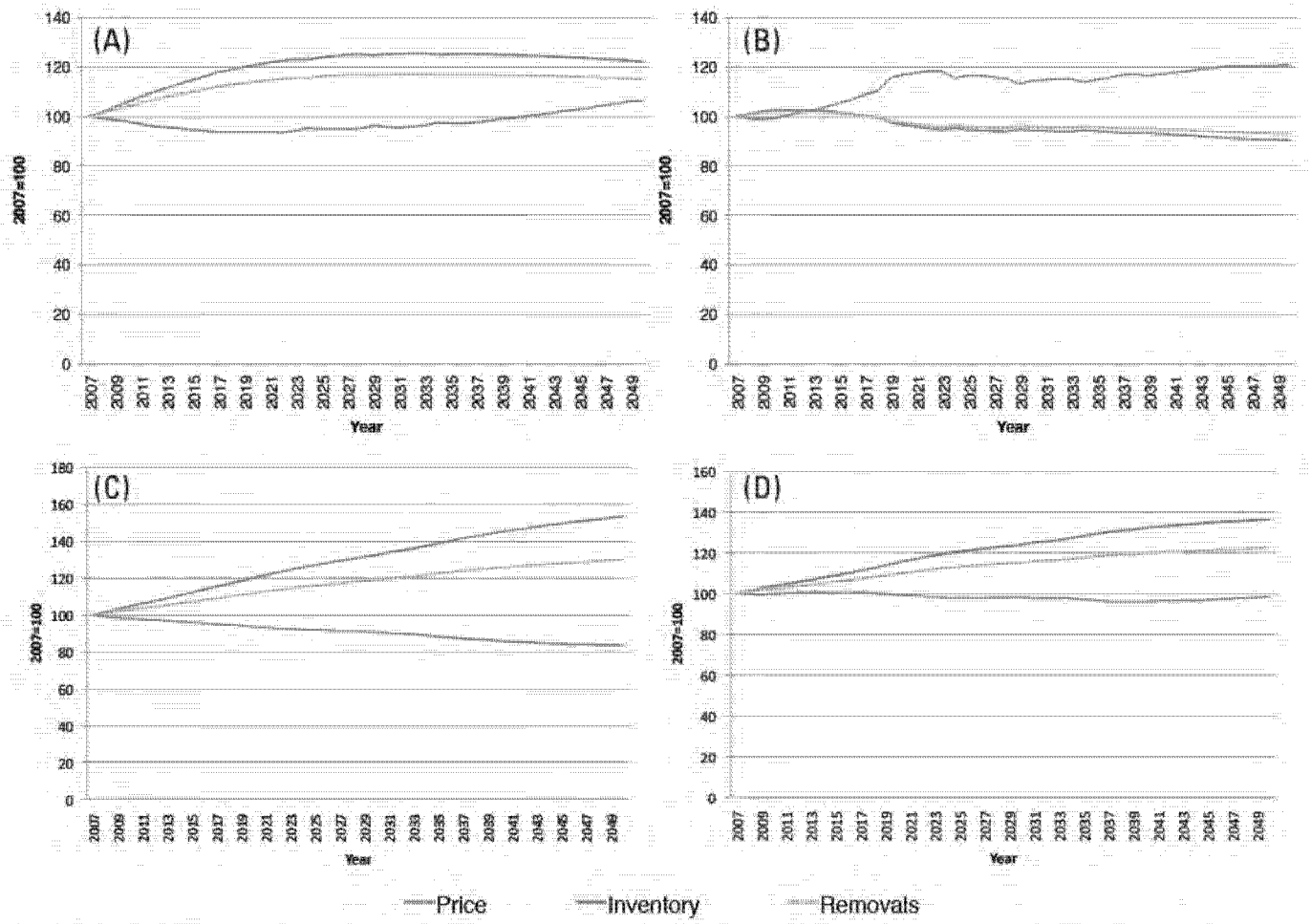


Figure 10.3—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods in a constant forest industry consumption scenario (no biomass diverted to energy).

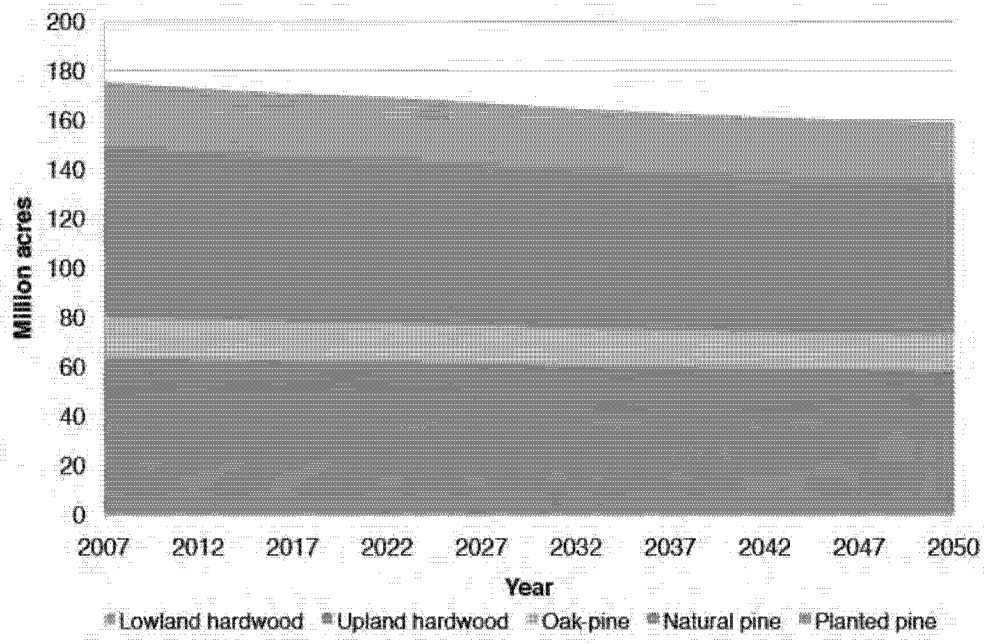


Figure 10.4—Private forest acreage change in the South under a constant forest industry consumption scenario (no biomass diverted to energy).

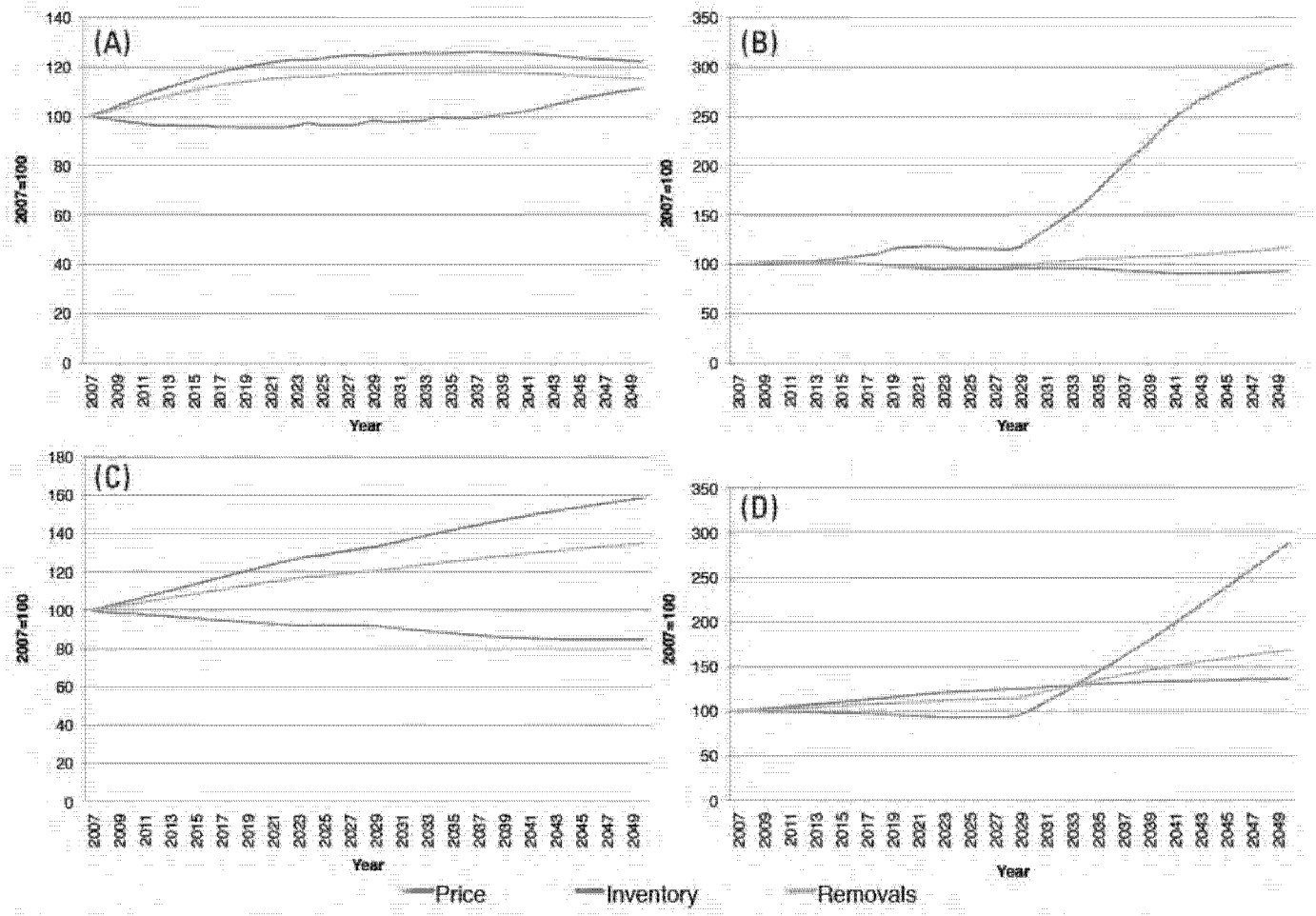


Figure 10.5—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods, assuming low consumption of woody biomass for energy.

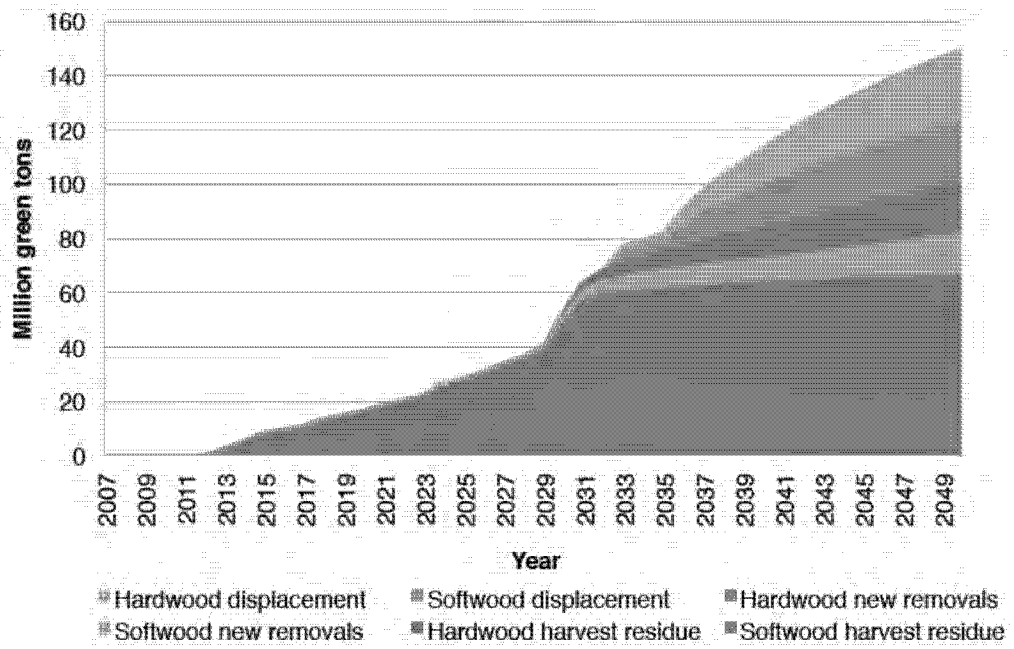


Figure 10.6—Feedstock composition in the South, assuming low consumption of woody biomass for energy.

forest industry for energy production (fig. 10.6), with 22 million green tons of softwoods and 26 million green tons of hardwoods diverted for bioenergy production by 2050. The impact of woody bioenergy markets on sawtimber is insignificant as the displacement of nonsawtimber products takes care of additional woody biomass requirements.

Under this scenario, private forest acreage declines by 3 percent from 175.39 million acres in 2010 to 170.86 million acres in 2050 (fig. 10.7), although still 8 percent higher than for the no bioenergy consumption scenario. Pine plantation acreage increases by 7 percent accompanied by declines in the other forest management types. The increase in pine plantation area is consistent with expansion in pine planting by landowners in response to increased product prices.

Medium woody biomass consumption—Compared to the low-consumption scenario, this scenario produces more dramatic price increases earlier (fig. 10.8). By 2050, prices of nonsawtimber softwoods, nearly four times higher than 2010 levels, are somewhat moderated as landowners by increase plantings and higher pine plantation acreages in response to greater demand, causing inventory to be higher than both the no-consumption and low-consumption scenarios. Nonsawtimber hardwood prices are even higher because the model assumes that landowners will not plant slow growing hardwoods in response to increased scarcity. Plantations of fast growing hardwoods (short rotation woody crops) have been treated separately as part of agriculture, and are not included in new plantation response. The pulp industry is adversely impacted as significant supply is diverted from forest industry to energy production (fig. 10.9). Forest industry demand for nonsawtimber hardwoods is completely wiped out by 2039, and 82 percent of stocking is diverted for energy production by 2050.

Price declines for sawtimber are lower, resulting in higher price levels in the later years of this scenario compared to the no-consumption scenario. The inventory and removals also respond to the price increase, as higher prices and inventory levels translate to increases in removals. The sawtimber industry faces significantly lower impact as most of the bioenergy demands are met by displacement and new removals of other hardwoods and softwoods.

Under this scenario, the private forest acreage increases by 3 percent from 175.39 million acres in 2010 to 181.41 million acres in 2050 (fig. 10.10), 14 percent higher than the no-consumption scenario, largely caused by increases in pine plantation acreage (19 percent from current levels) that offset the decline in the other four forest management types.

High woody biomass consumption—Compared to the medium- or low-consumption scenarios, this scenario assumes that a larger share of the U.S. energy portfolio is sourced from woody biomass (fig. 10.11); with prices

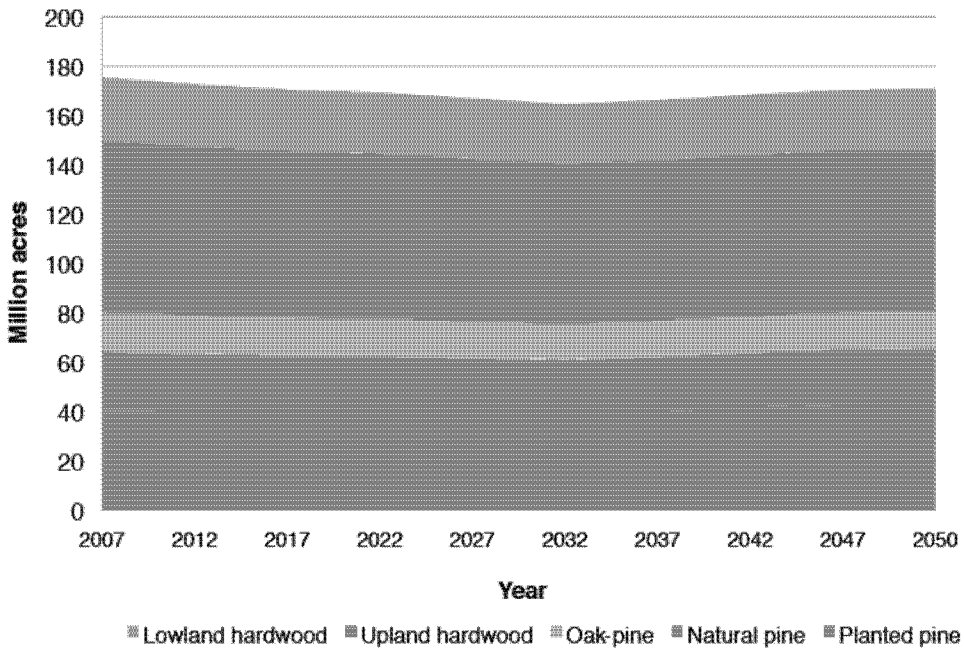


Figure 10.7—Private forest acreage change in the South, assuming low consumption of woody biomass for energy.

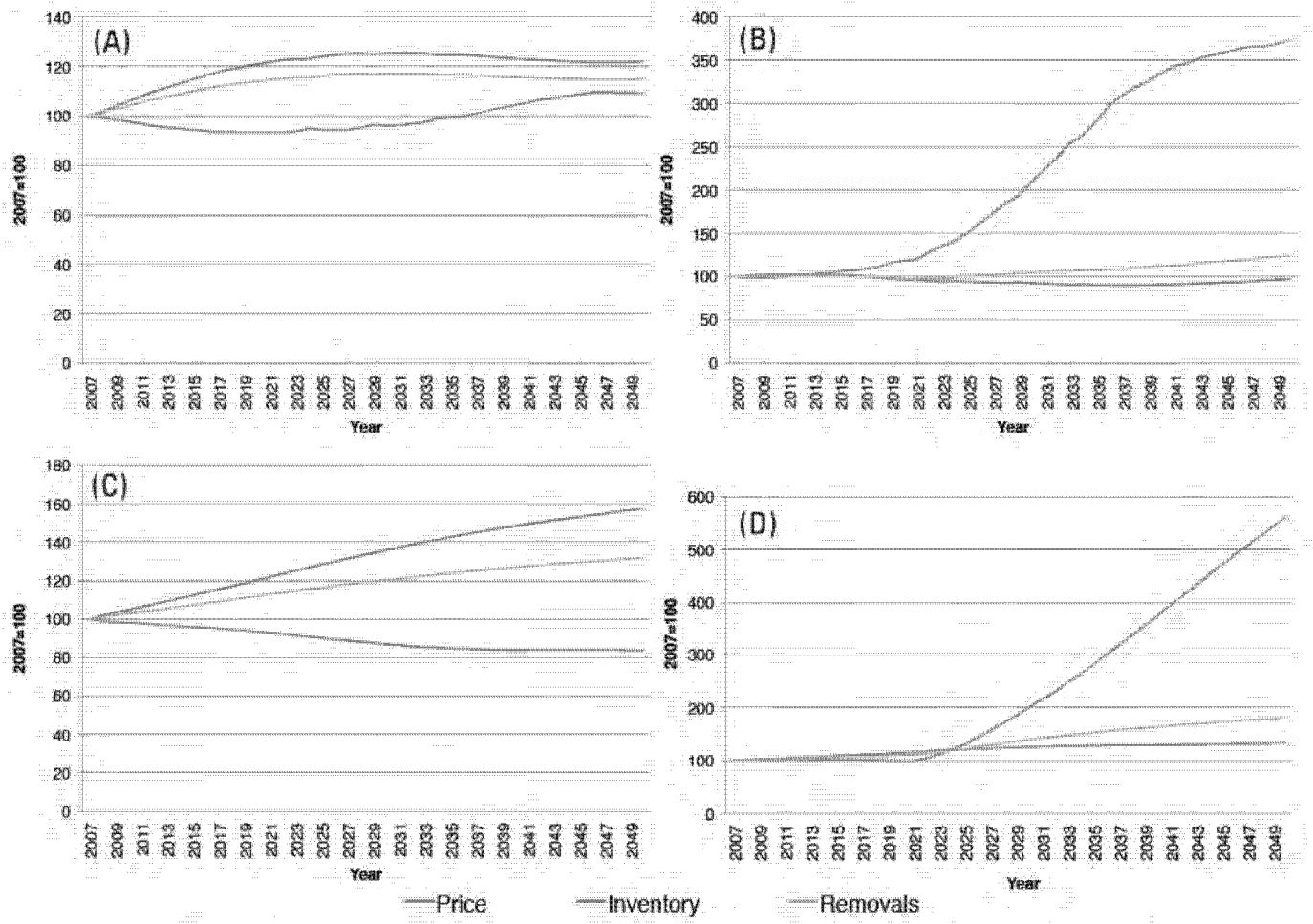


Figure 10.8—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods, assuming moderate consumption of woody biomass for energy.

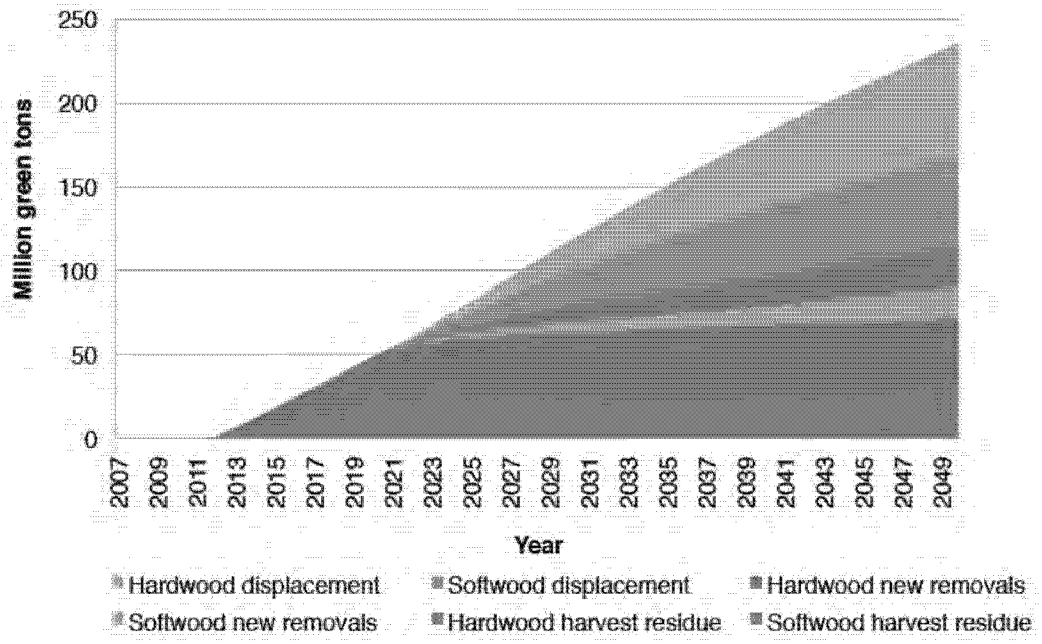


Figure 10.9—Feedstock composition in the South, assuming moderate consumption of woody biomass for energy.

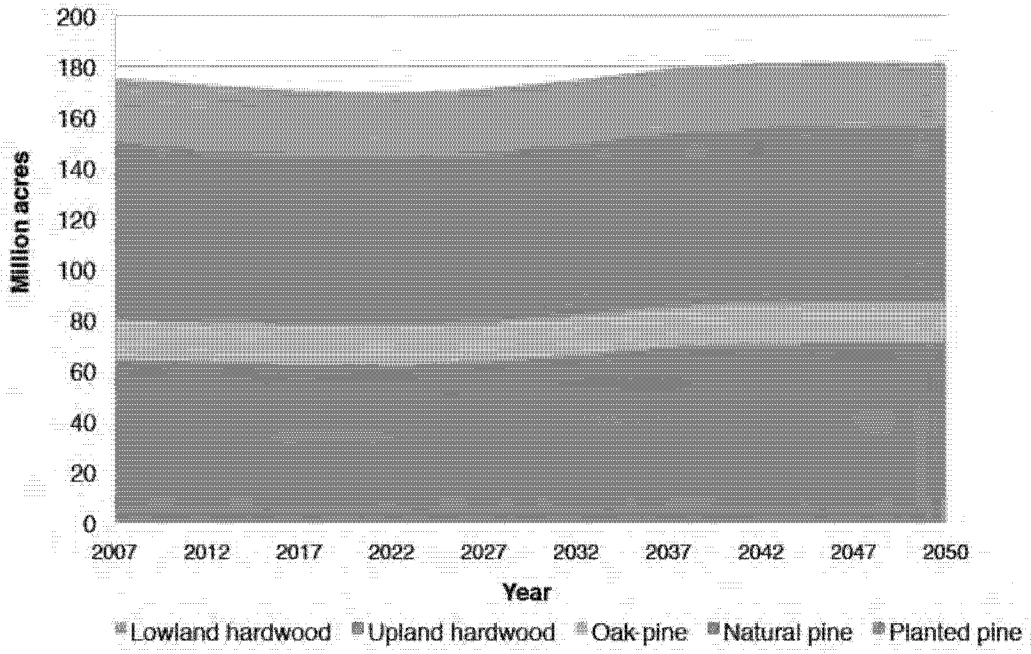


Figure 10.10—Private forest acreage change in the South, assuming moderate consumption of woody biomass for energy.

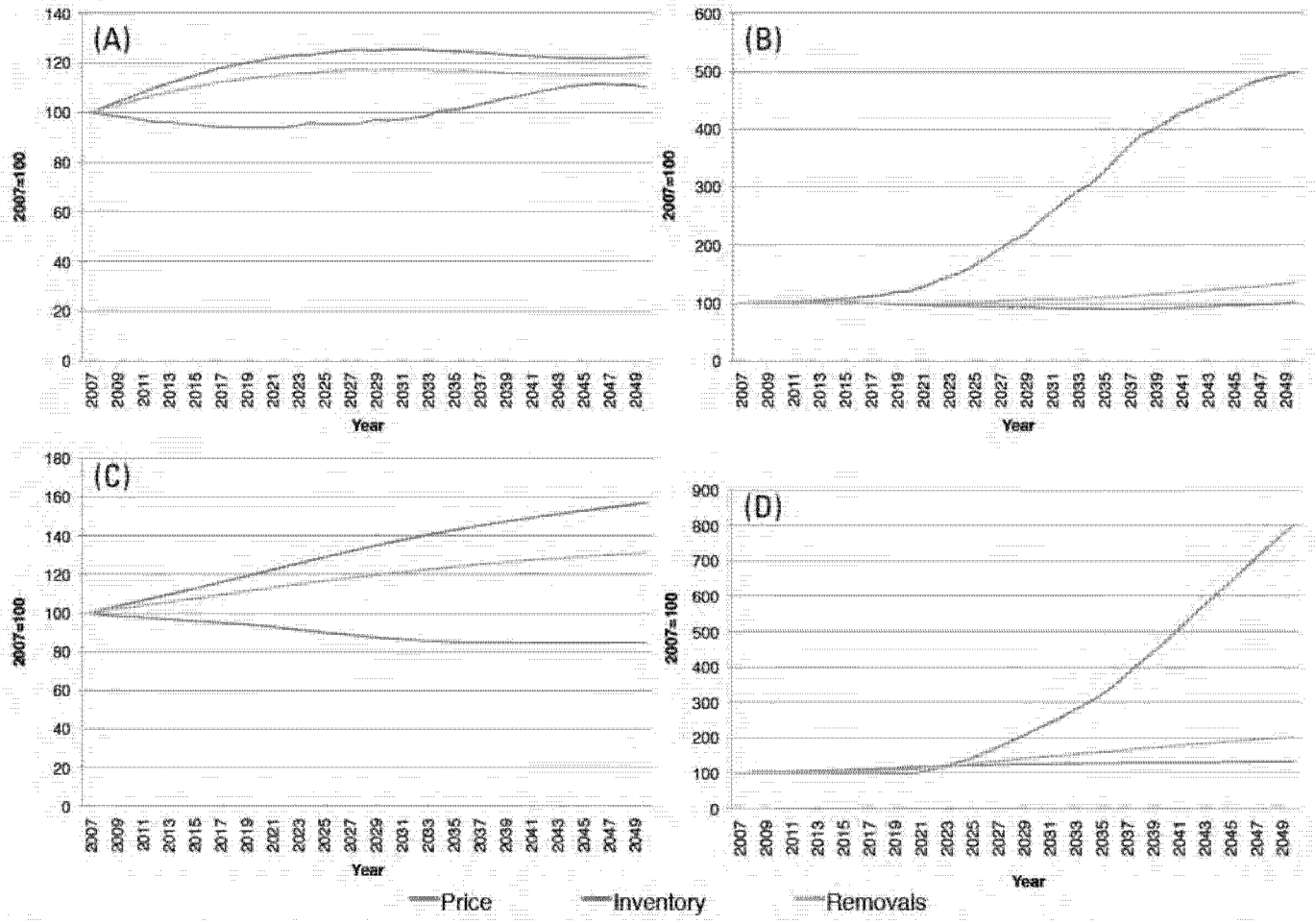


Figure 10.11—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods, assuming high consumption of woody biomass consumption for energy.

reaching five times the 2007 level for softwoods, and eight times the 2007 level for hardwoods. Inventory and harvest levels for softwoods are higher compared to low- or no-consumption scenarios, but lower than the medium scenario; for hardwoods, inventory levels are much higher than the no- or low-consumption scenarios and removals are higher than all other scenarios. The pulp industry is adversely impacted as significant supplies are diverted to energy production (fig. 10.12). The bioenergy requirement is not met by new removals, pulpwood, or harvesting residues, resulting in a complete elimination of forest industry demand for hardwoods by 2037 followed by softwoods in 2043.

The prices, inventory, and removal levels of sawtimber are similar to the other consumption scenarios. The industry would experience a significant impact as 91 million green tons of sawtimber is diverted to energy production. The increased acreage of pine plantations might result in some of the softwood timber moving to sawtimber diameters. Significant amounts of hardwood sawtimber are also diverted to energy production.

Private forest acreage increases by 9 percent from 175.39 million acres in 2010 to 191.6 million acres in 2050 (fig. 10.13), 21 percent higher than the no-consumption scenario. All forest management types except natural pines increase in area by 2050, led by a 33 percent increase in pine plantation acreage. Initial acreage declines for upland and lowland hardwoods and oak-pines are reversed after 2027, resulting in a 2-percent net increase by 2050.

Supply Adjustment Strategies

Increased consumption for wood by a new woody bioenergy industry can be expected to result in the supply side adjustments such as the use of short rotation woody crops and the increased productivity strategies described below.

Productivity increases limited to pine plantations—An increase in pine plantation productivity would do more to dampen nonsawtimber softwood price increases in the medium- and high-consumption scenarios (fig. 10.14) than in the no- and low-consumption scenarios (which do not stimulate productivity gains), with prices falling until the late 2020s before beginning to increase again. Inventory and removals levels are also higher. The increase in productivity of pines also lowers price responses for hardwoods, largely because increased softwood inventories fulfill the demands for bioenergy.

Figure 10.15 shows price, inventory, and removal projections for sawtimber under medium-and high-consumption scenarios. For softwood sawtimber, productivity increases in pine plantations also result in lower prices and higher inventory and removals under both increased productivity strategies, with the medium-consumption scenario providing a greater price dampening effect than the high-consumption scenario. Price trends are the same for hardwood sawtimber but the decreases are less extreme. Higher inventory levels result from the increase in productivity, which reduces prices. The impact on the sawtimber-using industry is also reduced. For example, in the high-consumption scenario 54.5 million green tons of sawtimber from both hardwoods and softwoods is diverted to energy use in the pine productivity strategy as compared to 91 million green tons associated with no productivity increases. The decreased impact on the forest industry is due to expanded removals supported by increased productivity.

Productivity increases result in higher removals and less displacement from forest industry (fig. 10.16). The softwoods being used by forest industry are still completely diverted for energy production in the high-consumption scenario, but this occurs later.

Forest management type trends are similar for the medium- and high-consumption scenarios, with increases in pine productivity resulting in lower levels of private forest acreage for both scenarios (fig. 10.17)—9.6 percent for the medium- and 10.2 percent for the high-consumption scenario—albeit much higher than for the no-consumption scenario. Because productivity gains are limited to softwoods, a higher share of the wood requirements for woody bioenergy markets is met by softwoods than hardwoods. Acreage declines across all five management types, with the highest rate of decline in pine plantations.

Productivity increase extended to all management types—A productivity increase for all forest types results in price, inventory, and removal responses that are similar to those observed for increases in pine plantations alone, the only difference being in the magnitude of change. Softwood price is lower and inventory and removal levels are higher (fig. 10.18). Hardwood trends for medium- and high-consumption scenarios are similar to the softwoods, with lower prices and higher inventories and removals than was projected for planted forest types alone (fig. 10.19).

Nonsawtimber softwoods used by forest industry are still completely diverted to energy production in the high-consumption scenario, but the impact on the sawtimber-using industry is reduced. For example, in the high-consumption scenario, 36.38 million green tons of sawtimber from is diverted to energy use as compared to 53.5 million green tons with pine productivity alone and 91 million green tons with no productivity (fig. 10.20). Higher removals of sawtimber are attributed to unharvested pulpwood timber moving into the higher diameter sawtimber class. The productivity increases therefore result in higher acreage and higher inventory at the aggregate level.

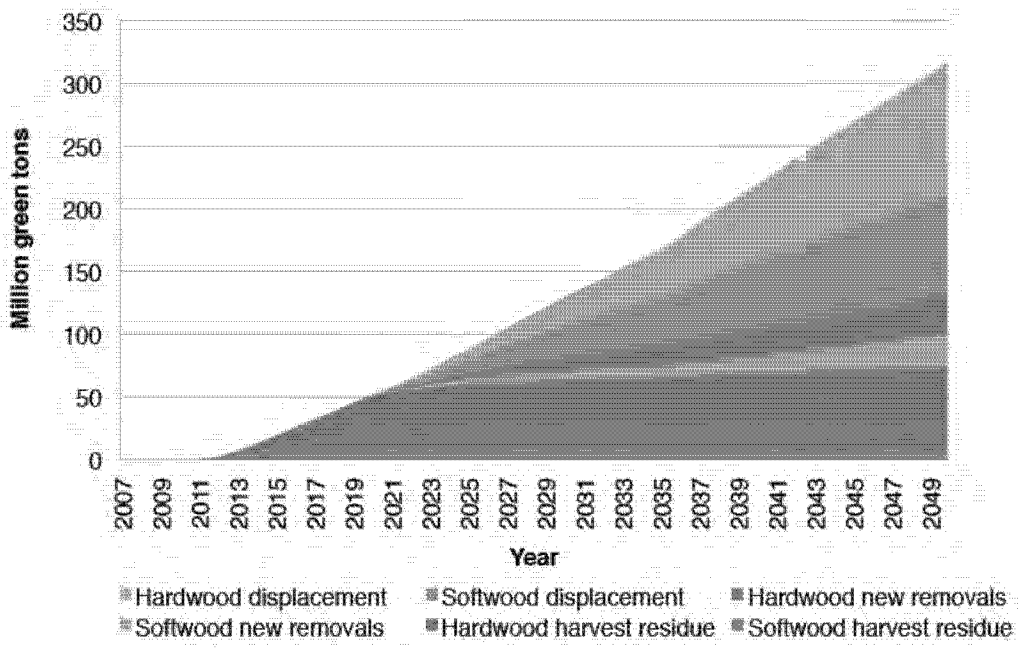


Figure 10.12—Feedstock composition in the South, assuming high consumption of woody biomass for energy.

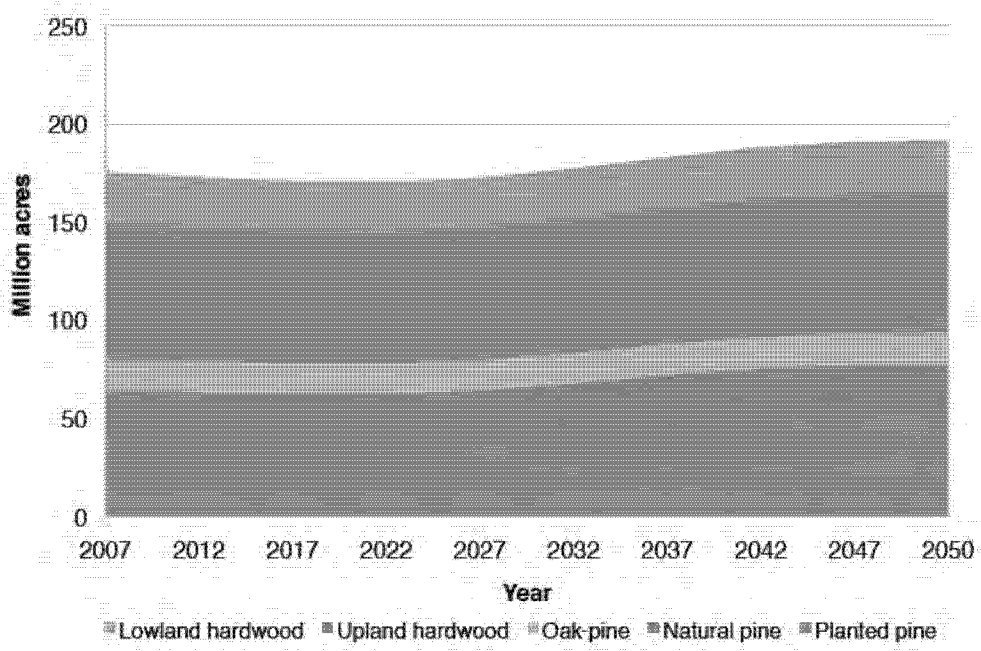


Figure 10.13—Private forest acreage change in the South, assuming high consumption of woody biomass for energy.

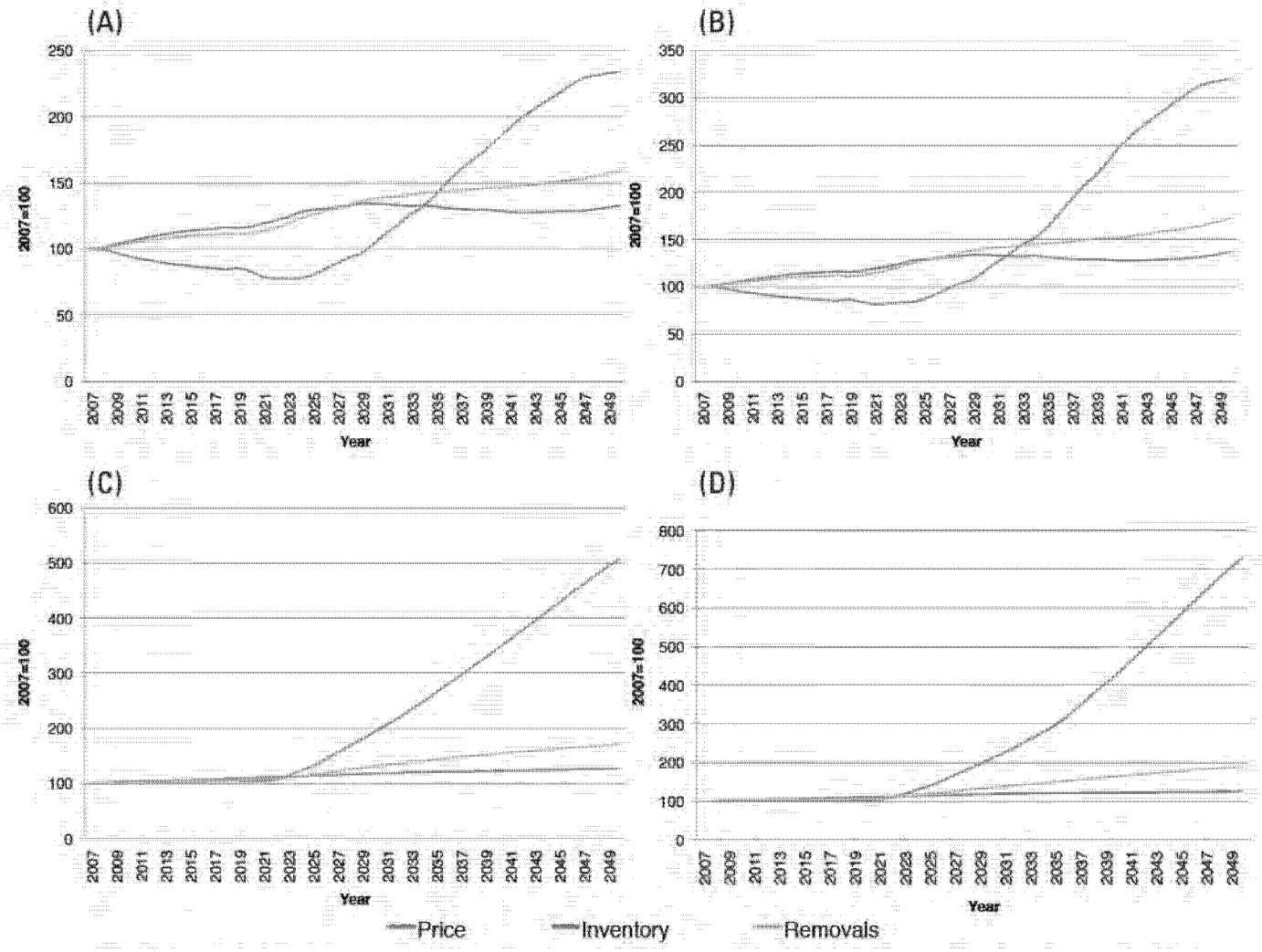


Figure 10.14—Under a productivity strategy that is limited to pine plantations, market responses in price, inventory, and removals for southern (A) nonsawtimber softwoods and (B) nonsawtimber hardwoods—both assuming moderate consumption of woody biomass for energy, and for southern (C) nonsawtimber softwoods and (D) nonsawtimber hardwoods—both assuming high consumption of woody biomass for energy.

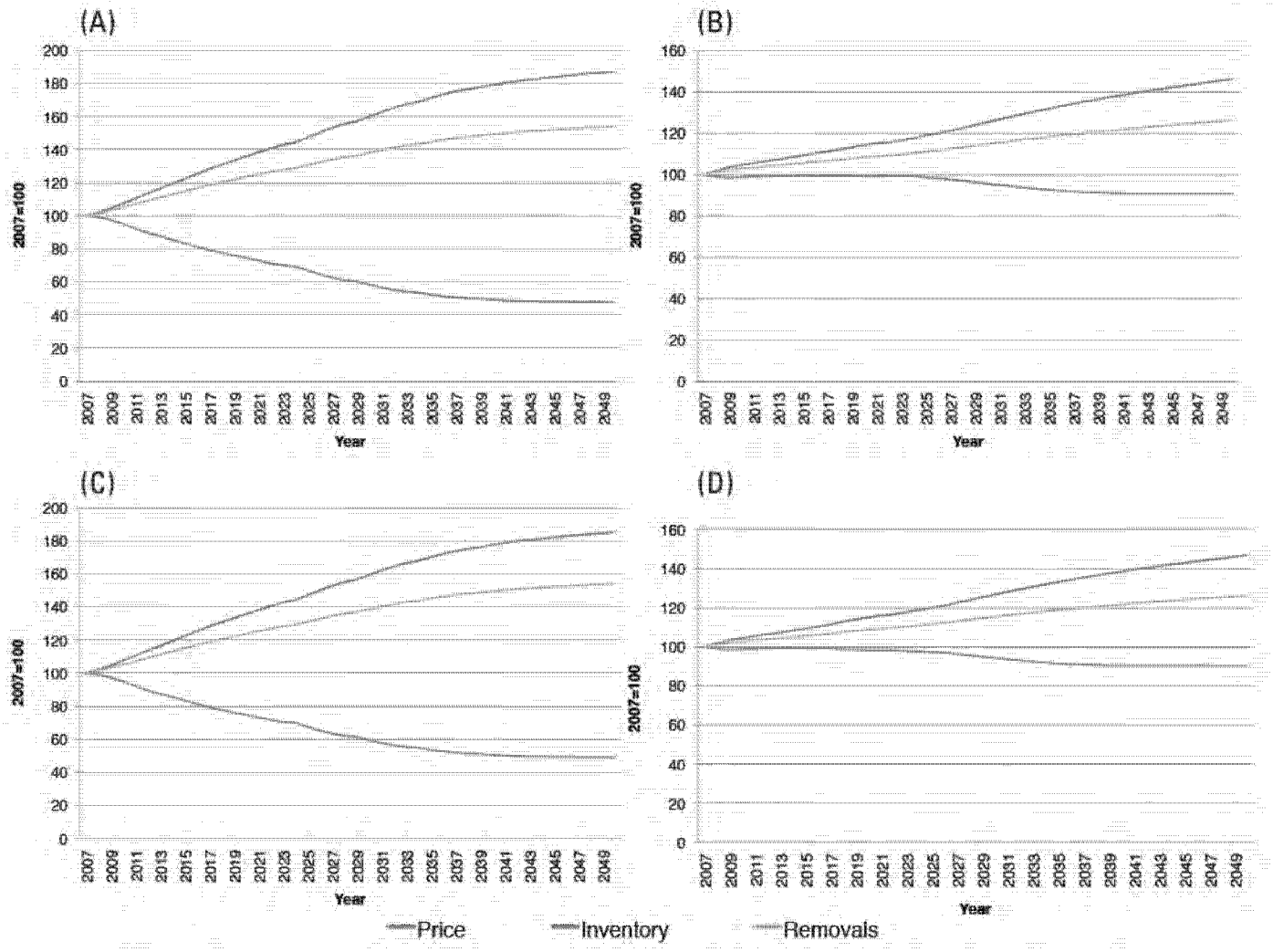


Figure 10.15—Under a productivity strategy that is limited to pine plantations, market responses in price, inventory, and removals for southern (A) softwood and (B) hardwood sawtimber—both assuming moderate consumption of woody biomass for energy; and (C) softwood and (D) hardwood sawtimber—both assuming high consumption of woody biomass for energy.

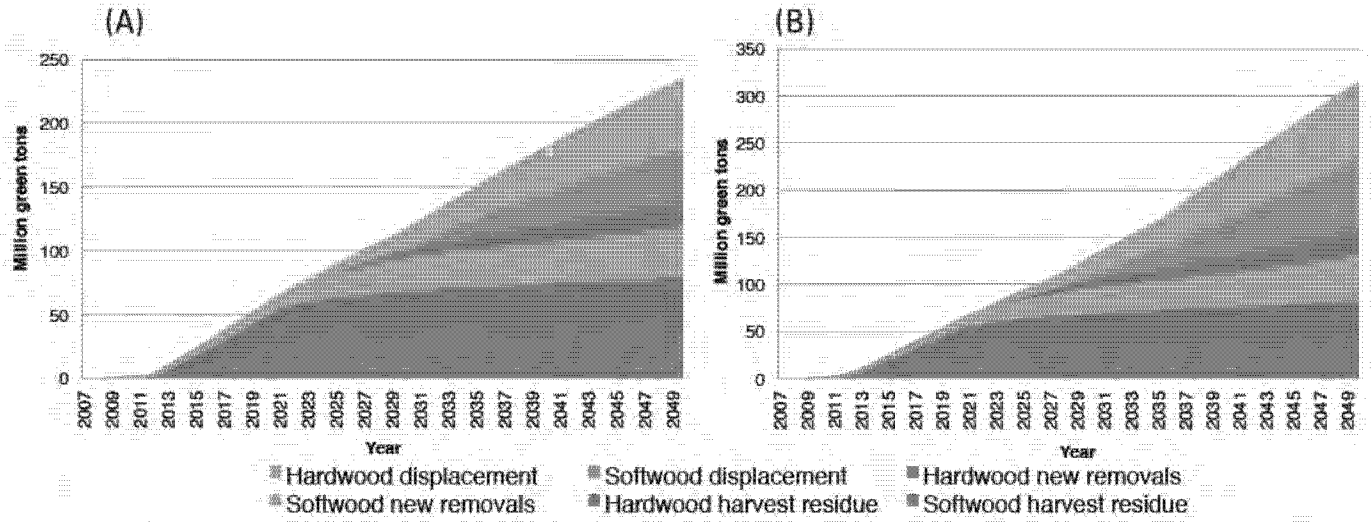


Figure 10.16—Under a productivity strategy that is limited to pine plantations, feedstock composition in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

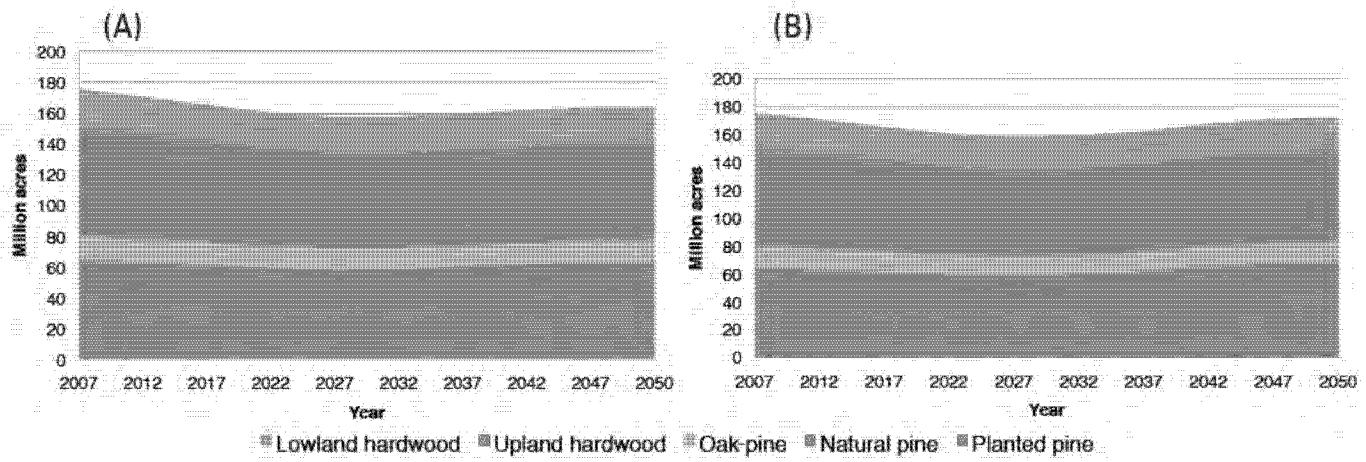


Figure 10.17—Under a productivity strategy that is limited to pine plantations, forest acreage change in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

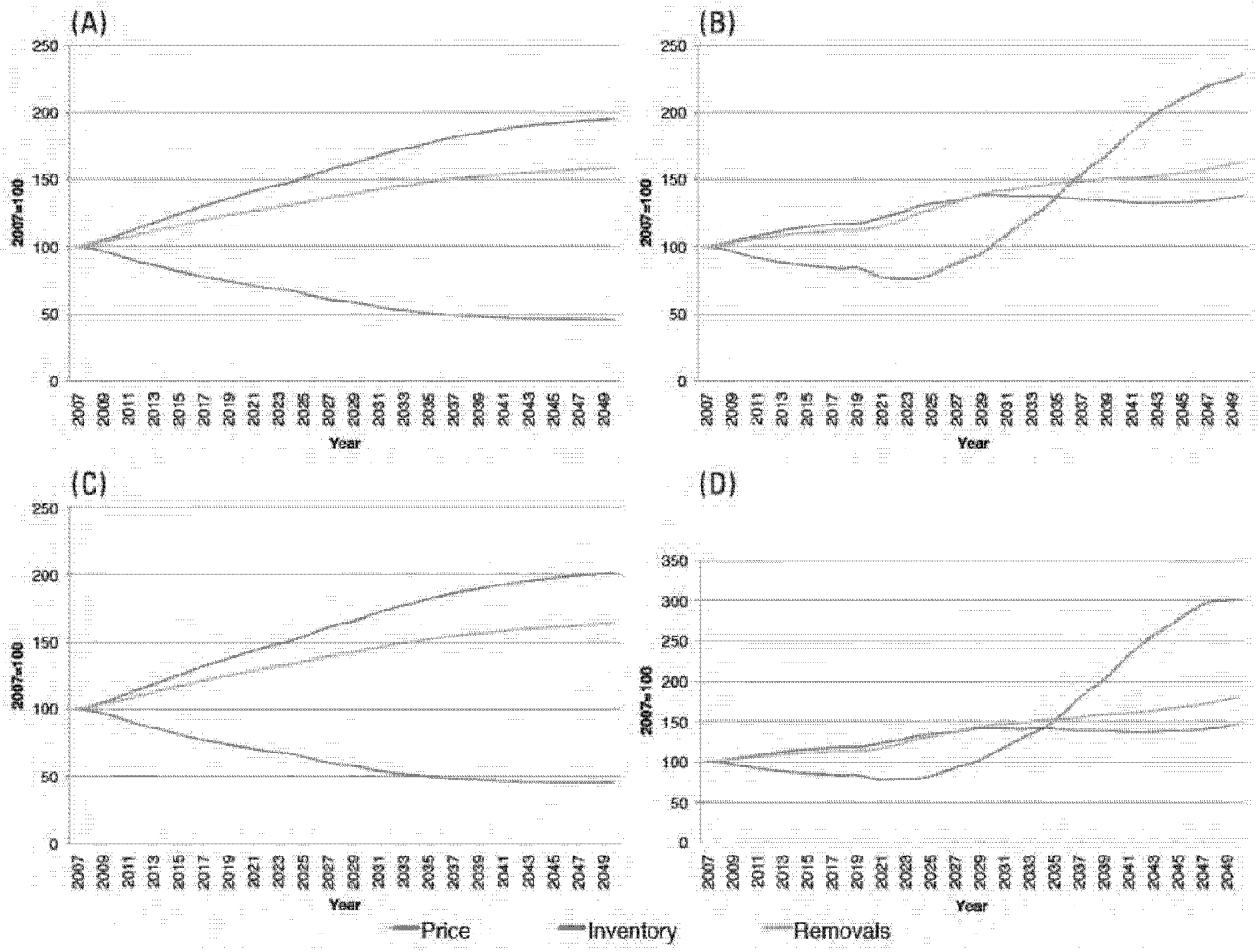


Figure 10.18—Under a productivity strategy that extends to all forest management types, market responses in price, inventory, and removals for southern (A) softwood sawtimber and (B) other softwoods—both assuming moderate consumption of woody biomass for energy; and (C) softwood sawtimber and (D) other softwoods—both assuming high consumption of woody biomass for energy.

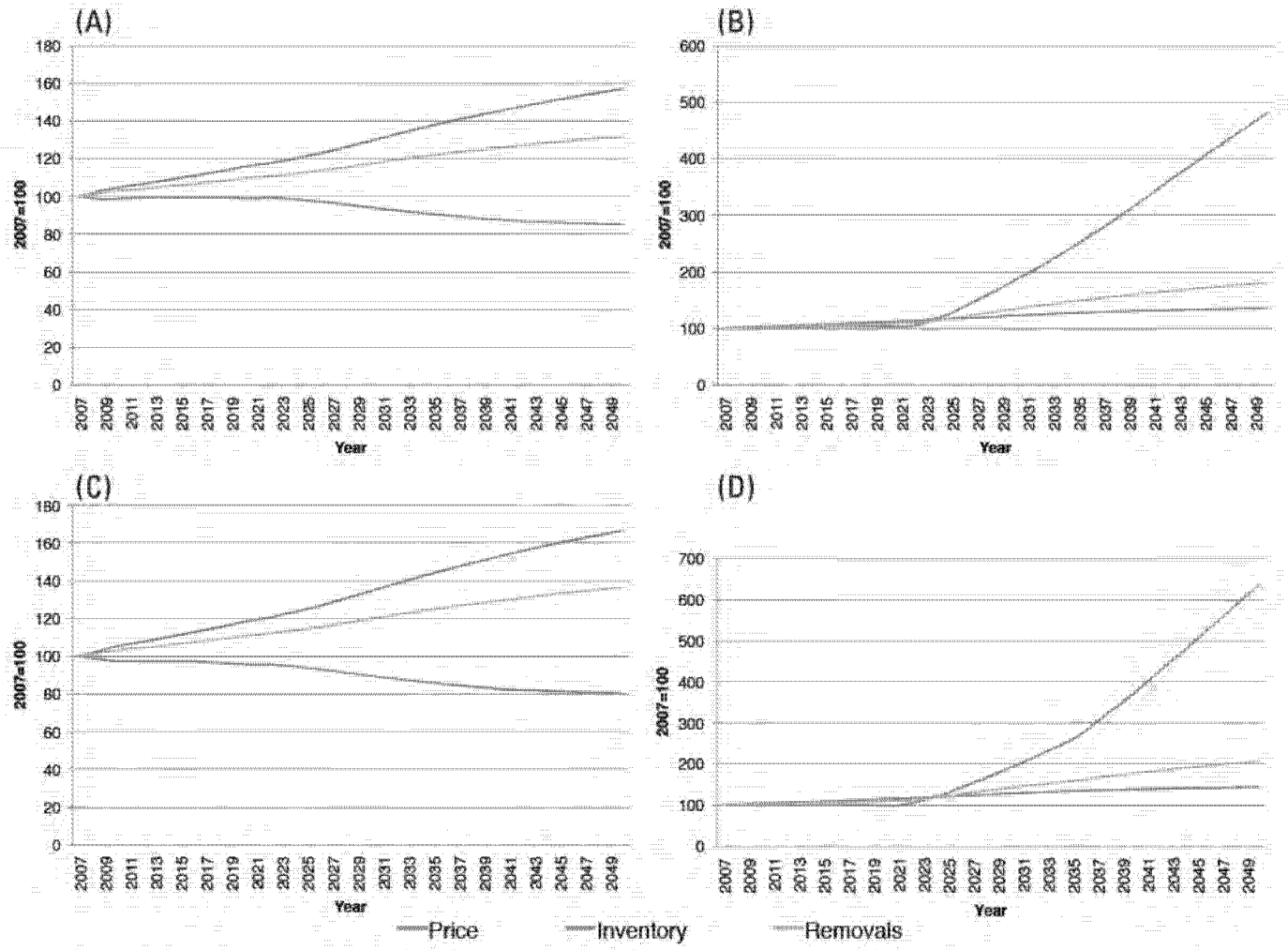


Figure 10.19—Under a productivity strategy that extends to all forest management types, market responses in price, inventory, and removals for southern (A) hardwood sawtimber and (B) other hardwoods—both assuming moderate consumption of woody biomass for energy; and (C) hardwood sawtimber and (D) other hardwoods—both assuming high consumption of woody biomass for energy.

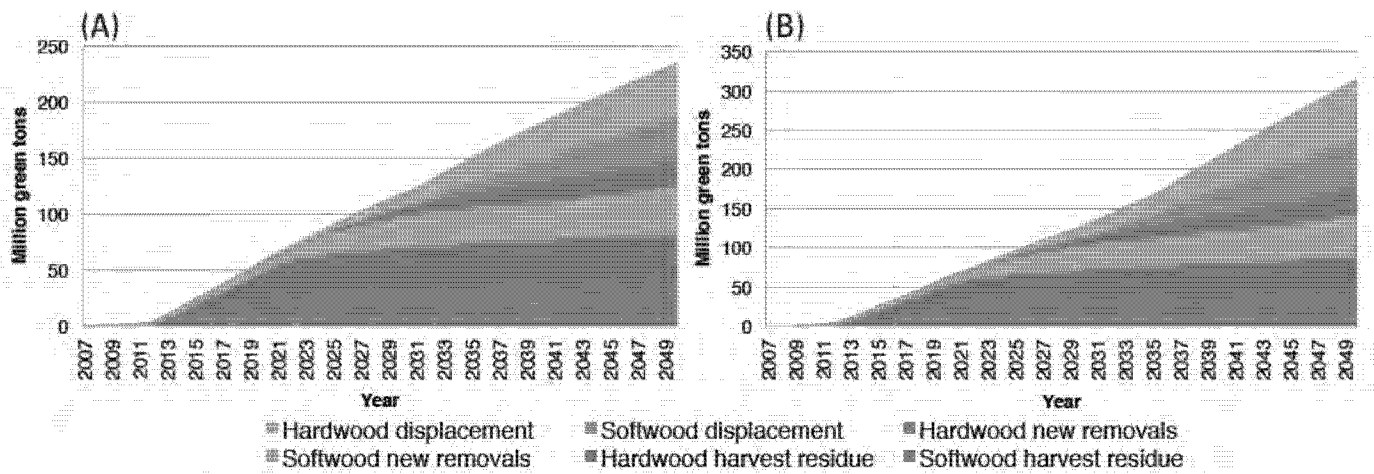


Figure 10.20—Under a productivity strategy that extends to all forest management types, feedstock composition in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

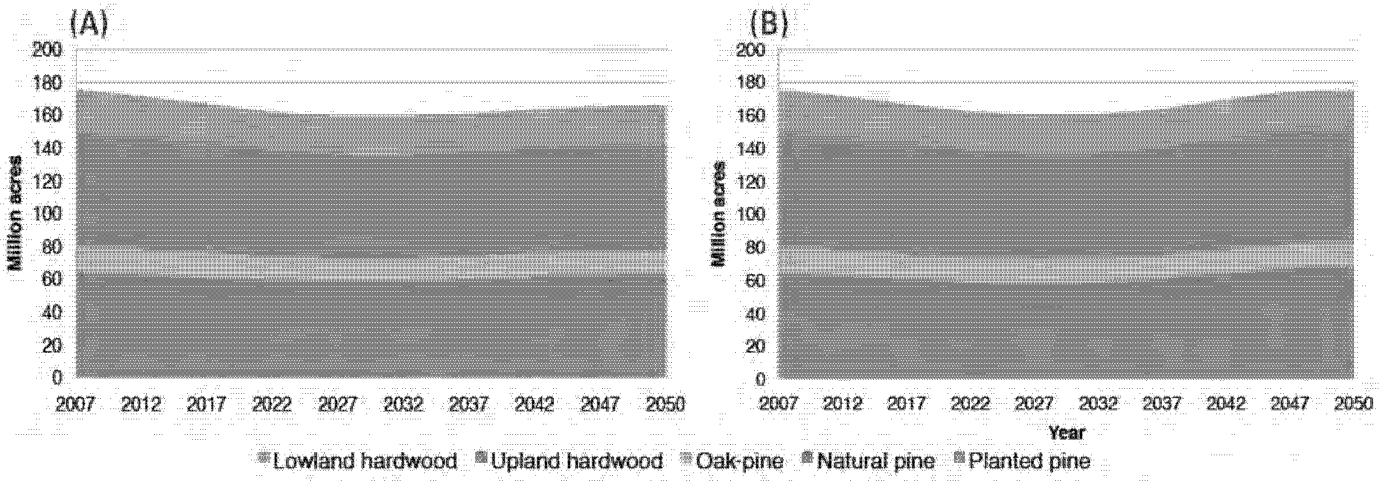


Figure 10.21—Under a productivity strategy that extends to all forest management types, private forest acreage change in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

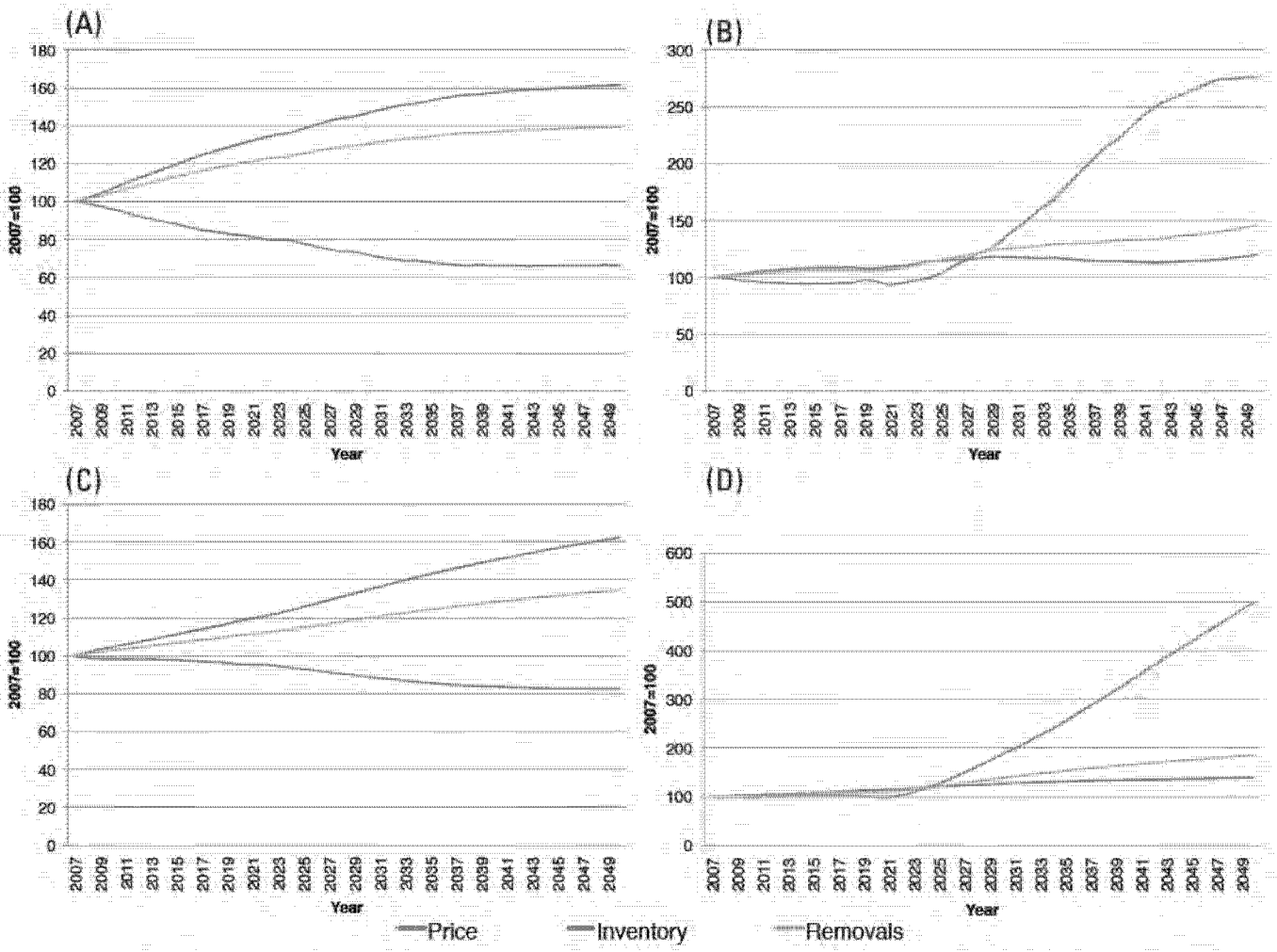


Figure 10.22—Under a low-productivity strategy, market responses in price, inventory, and removals for southern (A) softwood sawtimber (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods—all assuming moderate consumption of woody biomass for energy.

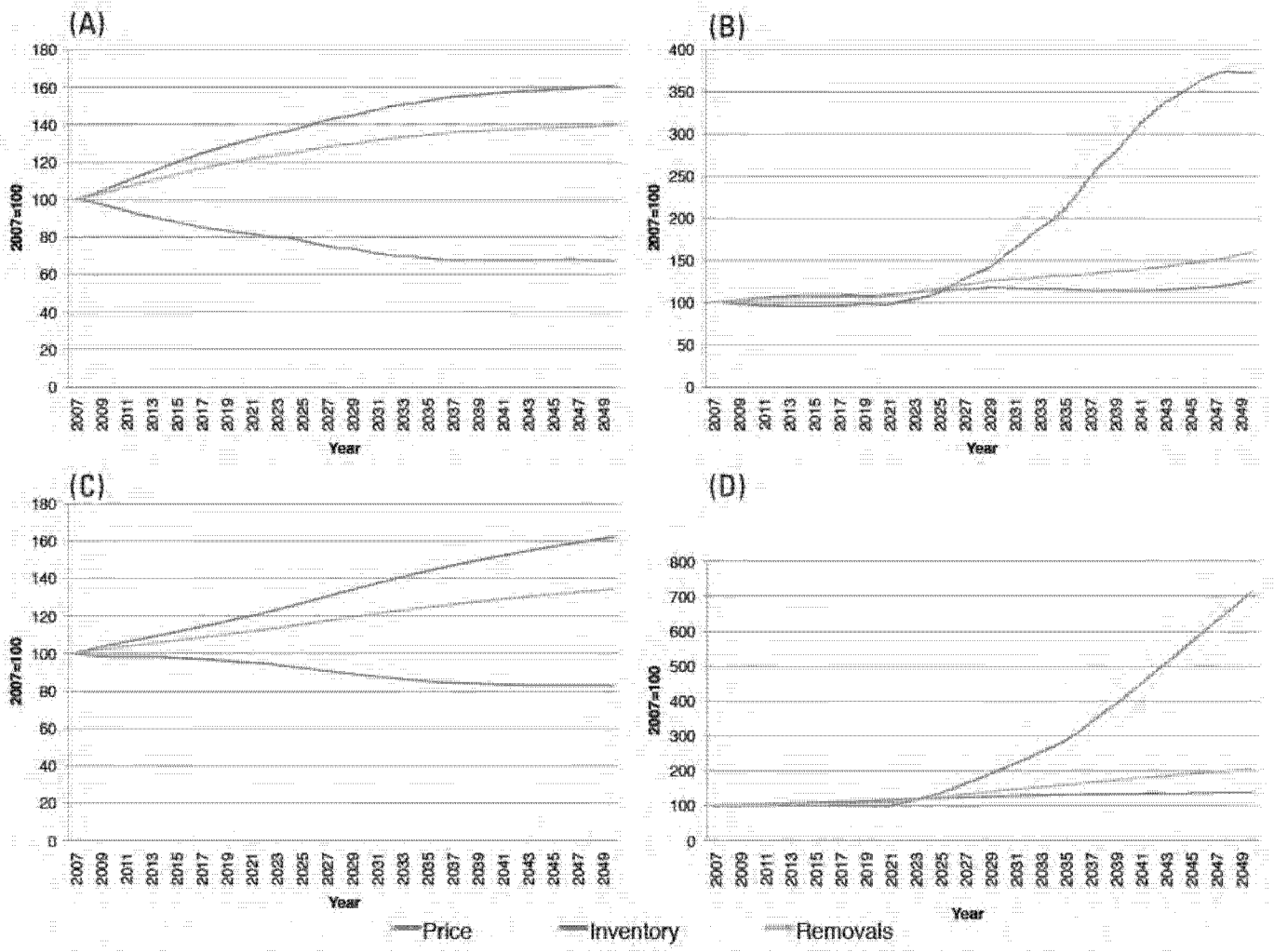


Figure 10.23—Under a low-productivity strategy, market responses in price, inventory, and removals for southern (A) softwood sawtimber (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods—all assuming moderate consumption of woody biomass for energy.

Compared to planted-pine-alone productivity strategy, this approach increases total forest area for both medium-consumption scenario (165.52 million acres) and the high-consumption scenario (175.01 million acres), with acreage increases for all forest management types except pine plantations (fig. 10.21).

Low productivity increase—Lower productivity increases combined with medium- and high-consumption scenarios result in price, inventory, and removal responses similar to the all productivity increase strategies (figs. 10.22 and 10.23).

The supply response of the low productivity strategy fails to offset the woody biomass requirements, with all nonsawtimber softwood being diverted from forest industry to energy production under the high-consumption scenario and a significant amount diverted under the medium-consumption scenario (fig. 10.24). The impact on the sawtimber-using industry is higher than for the all productivity or pine productivity strategies, but lower than if no productivity measures were taken. For example, in the high-consumption scenario, 57.18 million green tons of sawtimber is diverted to energy use as compared to 36.38 million green tons for the all productivity strategy, 53.5 million green tons for the pine productivity strategy and 91 million tons if no productivity measures were taken.

Private forest acreage is higher than for the other two productivity strategies. Forest land decreases from 175.39 million acres in 2010 to 172.47 million acres for the medium-consumption scenario, but increases to 181.85 million acres for the high-consumption scenario (fig. 10.25). Planted pine acreage increases more and other forest type acreage declines less as compared to the pine productivity or all productivity strategies.

Productivity increases on short rotation woody crops—We ran the model to simulate the results of a high productivity strategy coupled with the emergence of short rotation woody crops in the South. Inventories and removals (fig. 10.26) are higher than for the all productivity strategy coupled with high consumption (similar to results from a subsequent run combining a low productivity strategy with short rotation woody crops). Softwood and hardwood inventories are higher compared to the no-consumption scenario. Price increases for all products are dampened.

These results also suggest that the pulp industry would still face adverse impacts, as merchantable wood from forest industry would be diverted to energy production (fig. 10.27). However, the combination of increased supplies from short rotation plantations and from productivity gains on existing forests would provide most of the 'additional' sawtimber needed for energy production, resulting in just 26.7 million tons diverted from forest industry. The higher levels of aggregate inventory and removals counter the notion that diverting wood for energy would necessarily lead to inventory declines. Forest acreage is lower than for the other productivity strategies, but higher than the no-consumption scenarios (fig. 10.28).

Technologies

Considering the potential availability of wood that could be used in the traditional forest product industries and woody bioenergy industries, it is important to determine how current and likely suitable wood-to-energy conversion technologies can potentially impact the future of southern forests (for example, how technological preferences towards a particular species might increase its price, producing changes in inventory and removal). Dwivedi and Alavalapati (2009) found that a broad spectrum of stakeholders view conversion technologies as one of the main weaknesses for the development of forest biomass-based energy in the South. In addition, Nesbit and others (2011) found that under current levels of technology, slash pine ethanol is not a financially viable competitor for fossil fuels. They found that unit cost of producing ethanol from slash pine (*Pinus elliottii*) through a two-stage dilute sulfuric acid conversion process, and a synthesis gas ethanol catalytic conversion process was estimated to be $2.39 per gallon and $1.16 per gallon respectively. If adjustments are based on the lower energy content of ethanol relative to gasoline (Oak Ridge National Laboratory 2008), the cost of an energy equivalent gallon of ethanol increases to $3.55 and $1.74 per gallon for the two conversion processes, respectively.

Woody biomass can be converted into energy using a number of different processes. Broadly speaking, wood-to-energy conversion technologies can be grouped into two main categories: thermal technologies—such as co-firing and combined heat and power, direct combustion using wood pellets and wood chips, gasification and pyrolysis—and biochemical processes.

Co-firing and combined heat and power—Combustion of woody biomass can be applied to produce heat and electricity, particularly in industrial and residential sectors. Three major technology options are being developed for producing electricity and heat. These are: setting up dedicated cellulosic power plants, co-firing biomass in existing coal plants, and developing combined heat and power plants. All these options are being explored in the South, ranging from a dedicated power plant that will use urban wood waste, wood processing wastes, and logging residues in Gainesville, Florida to plants that blend biomass with coal or inject biomass separately into boilers. Currently, 27 co-firing plants supply a biomass/coal co-firing capacity of 2,971 megawatts. Virginia is the leader in the number of co-firing plants and capacity in the South, followed by North

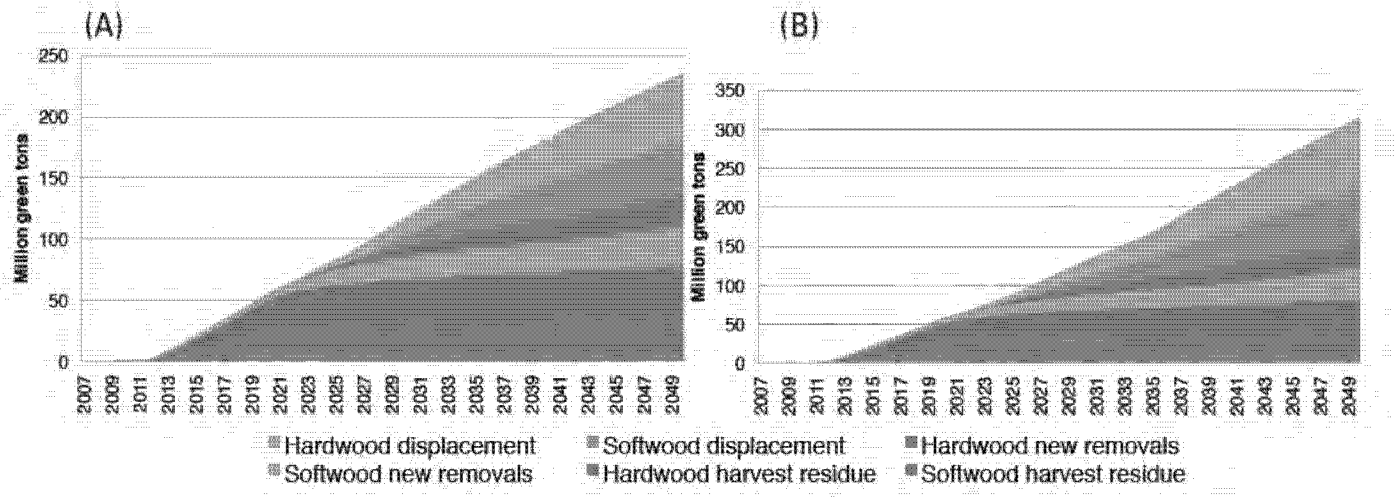


Figure 10.24—Under a low-productivity strategy, feedstock composition in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

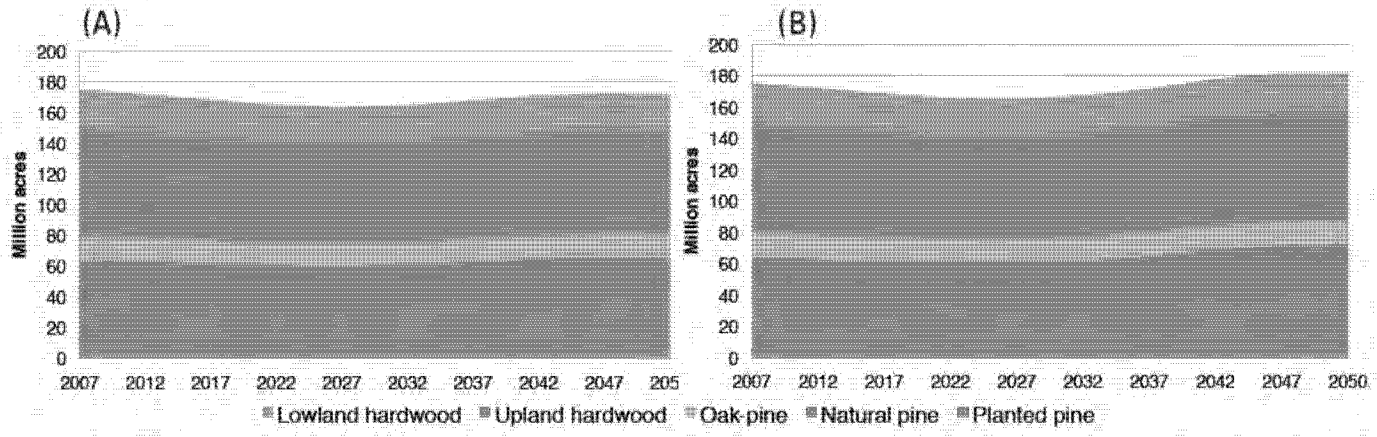


Figure 10.25—Under a low-productivity strategy, private forest acreage change in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

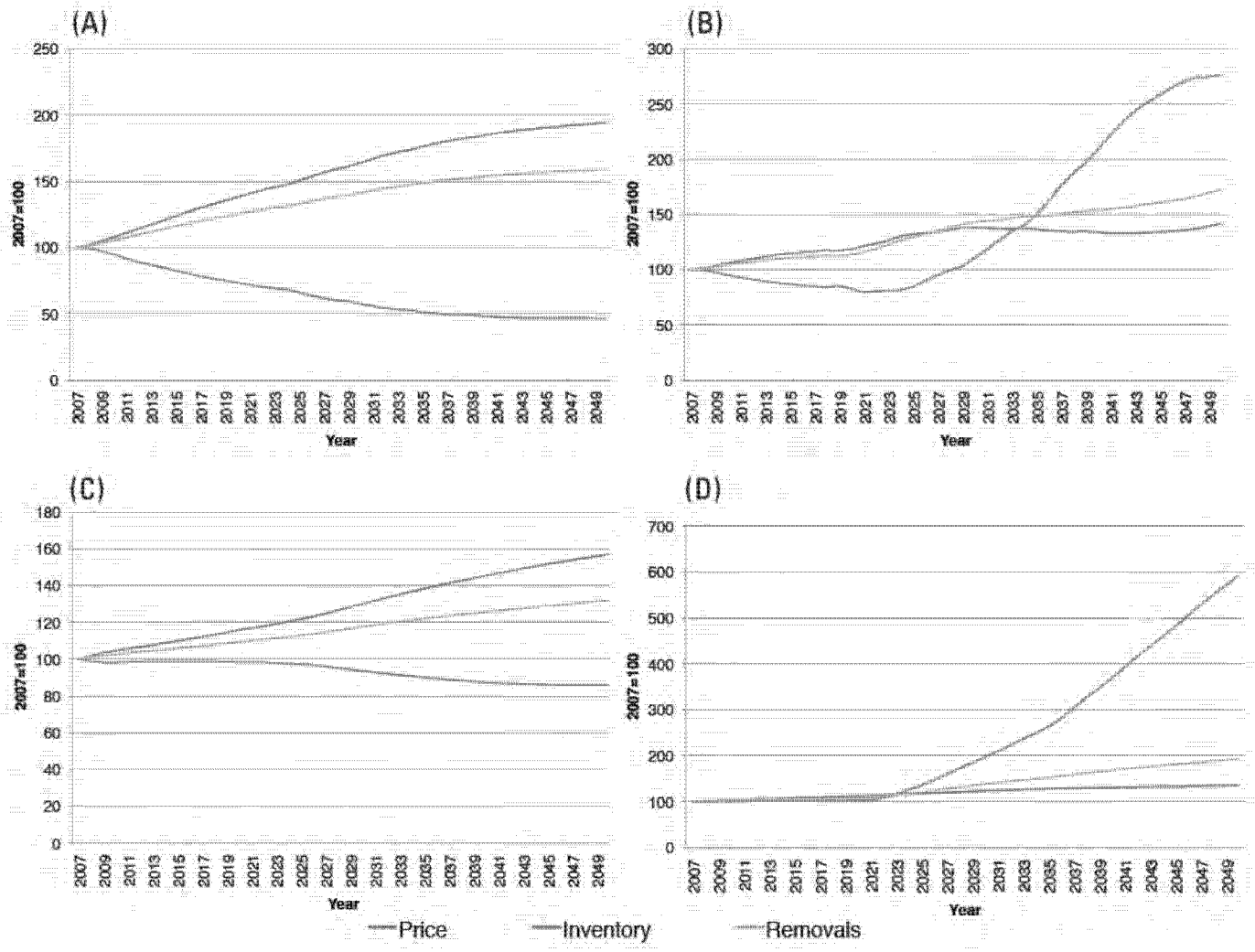


Figure 10.26—Under a high productivity strategy that expands short rotation woody crops, market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods.

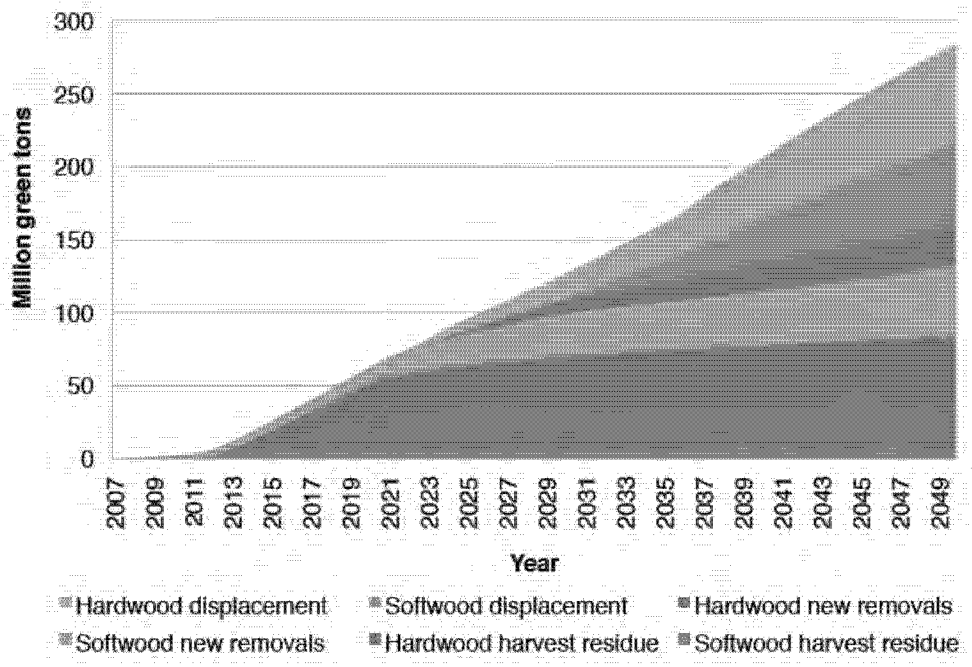


Figure 10.27—Under a high productivity strategy that expands short rotation woody crops, feedstock composition in the South, assuming high consumption of woody biomass for energy.

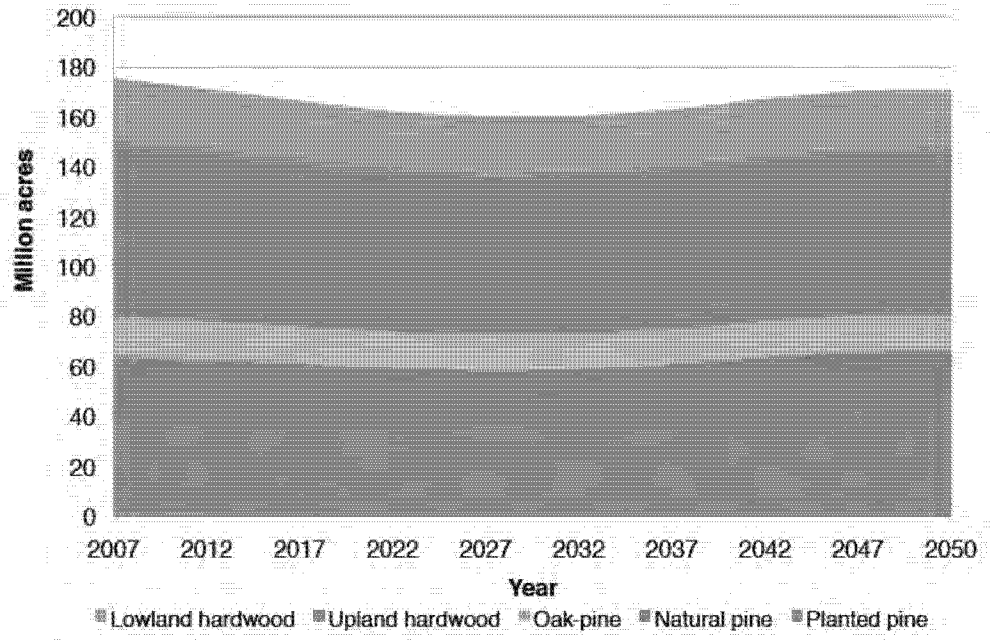


Figure 10.28—Under a high productivity strategy that expands short rotation woody crops, private forest acreage change in the South, assuming high consumption of woody biomass for energy.

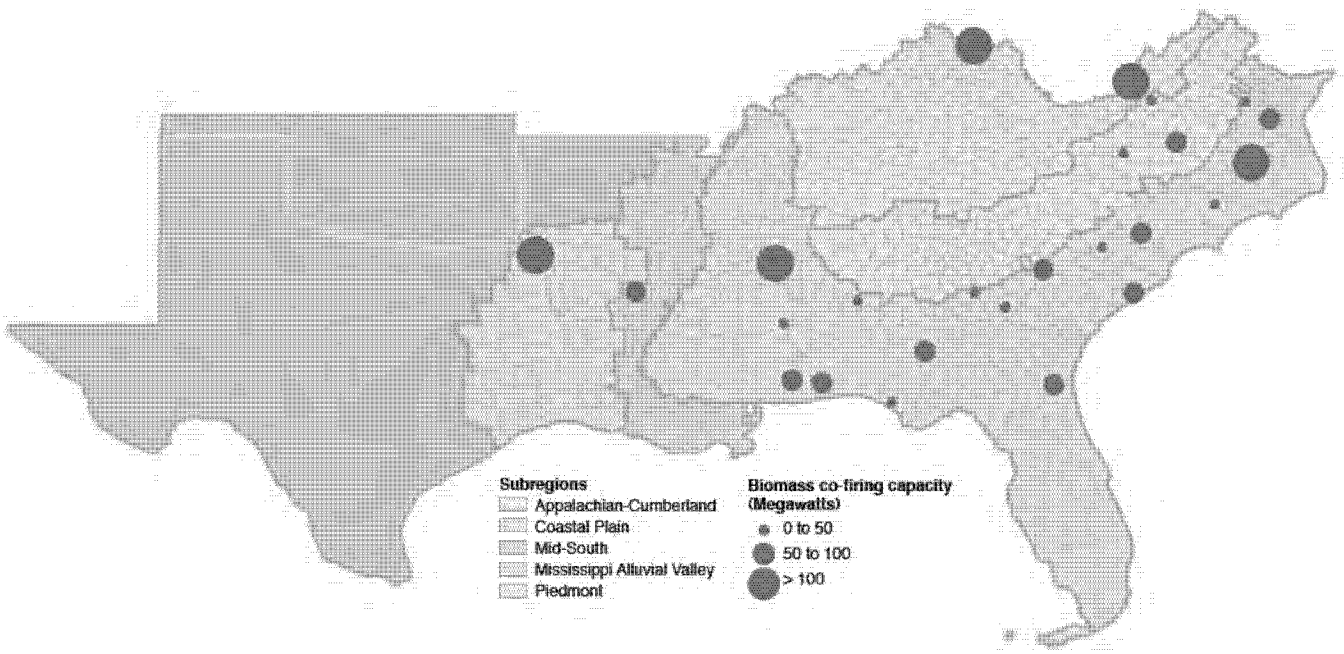


Figure 10.29—Co-firing plants, location and megawatt capacity, in the South, 2007. (Source: Energy Information Administration 2010c)

Carolina in terms of co-firing plants, and Kentucky in terms of co-firing capacity (fig. 10.29).

Combined heat and power plants are smaller and have lower electrical efficiency than co-firing plants, but they use a similar combustion system to generate heat and electricity. The primary product for small plants is heat, and electricity for the larger ones produce electricity as the primary product (Jackson and others 2010). They generate a net summer capacity of 20,336,000 megawatt-hours about 127,880 billion Btu of biomass fuels including agricultural crop byproducts, municipal solid waste, wood and waste solids, black liquor, sludge waste, wood waste liquids, and landfill gases. The South represents about 58 percent of the total consumption of biomass and 65 percent of the net generation of biomass-based electricity in combined heat and power plants (fig. 10.30). While it helps improve overall conversion efficiency, the Scandinavian-style community-based CHP systems might not work in the Southern United States. Most of the existing CHP use in the South is associated with the paper, pulp, and forest products industries. However, other entities are also focusing on CHP generation. For example, the Department of Energy is slated to replace coal for a steam plant at its Savannah River Site with woodchip and other biomass, while Baycorp Holdings Ltd. and the Nacogdoches Economic Development Corporation gained approval to set up the first woody biomass electricity plant in Texas.

Direct combustion using wood pellets and wood chips— Wood pellets, compressed byproducts from forest industry such as sawdust and woodchips, are used as fuel for domestic heating and for combined heat and power plants. These high-density pellets are characterized for having high energy content (about 40 percent higher than wood chips with 30 percent moisture content by mass and more than 300 percent by volume), being of uniform size and shape (facilitating automated handling), and being economically attractive. Rather than just using sawdust from mills for producing pellets, companies have built plants that use whole trees and chips as well. In the recent past, some of the largest pellet producers in the world have been established in the South, with 24 mills contributing about 46 percent of the country's 2 million ton annual capacity (Pellet Fuels Institute 2010, Spelter and Toth 2009). The States with the largest number of wood pellet mills are Georgia, Kentucky, and Virginia (fig. 10.31).

Gan and Mayfield (2007b) suggest that forest biomass, in general, is not cost competitive with coal for electricity production. Gan and Smith (2006a) through their comparative analysis of wood and coal based electricity found that the production cost of short-rotation woody crops was $10.80 per Megawatt hour, more than double the national average price of delivered coal based electricity in 2005 ($5.32 per Megawatt hour). Even the electricity from logging residues ranged between $47 to $50 per megawatt hour (Gan

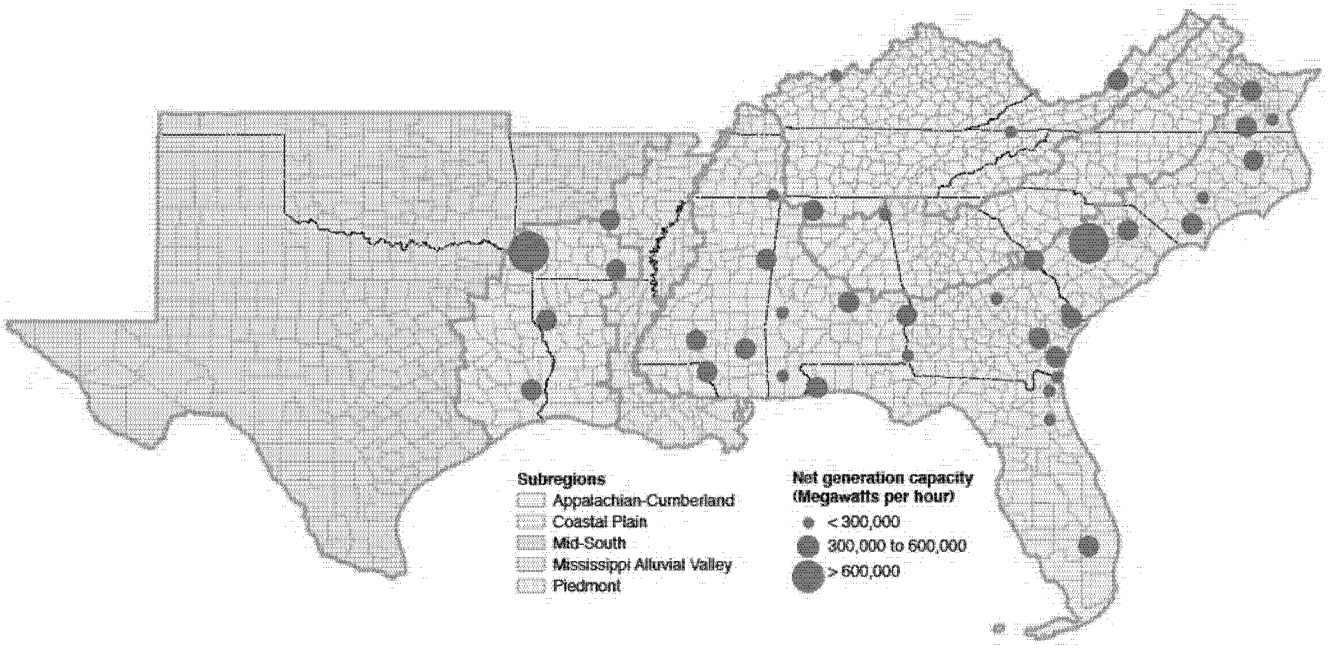


Figure 10.30—Combined heat and power plants, location and capacity, in the South, 2009. (Source: Energy Information Administration, 2010d)

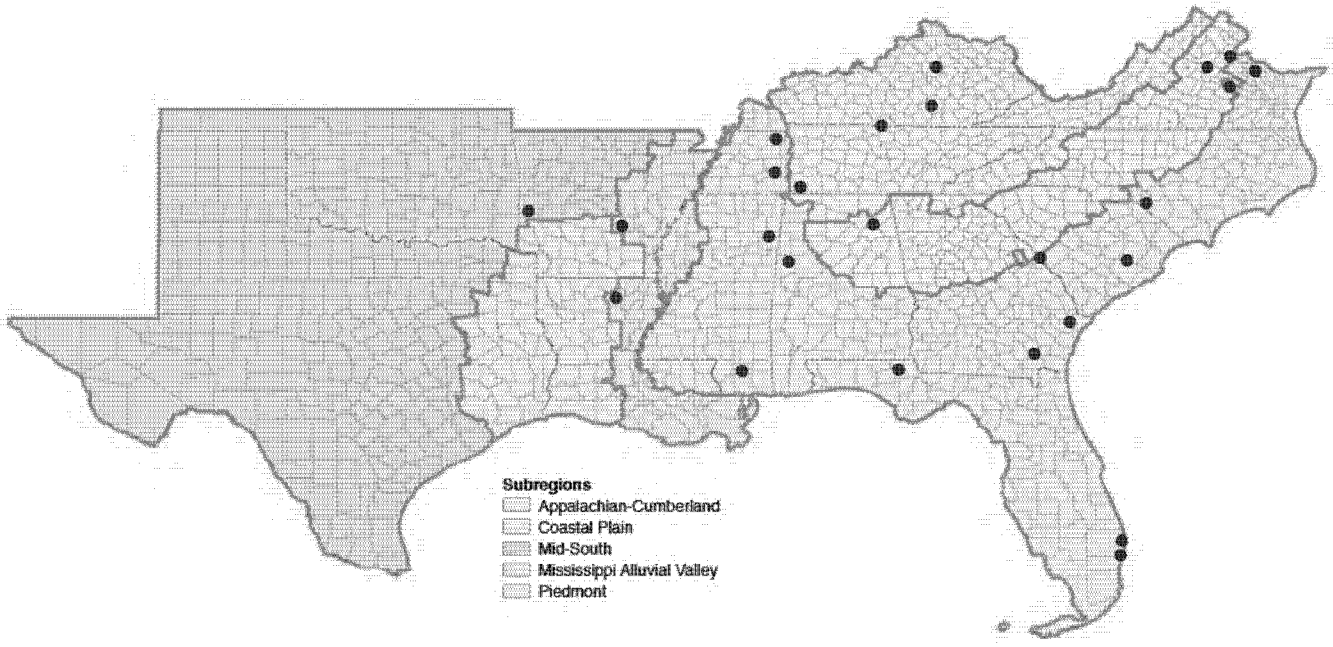


Figure 10.31—Wood pellet mills and locations in the South. (Source: Pellets Fuels Institute, 2010)

and Smith 2006b). Drawing from a study conducted in 15 Western States, the estimated costs for procuring biomass from forest fuel treatment thinnings range from $6.20 to $8.30 per Megawatt hour for cut and skid treatment, while this increases to cost $7.00 to $9.90 per Megawatt hour in cut/skid/chip method (USDA Forest Service 2005).

Other thermal technologies—Other thermal technologies (also known as advanced thermal technologies) are gasification and pyrolysis, both of which are technically feasible. Gasification is a high temperature process in which biomass is used to generate different bioproducts such as heat, electricity, methanol, ethanol, and syngas (hydrogen). If the gasification process includes a devolatization and conversion of biomass in a steam environment, it can produce a medium calorific gas that can be transformed into fuel for combined cycle power generation (Guo and others 2007). Otherwise, the syngas is converted to ethanol or hydrocarbon chemicals and fuels. Nexterra has commercial gasification units in British Columbia (Tolko and Kroger) using wood waste as a fuel source. A similar wood based gasifier is being set up in University South Carolina by Nexterra. Pyrolysis is a type of gasification technique that converts biomass at higher temperatures in the absence of oxygen to bio-oil (fast pyrolysis) and charcoal (slow pyrolisys). Bio-oil can be used as fuel in heating or electrical applications and for production of chemical commodities (Faaij and Domac 2006). Converting woody biomass to bio-oil increases energy density, which translates to improved transportability. Its main disadvantages are low heating value, poor ignition performance, and thermal instability (Jackson and others 2010). The pyrolysis plants are not yet commercially viable for large-scale production.

Biochemical—Processed biodiesel and ethanol (fig. 10.32) are the primary liquid fuels that can be derived from biochemical processes. Wood-based ethanol can be obtained through hydrolysis and fermentation. Cellulose and hemicellulose are broken down into sugars in hydrolysis, which are then fermented to generate ethanol.

Two hydrolysis stages are currently in practice: thermal, acid, alkaline, and biological pretreatments followed by an acid or enzymatic treatment. Hydrolysis and fermentation can be conducted separately or simultaneously. Separate processes

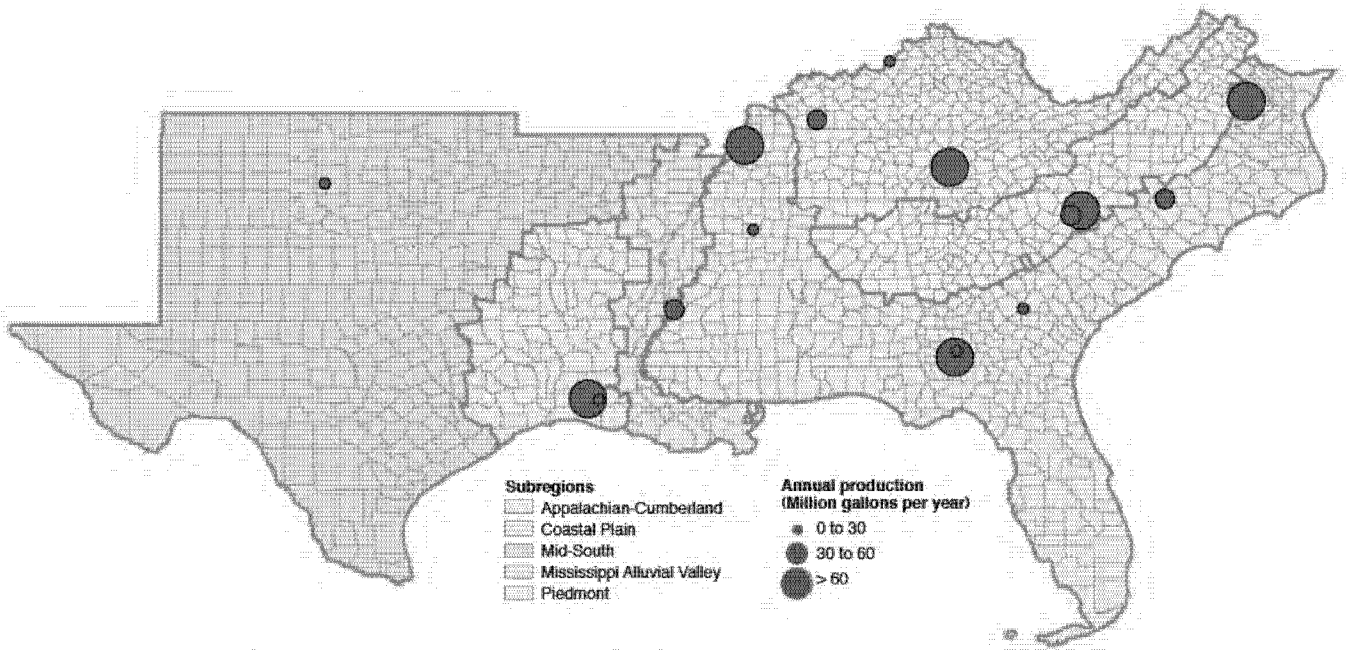


Figure 10.32—Producers of ethanol in the South, with locations and capacity. (Source: Renewable Fuels Association 2010)

are more expensive and have lower ethanol yields, but they allow each to be carried out at its optimal temperature (Jackson and others 2010).

Although several hydrolysis techniques have gained momentum in the last decade, efficiency and cost issues have hindered commercial viability. An integrated enzymatic process could contribute to cost reductions, but it has not yet moved out of the laboratory stage.

The Department of Energy set 2012 commercialization targets for research and development which included reducing the selling price of ethanol by 2012 to $1.07 rather than $1.61 per gallon, increasing ethanol yield per dry ton from 56 gallons in 2005 to 67 gallons in 2012, and reducing installed 2005 capital and operational costs by 35.5 percent and 65.3 percent respectively. For fermentation based ethanol production, the target is to increase yield from 65 gallons per ton in 2005 to 90 gallons per ton in 2012. The target also sets feedstock cost target for 2012 as $35 per dry ton. Efforts are ongoing to achieve these targets, but no technological breakthrough has yet achieved these large-scale production targets. The Range Fuel plant in Soperton, Georgia produced waste wood methanol in August 2010, and currently producing its first batch of cellulosic ethanol. However, the plant is shutting down operations after demonstrating its cellulosic production technology. The scale of bioenergy plant in terms of capital and biomass demands from the forest landscape are issues that need further attention. If a large plant is set up, then the transportation cost of procuring biomass from areas farther from the plant site might increase per unit cost and/or lead to procuring lower quality feedstock. The scale of the plant not only depends on cost issues, but also on the purpose for which it is being built. For example, Van Loo and Koppejan (2008) suggest that small combined heat and power plant facilities with lower conversion efficiency (10 percent) can be used where heat is the primary product with power as the secondary product, while facilities (more than ten megawatts) generally have higher efficiency (25 percent) as they produce electricity as the primary product.

The Policy Environment

A number of current and proposed policies and programs may influence the future of woody biomass-based energy markets in the South. Some of these policies are directed specifically at the expansion of woody biomass use for energy, and others influence indirectly by focusing on reductions of greenhouse gas emissions.

Incentive-based policies provide financial support such as cost-shares, tax reductions, subsidies or grants, and low- or no-interest loans for project financing. The Database of State Incentives for Renewables and Efficiency (2010) reports that policies for renewable energy (including woody biomass for energy) in the Southern States are generally in the form of tax rebates, grants, loans, industry support, bonds, and performance-based incentives.

Regulatory and support mechanisms include policies that set goals, targets, and limits; and compel certain types of behavior, as well as creating supportive infrastructure and facilitating public educational outreach. Rules, regulations, and policies (regulatory and support policies) are in the form of public benefit funds, renewable portfolio standards, net metering, interconnection standards, contractor licenses, equipment certification, access laws, construction and design rules, green power purchasing guidelines, and green power policies.

Incentive-based policies—In an effort to support market-based solutions, Federal and State governments have introduced a number of incentive-based policies. This generally results in altering prices by assigning a monetary value to something that was previously external to market forces (Shrum 2007). Subsidies are intended to encourage planting and management activities that might promote feedstock availability, and tax support encourages the use of renewables. Support in the form of grants and loans are also provided to encourage clean technology development and adoption.

Incentives for liquid biofuels were first instituted in the Energy Tax Act of 1978, which provided a $0.40 per gallon exemption from the gasoline excise tax for blends with at least 10 percent ethanol. Then it was increased to $0.51 per gallon by the 1998 Transportation Equity Act of the 21st Century. The American Jobs Creation Act of 2004 replaced the excise tax exemption with a volumetric ethanol excise tax credit of $0.51 per gallon until 2010 (reduced to $0.45 per gallon by the Farm Bill of 2008). The Energy Independence Security Act (2007) provided a production tax credit of $1.01 per gallon for cellulosic biofuels through 2012. The following section summarizes the current bioenergy policies in the South.

The 2008 U.S. Farm Bill created a new Biomass Crop Assistance Program (BCAP) to encourage development of large-scale energy crops that can support commercial-scale bioenergy production. BCAP provides incentives to farmers, ranchers, and forest landowners to establish, cultivate and harvest biomass for heat, power, bio-based products, and biofuels. The program shares the establishment cost and matches cost related to transportation and logistics up to $45 per ton to producers with user facilities contracts. The program reduces the financial risk to farmers and forest landowners to supply eligible biomass materials to qualifying facilities, and can reduce the cost of raw materials to the facility. These also promote conservation and stewardship by emphasizing that biomass is collected and harvested

Table 10.4—Number of financial incentives for renewable energy at Federal and State levels (blanks indicate no incentives): Number in the parentheses means whether incentives are State governments (S), utility companies (U), local governments (L), or nonprofit organizations (N)

State(s)	Personal tax	Corporate tax	Sales tax	Property tax	Rebates	Grants	Loans	Industry support	Performance-based incentive
All States (Federal incentives)	3	4				3	5	1	1
Alabama	1(1S)				3(3U)	1(1S)	3(1S,2U)		1(1U)
Arkansas					2(1S,1U)		1(1U)	1(1S)	
Florida		2(2S)	2(2S)		12(1S,10U,1L)		6(1S,5U)	1(1L)	2(2U)
Georgia	1(1S)	1(1S)	1(1S)		10(1S,9U)		1(1S)		2(2U)
Kentucky	1(1S)	2(2S)	1(1S)		11(1S,10U)	1(S)	4(1S,1U,1L,1N)		1(1S)
Louisiana	1(1S)	1(1S)		1(S)			2(2S)		
Mississippi					5(1S,4U)		4(1S,3U)		1(S)
North Carolina	1(1S)	1(1S)	1(1S)	2(2S)	6(6U)	1(1S)	4(3S,1U)		4(3S,1N)
Oklahoma		1(1S)			3(3U)		6(4S,2(U)	1(S)	
South Carolina	1(1S)	2(2S)	1(1S)		6(6U)		6(1S,5U)		4(1S,2U,1N)
Tennessee				1(S)	2(1S,1U)	2(2S)	3(2S,1U)	1(S)	1(S)
Texas		1(1S)		1(1S)	27(25U,2L)	2(2S)	2(2S)	1(1S)	2(2U)
Virginia				1(1S)	1(1S)		1(1S)	1(1S)	1(1U)
Total	**9**	**15**	**6**	**6**	**88**	**10**	**48**	**7**	**20**

Source: Database of State Incentives for Renewables and Efficiency (2010).

according to an approved conservation, or similar plan to protect soil and water quality and preserve future land productivity.

Rebates followed by loans are the most popular financial incentives in the South (table 10.4). Federal financial incentives are mainly comprised of corporate tax rebates, research and development grants, and loans. Loans and performance-based incentives are the policies most frequently used in the 76 State financial incentive programs in the South. North Carolina has the largest number of State financial incentives (eight), and Texas has the smallest (two).

Few State programs are specifically aimed at increasing woody biomass stock for energy use, partly because wood-for-energy markets have not yet been established. However, more often than not, improvement in forest biomass availability and sustainable use is an offshoot although not the overarching goal of these programs. Although the minimum acreage and stocking levels for property tax calculations vary across Southern States, the general objective of all these taxes is to provide an incentive for managing land on a sustained yield basis and a disincentive for converting forest land to other uses. The objectives of State cost-share programs are to reforest cutover land, plant open land, or improve woodlands; and many States offer to share the costs of other forest management activities. For example, South Carolina has forestry commission cost-share programs and North Carolina has forest agriculture cost-sharing programs. These programs lead to higher availability of feedstocks for energy conversion.

Several Federal programs provide incentives for conservation of forestlands and maintaining sustainable forest management practices. For example, the Environmental Quality Incentives Program (EQIP) provides cost shares for installing greenhouse gas mitigating technologies and the Landowners Incentive Program provides financial assistance to landowners for a variety of conservation goals including carbon sequestration. The Forest Land Enhancement Program promotes additional carbon sequestration and other ecosystem services through cost shares with landowners. These programs help to reduce land use change away from forests, in turn indirectly maintaining the forest stock that can be used for energy production at a later date. Incentive programs for reforestation have long been established in a number of States. For example, Mississippi provides tax credits for reforestation.

Regulations and support programs—At the Federal level, the Energy Policy Act of 2005 established Renewable Fuel Standards, which mandated that transportation fuels contain a minimum volume of renewable fuels, starting with 4 billion gallons in 2006 and 7.5 billion gallons by 2012. The Energy Independence Security Act (2007) called for production of 36 billion gallons of biofuels by 2022, of which 21 billion gallons must be cellulosic biofuel. The 2008 Farm Bill authorized mandatory funding of $1.1 billion for the 2008 to 2012, providing grants and loans to promote alternative feedstock resources including woody biomass. Interconnection standards and green power purchasing have also been formulated at the Federal level.

Construction and design support for establishment of bioenergy production facilities and net metering available to biomass based energy facilities so they can sell power back to the grid are the most employed State-level policies in the South and 10 Southern States have also formulated renewable portfolio standards as targets for using cleaner sources of energy in utilities and industries.

Extension and support activities have facilitated knowledge transfers, technology demonstrations, and information sharing sessions; and have developed multi-stakeholder partnerships to reduce greenhouse gas emissions. Extension agents and specialists at land-grant universities and government institutions transfer knowledge about natural resource management (including woody biomass-based energy) to client groups, such as forest owners, foresters and other natural resource managers, tree growers, loggers, and forest workers. Non-State efforts aimed at landowners include a State Tree Farm program that recognizes landowners who are doing a good job of managing their land with a certificate, subscription to Tree Farm magazine, and Tree Farm sign to display on their property. Regular interaction between landowners and professional foresters is facilitated through periodic visits by foresters.

There have been number of efforts by policymakers in the United States to create markets as a mechanism to regulate GHG emissions, although no bill has yet become law. For example, the House passed the American Clean Energy and Security Act (a.k.a. Waxman-Markey) on June 26, 2009, and three other bills were submitted to the Senate in 2009 and 2010: the Clean Energy Jobs and American Power Act (Kerry-Boxer), the American Power Act (Kerry-Lieberman), and the Carbon Limits and Energy for America's Renewal Act (Cantwell-Collins). Waxman-Markey, Kerry-Boxer, and Kerry-Lieberman would create markets for emitting and offsetting carbon dioxide and permit the purchase of up to 2 billion metric tons of carbon offsets annually (Mercer and others 2011). Gorte and Ramseur's (2008) estimate that at a CO_2e price of $50 per metric ton, more than 800 million metric ton of CO_2e could be sequestered through afforestation activities, and approximately 380 million metric ton through improved forest management activities. Since 2010, little congressional effort has focused on climate in general and carbon sequestration policies in particular.

Forestry offset projects including mitigation of green house gases through bioenergy production can potentially accrue carbon credits but the accounting is challenging. Assuming that energy crops do not lead to land use changes, life cycle analyses of different biofuels (including woody biomass) suggest overall green house gas reductions (Blottnitz and Curran 2006, Eriksson and others 2007, Gustavsson and others 2007). Searchinger and others (2008) argue that life cycle studies have failed to factor in indirect land use change effects, and suggest that using U.S. croplands or forestlands for biofuels results in adverse land use effects elsewhere, thus harming the environment rather than helping it. Indirect land use change effects are difficult to assess, and today there is no generally accepted methodology for determining such effects. Fritsche and others (2006) argue for assessing indirect influence of bioenergy on land use change through measures such as land prices and rents. However, conducting such assessments at the site level and translating these to operational indicators is quite costly. A satisfactory methodology for incorporating the effects of indirect land use changes into the lifecycle greenhouse gas emissions of fuels remains an important challenge.

There are also policies and regulations that could limit development of a bioenergy industry in the South. The Environmental Protection Agency's final Greenhouse Gas Tailoring Rule, does not exempt biomass power producers from greenhouse gas permitting requirements, and might act to limit the establishment of bioenergy conversion plants (Mendell and others 2010). This rule treats carbon emissions from biomass combustion identically to fossil fuels emissions and increases costs associated with obtaining permits and costs associated with technology requirements, such as Best Available Control Technology. Mendell and others (2010) suggest that regulatory uncertainty created due to this regulation could affect establishment of 130 renewable energy projects, and $18 billion in capital investment across the country. Similarly, the Environmental Protection Agency's air quality permitting for biomass boilers impacts biomass based electricity producers adversely.

Assessing efficacy of policies—A number of researchers suggest that private landowners are by and large unresponsive to property tax and capital gains provisions, and that forest property tax programs are only modestly successful in achieving their goals (Greene and others 2005, Jacobson and others 2009, Kilgore and others 2007). Many authors have found that landowners are largely unaware of the existence of incentives or do not understand how incentives might apply to them. For example, Butler (2008) based

on landowner responses to the Forest Service's National Woodland Owner Survey, concluded that not all landowners are price-responsive. Factors such as maintaining forest land for aesthetics or wildlife conservation, as well a movement towards smaller ownerships, might be responsible for this price unresponsiveness. Nevertheless, at aggregate level, these incentive based policies result in increased welfare, as shown by Huang (2010) who found that when combined with investment in technology, they can result in overall positive outcomes for the South's economy and household welfare.

Beach and others (2005) and Greene and others (2005) found that nonindustrial private forest owners more often respond to targeted government programs than to market prices or other financial incentives. They also suggest that technical assistance, cost-share payments, and direct contact with professional foresters or natural resource specialists more often than not succeed in changing forest management decisions. Authors like Haines (2002) and Arnold (2000) have proposed integrating land use planning (and woody biomass-based energy use) into extension programs. Educating landowners and the general public about the benefits derived from cleaner energy sources such as woody biomass will improve and increase interest in forest biomass utilization. Mayfield and others (2008) indicated that education and community engagement play important roles in the development of cleaner technology like wood-based energy. Joshi and Arano (2009) agree that landowners are largely unaware of incentive programs available to them, and thus argue that much remains to be done to encourage private investment in forestry activities. In light of these findings, extension and outreach support programs become important for increasing the acceptability of wood-for-energy technology options and improving forest and land management practices.

Sustainability

The development of forest bioenergy systems presents new opportunities as well as risks. Many sustainability concerns are being raised about wood biomass utilization for energy. These concerns range from production processes to consumption processes—feedstock production, harvesting, transport, conversion, distribution, consumption, and waste disposal—and include issues of job creation and societal benefit distribution.

Forests provide not only wood for traditional uses but also several ecosystem services such as clean water and biodiversity (Amacher and others 2008, Neary 2002, Stupak and others 2007). These potential impacts—grouped into productivity, water quality, and biodiversity categories—are described in detail below.

Productivity—The forest floor accumulates nitrogen, phosphorus, calcium, and other nutrients that are essential for tree growth. Unlike traditional timber harvests, biomass harvests for energy production could impact regeneration and site productivity unless productivity reductions associated with site quality are offset by fertilization. Studies of forest biomass based energy production raise concerns regarding soil compaction and rutting (Reijnders 2006), decreased amounts of decaying wood on forested landscapes, changes in the chemical and physical environment of soils (Astrom and others 2005), increased use of agrochemicals (Fritsche and others 2006), increased soil erosion (Burger 2002), and nutrient loss (Burger 2002). These issues suggest a need for intensified site and off-site monitoring where forest management is intensified.

The machinery used to build roads and infrastructure for biomass harvesting biomass for energy might be different from what was used in traditional timber harvesting and harvesting might take place in areas where timber harvesting is traditionally not undertaken, resulting in new roads or pathways (Lal and others 2011, Smith and Lattimore 2008). Frequency of harvests for biomass removal could also be generally higher than for traditional harvests, and second operations or harvest residue collections might result in vehicle re-entry at the site (Lal and others 2009). Intensive removals of forest biomass for bioenergy might reduce soil carbon and organic matter to levels that are inadequate for sustaining forest productivity. Hope (2007) through their site experiments in British Columbia observed that stump removal decreases the soil stock of carbon by 53 percent, nitrogen by 60 percent, and phosphorus by 50 percent; and that the forest floor depth was decreased by 20 to 50 percent. Peng and others (2002) through their study in Central Canada reported that whole-tree harvesting produces an additional 32 percent loss of soil carbon compared to conventional tree harvesting. Smith and Lattimore (2008), while discussing potential environmental impacts of bioenergy harvesting on biodiversity list contributing activities such as mechanical damage to residual trees; expanded road networks; increased removals and land use changes that might impact productive and diverse ecosystems. Scott and Dean's (2006) Long Term Site Productivity Study found that whole-tree harvesting reduced productivity on over 75 percent of the study blocks in South by an average of 18 percent. However, they also found that a one-time application of nitrogen and phosphorus fertilizer maintained productivity and increased productivity by an additional 47 percent above the stem-only harvest level.

Harvesting slash remaining after conventional harvesting of loblolly pine (*Pinus taeda*) in the Coastal Plain along the Gulf of Mexico reduced site productivity, decreasing soil organic matter and associated nutrients by 18 percent (Scott

and Dean 2006). Reductions of jack pine (*P. banksiana*) height growth of 18 percent on whole-tree harvested plots in sites of Quebec region of Canada were attributed to lower soil moisture and nutrient availability (Thiffault and others 2006). To avoid decreased productivity from soil compaction during biomass harvesting, Janowiak and Webster (2010), after reviewing the state of knowledge regarding the impacts of intensive forestry with respect to issues relevant to bioenergy production, recommended using machinery that is similar to what is used in conventional harvesting.

Water quality—Increased biomass harvesting activities for a wood-to-energy market might have adverse impacts on water quality in streams, rivers, and lakes. Increased road construction required for woody biomass harvesting might lead to soil erosion, high soil moisture, and increased runoff and sediments from forest roads and landings (Janowiak and Webster 2010). Increased machinery use might also impact the water table at the harvest site, leading to impermeable soils from compaction. Removal of younger trees and lopping and topping during biomass harvests might decrease leaf surface area, resulting in decreased transpiration and interception (Lal and others 2009).

Machine re-entry at harvest sites might increase sedimentation and flow levels in waterways, increasing the chances of sediment movement into wetlands through damaged erosion control features. Frequent harvests might increase suspended solids and aluminum levels in water, raising acidification levels and negatively impacting fish and other aquatic organisms (Grigal 2000). In addition, woody biomass harvesting adjacent to waterways might increase the probability of higher water temperatures, disturbed chemistry, and reduced clarity that would damage biological communities and alter ecological processes (Janowiak and Webster 2010). Aust and Blinn (2004) reviewed best management practices for timber harvesting and site preparation in the eastern United States in terms of water quality and productivity research during for the time period between 1982 and 2002, and concluded that effects of harvesting on forest hydrology are highly variable across sites and time periods. However, harvesting impacts on forest hydrology are likely to be greater immediately following harvest, with the recovery to preharvest conditions taking up to 5 years

Biodiversity—The extraction of additional biomass for bioenergy could degrade habitats beyond the range of natural variability and produce negative effects on some species (Janowiak and Webster 2010). Increased access and intensity of harvest can also fragment habitats and adversely impact wildlife corridors (Fletcher and others 2011, Lal and others 2009). Natural disturbances such as fire, wind, and pest outbreaks permit a continuous supply of deadwood in unmanaged forests. Intensive forest management leading to removal of stumps might reduce the amount of deadwood that is considered essential to forest ecosystems and provides habitats for different organisms (Humphrey and others 2002).

The removal of residues and stumps might negatively alter the entire soil fauna community and structure of the food web, harming small mammals, and reducing ecological niches, thereby lowering diversity and numbers of invertebrates such as spiders and predatory insects (Ecke and others 2002). There is also a chance of insects or other wood-colonizing species getting trapped in wood burnt for fuel.

However, intensive forest management practices controlling pests and disease can also improve forest habitats. For example, certain fungi species cause root and butt rot disease to conifers worldwide. Stump removal associated with whole-tree harvesting generally leads to significant reductions in the area of the stump colonized by these fungi, reducing the risk of attack (Thor and Stenlid 2005). Conversely, the harvesting of forest residues and stumps would also favor pioneering species of flora that are also more tolerant of exposure and soil moisture levels. When all biomass is removed, growth these species is more vigorous, particularly the invasive nonforest field vegetation, which—if it is not managed—might lead to a reduction in timber productivity (Walmsley and Godbold 2010). Scott and Dean (2006) also suggest that in the Gulf Coastal Plain, soil analyses could be used to identify harvesting sites at risk of harvesting-induced productivity loss, and fertilization treatment could be used to avoid productivity loss caused by whole-tree harvesting.

Meta-analysis by Fletcher and others (2011) of studies on crops being used or considered in the United States, found that vertebrate diversity and abundance are generally lower in biofuel crop habitats relative to the non-crop habitats. They found diversity effects are lower for pine and poplar than for corn, and birds of conservation concern experience lower negative effects. However, for minimizing impacts of biofuel crops on biodiversity, they suggest practices that reduce chemical inputs, increase heterogeneity within fields, and delay harvests until after bird breeding. Many of these practices might already be incorporated under intensive management regimes in South and could be incorporated into biomass production systems and management planning used to avoid adverse impact on forested landscapes.

Results of direct and indirect land use change to agricultural row systems can also cause habitat loss (Jonsell 2007). The land use change from natural forests to forest plantations, including short rotation woody crops, is of the greatest concern from an ecological point of view (Wear and others 2010). Interventions focused on ecological restoration or fuel reduction activities associated with woody biomass would also benefit wildlife habitat (Janowiak and Webster 2010).

However, biomass production might also have negative consequences unless coordinated with breeding and nesting seasons and maintaining cover for overwintering small mammal species (Bies 2006).

Just as important to southerners, but less quantifiable, are the potential impacts of increased woody biomass removals on quality-of-life issues: aesthetics, community relationships, and appreciation of forest land as an integral part of the social and physical landscape (Wear and others 2010).

DISCUSSION AND CONCLUSIONS

Markets

Our demand analysis shows that the consumption requirements for wood from bioenergy markets would not likely be met by urban wood waste alone, and that demands for woody biomass would require harvesting residues or biomass from timber markets by 2013 (fig. 10.2). Prices for all forest products would likely increase, resulting in increased returns to forest landowners. Price changes are greater than changes in removals or inventory, consistent with an inelastic market response. Although removals are responsive to price changes (higher removals at higher prices), forest inventories will also depend on factors like forest growth, afforestation of agricultural or pasture lands, intensive management of forest land, and increased plantations of fast growing species. The models used for our analysis attempt to account for these factors, but future conditions are clouded by large uncertainties about demand and supply factors. Consistent with chapter 4, the market model indicates that increased prices under bioenergy futures would mitigate the loss of forest land in the future. Planted pine forest area is the most responsive to these price trends. Bioenergy demands would result in declining use of timber by forest industry, with impacts more pronounced for pulp-based industries than for sawtimber industries.

With high demand for woody biomass, sawtimber industries could also be impacted, although at lower levels. This projection is consistent with studies by Aulisi and others (2007) and Galik and others (2009), who found that pulpwood markets are more likely to be impacted by an emerging wood-based energy industry. Furthermore, Aulisi and others (2007) suggest that sawmills might benefit from the higher prices paid by bioenergy markets for secondary products such as sawdust and chips. Our simulation indicates that at high levels of bioenergy demands, the softwood sawtimber industry would eventually be adversely impacted.

Forest industry might also face increased feedstock prices for their pulp and sawtimber operations. In the long run, price increases for softwood nonsawtimber are less severe than for hardwood nonsawtimber because pine plantation area can respond quickly, and hardwood plantations are not common in the South.

Increased forest productivity could moderate price growth and result in higher rates of removals and inventories. Although productivity has grown substantially in the South as a response to intensive management and genetic improvements, productivity effects are not limited to softwoods. Price increases are smallest with productivity growth strategies that extend to all management types along with an increase in short rotation plantations. Expanding demands for bioenergy would not necessarily reduce the levels of forest inventories. Our simulations show that an increase in demand from the energy industry, coupled with productivity increases, could lead to higher levels of both removals and inventory.

With management and technological advancements, woody bioenergy markets could result in increases in inventory, removals, forest acreage, and returns to landowners. Southern forests could be managed to produce substantially more timber for bioenergy and other forest products consistent with the projections shown in chapter 9.

These results indicate that the future trajectory of southern forests will depend on the state of wood-based energy markets as influenced by technological developments and cost considerations. Markets will also be shaped by other unknowns, including the amount of renewable energy that will come from solar, wind, and other sources of renewable energy. Similar to any nascent industry, the future of wood-based energy will depend on a number of uncertainties, including the costs of production, technological breakthroughs, the government policies that support renewable technologies, forest productivity decisions, and the expansion of short rotation woody crops. Along these lines, if carbon markets emerge and carbon credits for displacing fossil fuels with woody bioenergy are considered, more changes in forest management and short rotation woody crops might be expected, but inclusion of these details is beyond the scope of this chapter.

Technologies

On the woody biomass-based energy technology front, there is no emergent favorite. Even supposedly “low-hanging fruits” such as co-firing face significant challenges, such as boiler ash deposition, corrosion, and feedstock selection. Federal and State governments, along with forest industry, are investing research dollars into these technologies with hopes of commercial success. Different types of woody bioenergy occupy different places on the cost feasibility spectrum. Wood pellets are already feasible under current

markets, while biofuels are not economically competitive at the current level of technology.

Advantages of wood pelletization include high energy-to-weight ratio, lower capital requirements, ability to operate production facilities at a variety of scales based on demand or wood supply, lower costs of shipping the final product, easier handling, and, most of all, high demand in European countries. Conversely, preferred conversion technologies for wood-based fuels remain largely uncertain because of the high cost of production, project-specific factors, and environmental standards (McKendry 2002). The high unit cost of woody biomass-based energy is largely attributed to high harvesting and transport costs; for example, making woody biomass-based ethanol competitive with starch-based ethanol or gasoline would require reduced capital costs through technology improvements, reduced feedstock costs (primarily from yield improvement), and densification of wood at the harvest site to lower harvesting costs (Alavalapati and Lal 2009, Dwivedi and others 2009, Jackson and others 2010). The cost of transport from the supply source (for example, the forest) to the conversion plant also determines the viability of the manufactured product (electricity, heat, or liquid fuels). Overcoming this significant challenge requires that plants have easy access to the wood supply and to distribution markets.

No species group has emerged as a favorite for woody bioenergy. Both softwoods and hardwoods can be co-fired with coal, used in combined heating and power plants, and compressed for wood pellet production (Spelter and Toth 2009). Evidence supporting a clear preference for hardwood or softwood species for wood-based liquid fuel is lacking as well. Zhu and Pan (2010) suggest that sulfite pretreatment to overcome lignocelluloses recalcitrance process holds promise for woody biomass conversion, especially for softwood species. However, softwoods contain more lignin than hardwoods (Galbe and Zacchi 2002), meaning that the conversion to liquid fuels might be less efficient in softwoods because lignin needs to be removed during the pretreatment process. Even Zhu and Pan (2010) noted that in one of the most common pretreatment processes (acid catalyzed steam explosion) sugar was successfully recovered from hardwoods (for example, 65 to 80 percent recovery from poplars) compared to less encouraging results for softwood species.

Regardless of the conversion technology employed, a continuous long-term flow of wood would be needed as raw material. Because many Southern States are emphasizing renewable technologies, new co-firing and combined heat and power plants and ethanol biorefineries are likely to be established in the future. Expansion of this sector—more woody biomass-based energy plants or expansion of existing facilities to achieve economies of scale—will be associated with an increase in the demand for wood fiber. To meet the burgeoning demand for woody biomass for energy estimated by SRTS simulation runs, merchantable timber and small-diameter wood would be required in addition to logging residues or wood waste such as sawdust, shavings, and chips from other wood product manufacturing processes.

Technological advancements are essential for making wood energy competitive with other sources such as gasoline and coal. Policy support for woody biomass-based energy, a nascent industry, might help in attaining commercial viability and developing a mature market.

Policies

Available policy instruments have advantages and disadvantages (Aguilar and Saunders 2010, Alavalapati and others 2009). Financial incentives allow directly measurements of their impact on prices. Moreover, they can promote sustained demand for and supply of energy feedstocks, and can lower the capital costs of investments. However, funding for these programs is vulnerable during hard economic times. Regulations such as renewable portfolio standards are easy to adopt, and producers generally bear incurred costs. However, these types of policies might suffer from inflexibility, and information needed for effective targeting can be elusive. A better option might be to develop a suite of policy options geared towards woody biomass-based energy. For example, an Environmental and Energy Study Institute proposal (2010) suggests that in uncertain times, an integrated policy approach for bioenergy might include: inventorying bioenergy resources and markets and developing a long range bioenergy plan; developing sustainable feedstock production guidelines; developing locally appropriate feedstocks and conversion technologies; creating easement programs for sustainable feedstock production; establishing minimum renewable fuel standards; enacting a low carbon fuel standard; promoting interagency cooperation and cooperation with other States; providing tax incentives for producers and retail distributors; and leveraging State resources through Federal and private partnerships.

Given current logistical and technological challenges, developing a mature woody biomass-based energy market would likely depend on some level of government support that includes financial incentives and other regulatory and support policies. Indeed, such policies have emerged in various forms, including research and development, consumption incentives (such as fuel tax reductions), production incentives (such as tax incentives, direct subsidies, and loan guarantees), and mandatory consumption requirements. These and future policies for production, conversion technologies, and markets

and distribution can potentially impact the production and commercialization of woody biomass for energy, but might also alter the ecosystem services provided by forests.

Financial incentives might facilitate the increased production and diversion of woody biomass, likely increasing wood demand and adding to the profitability of landowners and those engaged in wood-to-energy conversion. Stand improvement and restoration activities prioritized by States, such as land recovery and cost share programs, might help landowners make the long-term investments. Support for weed and pest management, such as the pine bark beetle prevention program in Virginia, might also increase biomass availability. Best management practices and harvesting guidelines developed especially for bioenergy could restrict wood availability by reducing harvesting impacts through minimum tillage and reduced applications of fertilizers and pesticides; protecting wildlife corridors, riparian zones, and other sensitive areas; and adopting wildlife habitat enhancement measures such as leaving patches of undisturbed areas, promoting certain species mixtures and crop rotations, and retaining quantities of harvest residues, litter, deadwood, snags, and den trees.

Research and technology grants, coupled with subsidies, could help develop current and future wood-for-energy markets. Other financial incentives targeting energy producers might also favor the progress of new conversion technologies and the integration of new technologies with existing ones. Policy efforts geared towards development of gasification techniques or an integrated process with biomass-based electricity generation would likely increase the production of woody biomass-based energy. Technological innovations channeled towards reducing feedstock production costs are significant, as they are likely to spike the demand of wood, luring away some share from traditional forest industries.

A wide array of policy instruments geared towards improving the marketing and distribution of woody biomass-based bioenergy—such as appliance efficiency standards, mandatory utility green power options, and renewable portfolio standards—could play a pivotal role in deciding where the wood–to-energy conversion plants and distribution centers are set up. Because location of infrastructure translates to increased demand for forest biomass, the conditions of nearby forests might change.

Economic and technological uncertainties might influence the impacts that current and future policies have on southern forests. However, the great variety of policies—and the multitude of ways in which the can interact—confounds efforts to predict their potential effects. Policies addressing other environmental and societal benefits associated with forests and wood-to-energy markets might also alter the impacts of bioenergy policies. In particular, emergence of carbon markets could spur further growth in the wood-to-energy industry, but formulating a policy mechanism to realize carbon payments is a huge challenge. For example, under the Carbon Cap and Trade Bill currently in the U.S. Congress, many forest landowners would not qualify for carbon market benefits because they would not get credit for existing levels of carbon sequestration, nor could they meet sequestration permanence standards.

Sustainability Issues

Production of woody biomass for bioenergy can help meet energy goals, but can also stimulate accelerated harvesting, with potentially negative implications for forest ecosystems. Reduction of soil nutrients as well as soil compaction would likely decrease forest productivity. Intensive biomass removal might affect aquatic communities by increasing erosion, runoff, and waterway sedimentation. Intensive forest management might also degrade forest habitat conditions, negatively affecting flora and fauna and reducing biodiversity. Land use changes from natural forest to managed plantations might adversely affect imperiled species in certain locations (see chapter 14). However, changes from agricultural systems to forests might improve habitat conditions. Further, the highgrading of stands generally observed during some timber harvesting might be eliminated with biomass harvesting.

Intensive woody biomass removal might also have some negative implications for community relationships, aesthetics, and public perceptions about forest land as an integral component of southern ecosystems. Potential impacts on forest ecosystems at local and regional levels is most likely to challenge the forestry community to consult new research findings like those summarized below and update existing certification systems with guidelines on how, when, and where woody biomass removals should be conducted:

Janowiak and Webster (2010) provide a framework that includes adapting management to site conditions, increasing forested land where feasible, using biomass harvests as a restoration tool, evaluating the possibility of fertilization and wood ash recycling, and retaining deadwood and structural heterogeneity for biodiversity.

Hennenberg and others (2009) suggest creating protected areas that can be used to conserve relevant portions of biodiversity.

Lal and others (2011) similarly report a set of nine criteria that are necessary to the pursuit of sustainable woody biomass extraction: reforestation and productive capacity, land use change, biodiversity conservation, soil quality

and erosion prevention, hydrologic processes, profitability, community benefits, stakeholder participation, and community and human rights.

Fletcher and others (2011) recommend the following strategies to ensure habitat for biodiversity: reducing harvesting impacts through minimum tillage and reduced fertilizers and pesticides; protecting wildlife corridors, riparian zones, and other sensitive areas; and adopting wildlife habitat enhancement measures such as leaving patches of undisturbed areas, promoting certain species mixtures and crop rotations, and retaining quantities of harvest residues, litter, deadwood, snags, and den trees.

Multi-stakeholder efforts such as the Roundtable on Sustainable Biofuels and the Global Bioenergy Partnership for biomass harvesting are already underway. The Roundtable on Sustainable Biofuels and Global Bioenergy Partnership are in the process of developing global principles and criteria for developing a set of global, science-based criteria and indicators coupled with field examples and best practices (including benchmarks) for bioenergy sustainability.

In addition to the overall scale of biomass production, the location and methods of woody biomass harvests would affect the health, vitality, and ecological function of southern forests. Existing certification systems such as the Forest Stewardship Council, American Tree Farm System, and Sustainable Forestry Initiative have criteria and indicators to safeguard site productivity, water quality, and biodiversity but some additional indicators may be required for woody biomass harvests. For example, an indicator might be needed to address harvest residues left on site to maintain habitat for small mammals, insects, reptiles, and amphibians. Levels of necessary residues would depend on site-specific conditions, although general guidelines could be formulated at State or Southwide levels. Similarly, erosion-preventing indicators (such as those prohibiting harvests on shallow and nutrient-poor soils) would need to consider specific soil conditions such as depth of soils, nutrient conditions, and regeneration potential.

Biomass harvesting at the levels explored in this chapter could have negative implications for future forest conditions and ecosystem services flowing from southern forests including water (chapter 13) and wildlife/biodiversity (chapter 14). These outcomes depend on the amount and location of harvesting, but perhaps more critically on the management strategies used. The research described above indicates that management systems can be designed to mitigate damages to various ecosystem services. Of course, this requires management planning that addresses management objectives in the context of local conditions.

The need for additional best management practices or other guidelines will depend on the rate of development of the bioenergy sector, which is highly uncertain. The acceptability of these approaches would depend on the process of updating best management practices, which would ideally combine public involvement with a science-based process at appropriate scales (Alavalapati and Lal 2009).

SUMMARY

Wood-based energy markets have been proposed as a means to ensure sustainable forests, enhance energy security, promote environmental quality, and realize social benefits. However, several complex issues are influencing the ability to develop these markets in economically efficient, environmentally benign, and socially desirable ways. These issues include biomass availability or supply, market competitiveness and technology development, supportive Federal and State policies, tradeoffs with traditional forest product industries, sustainability, and ecosystem integrity.

This chapter has focused on four interrelated dimensions of bioenergy futures related to southern forests: markets, technologies, policies, and sustainability. Across the various bioenergy scenarios, these new demands would affect the markets for all wood products and lead to price increases for timber products and higher returns to private landowners. The degree to which other wood consumers are impacted would depend on expansion in supply, which in turn depends on intensification of forest management and changes in land use (primarily from agricultural to forestry).

New demands for bioenergy will be determined by expansion of existing technologies—for example, pellets and co-firing with coal—but more critically on the emergence of new technologies that are not yet economically viable. Accelerated technological developments and reduced production costs might be achieved through various policies at Federal and State levels. The sustainability issues surrounding bioenergy are defined by the negative externalities associated with accelerated harvesting in the South. Research indicates that management systems and standards can be designed to protect these values, defining another interface with future policy.

All of these dimensions are fraught with uncertainty. Market futures depend on demands for traditional wood products and on energy prices. Technology development depends on research funding but also on unknowable limits to technical feasibility and the prospect of economic returns. Policy development is highly uncertain and fundamentally engages tradeoffs among energy, environment, community, and other

societal objectives. The relationship between harvesting at unprecedented levels and forest ecosystem services is not fully known.

This chapter lays out a broad range of potential developments and management options. Clearly the path to sustainable bioenergy futures will involve enhancing knowledge, monitoring changes, updating expectations, and narrowing the overall uncertainty about future prospects. These issues will likely be the focus of forest assessments for years to come.

KNOWLEDGE AND INFORMATION GAPS

The future of woody bioenergy markets depends on a multitude of factors such as supply and availability of wood biomass; advancements in conversion technologies; improvements in harvesting, collection, storage, densification, preprocessing, and transportation; product prices and elasticities; infrastructure; and productivity increases.

Determining many such factors with confidence was difficult, and our analysis tools were limited. The bioeconomic model that we employed for market analysis calculates harvest levels, related prices, inventory, and acreage as functions of input demands, productivity increases, and various assumed parameters. These relationships are not known with high precision, and the market analysis cannot account for every economic variable and strategic response to the impacts on energy markets. Applying the models to a large number of scenarios provides insights into the range of potential market responses in the future. Improved estimates of the various supply, demand, and production relationships would enhance forecasts of future market developments. What's more, high-demand bioenergy futures imply important trades between wood products sectors with implications for employment, income, and rural economies that warrant additional study.

Our stylized approach to constructing consumption projections for the region leaves certain aspects of bioenergy futures unaddressed. Importantly, questions regarding interregional and international trade in wood products that could affect the ultimate expression of regional demands were not directly addressed. Trade modeling was beyond the scope of the Futures Project and explains why a broad range of futures was evaluated—i.e., to capture a reasonable range of futures regardless of the mechanisms leading to demand outcomes. The national assessment of timber and wood products markets contained in the 2010 RPA Assessment (Ince and others 2011) explores trade under similar scenarios and serves as a useful reference.

Woody bioenergy production might be more cost competitive under a greenhouse gas reduction strategy that assigns a market value to carbon emissions, in effect allowing social and environmental benefits to be accrued to woody bioenergy. This approach could monetize the benefits gained through greenhouse gas reduction, and those gains could be traded in a carbon market. Although likely to spur further growth in a bioenergy industry, the carbon market approach has yet to formulate a viable mechanism for realizing carbon payments to forest landowners.

The legal definitions of what qualifies as 'forest biomass' under different policy descriptions would generate large variations in forest biomass utilization and therefore require research attention. For example, the Energy Independence Security Act (2007) provides a restricted definition by excluding biomass from public forests and naturally regenerated private forests. Conversely, the 2008 Farm Bill provides a comprehensive definition for forest biomass.

Estimates of the volume of woody material that can used for energy production at secondary wood products manufacturing facilities are imprecise and based on varying assumptions about production facilities and per-unit production potential. Also needing research attention is comprehensive analyses of short rotation woody crops that can be made available for energy use; land use tradeoffs of short rotation woody crops with agriculture, pastures, and forest land; and potential for pine-switchgrass and other agroforestry systems to expand. Productivity gains from changing the geographic range of agriculture and woody biomass feedstocks and improving management is another research area that warrants further attention, as is documenting landowner willingness to participate in forest biomass markets and incorporating this information into woody biomass supply functions.

Additional research is needed to identify sustainability issues surrounding woody biomass utilization for energy. The focus of these concerns ranges from production processes to consumption processes (feedstock production, harvesting, transport, conversion, distribution, consumption, and waste disposal) to job creation and societal benefit distribution. Future research would necessarily focus on the tradeoffs arising from woody biomass diversion for energy use, and the level at which woody bioenergy might become ecologically, economically, and socially undesirable.

ACKNOWLEDGMENTS

The authors wish to thank Robert J. Huggett, Jr., and Karen L. Abt, U.S. Department of Agriculture, Forest Service, Southern Research Station; and Frederick J. Rossi, School of

Forest Resources and Conservation, University of Florida, for their support and insights. Thanks are also due to Carol Whitlock and Shawna Reid from the U.S. Department of Agriculture Forest Service, Southern Research Station, for technical edits and help in preparing GIS maps respectively.

LITERATURE CITED

Abt, R.C.; Abt, K.L. 2013. Potential impact of bioenergy demand on the sustainability of the southern forest resource. Journal of Sustainable Forestry. 32(1-2): 175-194.

Abt, R.; Abt, K.; Cubbage, F.; Henderson, J. 2010. Effect of policy-based bioenergy demand on southern timber markets: a case study of North Carolina. Biomass and Bioenergy. 34(12): 1679–1686.

Abt, R.C.; Cubbage, F.W.; Abt, K.L. 2009. Projecting southern timber supply for multiple products by subregion. Forest Products Journal. 59(7–8): 7–16.

Abt, R.; Cubbage, F.; Pacheco, G. 2000. Southern forest resource assessment using the Subregional Timber Supply (SRTS) model. Forest Products Journal. 50(4): 25–33.

Adams, D.M.; Alig, R.; Callaway, J.M. [and others]. 1996. The Forest and Agricultural Sector Optimization Model (FASOM): model structure and applications. Res. Pap. PNW–RP–495. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 60 p.

Aguilar, F.X.; Saunders, A. 2010. Policy instruments promoting wood-to-energy uses in the continental United States. Journal of Forestry. 108(3): 132–140.

Alavalapati, J.; Lal, P. 2009. Woody biomass for energy: an overview of key emerging issues. Virginia Forests. Fall: 4–8.

Alavalapati, J.R.R.; Hodges, A.W.; Lal, P. [and others]. 2009. Southern bioenergy roadmap. Research Triangle Park, NC: Southeast Agriculture and Forestry Energy Resources Alliance (SAFER), Southern Growth Polices Board. 127 p.

Amacher, A.J.; Barrett, R.H.; Moghaddas, J.J.; Stephens, S.L. 2008. Preliminary effects of fire and mechanical fuel treatments on the abundance of small mammals in the mixed-conifer forest of the Sierra Nevada. Forest Ecology and Management. 255(8–9): 3193–3202.

Arnold, C.L. 2000. Land use is the issue, but is land grant the answer? Journal of Extension. 38(6). http://www.joe.org/joe/2000december/comm1.html. [Date accessed: June 15, 2010].

Astrom, M.; Dynesius, M.; Hylander, K.; Nilsson, C. 2005. Effects of slash harvest on bryophytes and vascular plants in southern boreal forest clear-cuts. Journal of Applied Ecology. 42: 1194–1202.

Aulisi, A.; Sauer, A.; Wellington, F. 2007. Trees in the greenhouse: why climate change is transforming the forest products business. World Resources Institute Report. 74 p.

Aust, W.; Blinn, C. 2004. Forestry best management practices for timber harvesting and site preparation in the Eastern United States: an overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, and Soil Pollution Focus. 4: 5–36.

Beach, R.; Pattanayak, S.; Yang, J. [and others]. 2005. Econometric studies of non-industrial private forest management: a review and synthesis. Forest Economics and Policy. 7: 261–281.

Belanger, R.; Hedden, R.; Lorio, P. 1993. Management strategies to reduce losses from the southern pine beetle. Southern Journal of Applied Forestry. 17: 150–154.

Bies, L. 2006. The biofuels explosion: is green energy good for wildlife? Wildlife Society Bulletin. 34: 1203–1205.

Bingham, M.F.; Prestemon, J.P.; MacNair, D.A.; Abt, R.C. 2003. Market structure in U.S. southern pine roundwood. Journal of Forest Economics. 9: 97–117.

Blottnitz, V.H.; Curran, M.A. 2007. A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life-cycle perspectives. Journal of Cleaner Production. 15(7): 607-619.

Burger, J.A. 2002. Soil and long-term site productivity values. In: Richardson, J.; Bjorheden, R.; Hakkila, P. [and others], eds. Bioenergy from sustainable forestry: guiding principles and practice. Dordrecht, The Netherlands: Kluwer Academic Publishers: 165–189.

Butler, B.J. 2008. Family forest owners of the United States, 2006. Gen. Tech. Rep. NRS–27. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 72 p.

Carter, D.; Langholtz, M.; Schroeder, R. 2007. Biomass resource assessment part I: availability and cost analysis of woody biomass for Gainesville regional utilities. Gainesville, FL: University of Florida, School of Forest Resources and Conservation. 122 p.

Database of State Incentives for Renewables and Efficiency. 2010. summary Tables: Financial incentives for renewable energy/energy efficiency and rules, regulations and policies for renewable energy/energy efficiency. http://www.dsireusa.org/summarytables/index.cfm?EE=1&RE=1. [Date accessed: June 12, 2010].

De La Torre Ugarte, D.; English, B.; Jensen, K. [and others]. 2006. Economic and agricultural impacts of ethanol and biodiesel expansion. Study report by University of Tennessee, Agricultural Economics. http://beag.ag.utk.edu/pub/Ethanolagimpacts.pdf. [Date accessed: July 14, 2010].

De La Torre Ugarte, D.G.; Ray, D.E. 2000. Biomass and bioenergy applications of the POLYSYS modeling framework. Biomass and Bioenergy. 18(14): 291–308.

De La Torre Ugarte, D.G.; Ray, D.E.; Tiller, K.H. 1998. Using the POLYSYS modeling framework to evaluate environmental impacts in agriculture. In: Robertson, T.; English, B.C.; Alexander, R.R., eds. Evaluating natural resource use in agriculture. Ames, IA: Iowa State University Press: 151–172.

Dwivedi, P.; Alavalapati, J. 2009. Stakeholders' perceptions on forest biomass-based bioenergy development in the Southern U.S. Energy Policy. 37: 1999–2007.

Dwivedi, P.; Alavalapati, J.R.R.; Lal, P. 2009. Cellulosic ethanol production in the United States: conversion technologies, current production status, economics, and emerging developments. Energy for Sustainable Development. 13(3): 174–182.

Dwivedi, P.; Bailis, R.; Bush, T.; Marinescu, M. 2011. Quantifying GWI of wood pellet production in the Southern United States and its subsequent utilization for electricity production in the Netherlands/Florida. Bioenergy Research: 1-13.

Ecke, F.; Löfgren, O.; Sörlin, D. 2002. Population dynamics of small mammals in relation to forest age and structural habitat factors in northern Sweden. Journal of Applied Ecology. 39: 781–792.

Energy Independence and Security Act. 2007. H.R. 6. 110th U.S. Congress. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname= 110_cong_bills&docid= f:h6enr.txt.pdf. [Date accessed: June 16, 2010].

Energy Information Administration. 2007. Energy and economic impacts of implementing both a 25-percent renewable portfolio standard and a 25-percent renewable fuel standard by 2025. Report SR/OIAF/2007–05. http://www.eia.doe.gov/oiaf/servicerpt/eeim/index.html. [Date accessed: July 14, 2010].

Energy Information Administration. 2009. Annual energy outlook. Report DOE/EIA–0383(2009). http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2009).pdf . [Date accessed: January 12, 2010].

Energy Information Administration. 2010a. Annual energy outlook. Report DOE/EIA–0383(2010). http://www.eia.doe.gov/oiaf/aeo/index.html. [Date accessed: June 12, 2010].

Energy Information Administration. 2010b. Annual energy outlook. Year-by-year reference case tables (2007-2035). Report DOE/EIA–0383(2010). http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html. [Date accessed: June 14, 2010].

Energy Information Administration. 2010c. Net summer capacity of plants cofiring biomass and coal, 2007 and 2008. http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table1_9.pdf. [Date accessed: June 15].

Energy Information Administration. 2010d. Electric power generation and fuel consumption and stocks monthly time series file. Form EIA–923. http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html. [Date accessed: June 12, 2010].

Environmental and Energy Study Institute. 2010. Developing and advanced biofuels industry: State policy options and uncertain times. http://www.eesi.org/021610_state_biofuel_paper. [Date accessed: June 15].

Eriksson, E.; Gillespie, A.; Gustavsson, L. [and others]. 2007. Integrated carbon analysis of forest management practices and wood substitution. Canadian Journal of Forest Research. 37(3): 671-681.

Faaij, A.; Domac, J. 2006. Emerging international bioenergy markets and opportunities for socio-economic development. Energy for Sustainable Development. 1: 7–19.

Fletcher, R.; Robertson, B.A.; Evans, J. [and others]. 2011. Biodiversity conservation in the era of biofuels: risks and opportunities. Frontiers in Ecology and the Environment. 9: 161–168.

Fox, T.; Jokela, E.; Allen, H. 2007. The development of pine plantation silviculture in the Southern United States. Journal of Forestry: 337–347.

Fritsche, U.R.; Hunecke, K.; Schulze, F.; Wiegman. K. 2006. Sustainability standards for bioenergy. Darmstadt, Germany: WWF Germany, Oeko-Institut. www.wwf.de/fileadmin/fm-wwf/pdf_neu/Sustainability_Standards_for_Bioenergy.pdf. [Date accessed: July 6, 2010].

Galbe, M.; Zacchi, G. 2002. A review of the production of ethanol from softwood. Applied Microbiolgy Biotechnology. 59: 618–628.

Galik, C.; Abt, R.; Wu, Y. 2009. Forest biomass supply in the Southeastern United States—implications for industrial roundwood and bioenergy production. Journal of Forestry. 107(2): 69–77.

Gan, J.; Mayfield, C. 2007a. Benefits to landowners from forest biomass/bioenergy production. In: Hubbard, W.; Biles, L.; Mayfield, C.; Ashton, S., eds. 2007. Sustainable forestry for bioenergy and bio-based products: trainers curriculum notebook. Athens, GA: Southern Forest Research Partnership, Inc: 225-228.

Gan, J.; Mayfield, C. 2007b. The economics of forest biomass production and use. In: Hubbard, W.; Biles, L.; Mayfield, C.; Ashton, S., eds. 2007. Sustainable forestry for bioenergy and bio-based products: trainers curriculum notebook. Athens, GA: Southern Forest Research Partnership, Inc: 213-216.

Gan, J.; Smith, C.T. 2006a. A comparative analysis of woody biomass and coal for electricity generation under various CO_2 emissions reductions and taxes. Biomass and Bioenergy. 30(4): 296-303.

Gan, J.; Smith, C.T. 2006b. Availability of logging residues and potential for electricity production and carbon displacement in the USA. Biomass and Bioenergy. 30(12): 1011–1020.

Gorte, R.W.; Ramseur, J.L. 2008. Forest carbon markets: potential and drawbacks. Report prepared by CRS for Congress. Washington, DC: CRS RL34560. http://www.nationalaglawcenter.org/assets/crs/RL34560.pdf. [Date accessed: July 16, 2010].

Greene, J.L.; Daniels, S.; Kilgore, M.A. [and others]. 2005. Existing and potential incentives for practicing sustainable forestry on nonindustrial private forest lands. Final report to the National Commission on Science for Sustainable Forestry. http://www.srs.fs.usda.gov/econ/data/forestincentives/ncssf-c2-final-report.pdf. [Date accessed: July 15, 2010].

Grigal, D. 2000. Effects of extensive forest management on soil productivity. Forest Ecology and Management. 138: 167–185.

Guo, Z.; Sun, C.; Grebner, D.Q. 2007. Utilization of forest derived biomass for energy production in the U.S.A.: status, challenges, and public policies. International Forestry Review. 9(3): 748–758.

Gustavsson, L.; Holmberg, J.; Dornburg, V. [and others]. 2007. Using biomass for climate change mitigation and oil reduction. Energy Policy. 35(11): 5671-5691.

Haines, A.L. 2002. Blended teaching: land use planning education in Wisconsin and lessons learned. Journal of Extension. 40(5): 5IAW2. http://www.joe.org/joe/2002october/iw2.shtml. [Date accessed: June 12, 2010].

Hanson, C.; Yonavjak, L.; Clarke, C. [and others]. 2010. Southern Forests for the Future. Issue Brief 2. Washington, DC: World Resources Institute: 1-16.

Hardie, W.; Narayan, T.A.; Gardner, B.L. 2001. The joint influence of agricultural and nonfarm factors on real estate values: an application to the mid-Atlantic region. American Journal of Agricultural Economics. 83 (1): 120–132.

Hennenberg, K.; Dragisic, C.; Hewson, J. [and others]. 2009. The power of bioenergy-related standards to protect biodiversity. Conservation Biology. 24(2): 412–423.

Hill, J.; Nelson, E.; Tilman, D. [and others]. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proceedings of the National Academy of Sciences. 103(30): 11,206–11,210.

Hope, G. 2007. Changes in soil properties, tree growth, and nutrition over a period of 10 years after stump removal and scarification on moderately coarse soils in interior British Columbia. Forest Ecology Management. 242(2–3): 625–635.

Huang, M.Y. 2010. Regional impacts of bioenergy policies in the Southeastern United States: a computable general equilibrium analysis. University of Florida. 134 p. Ph.D. dissertation. http://purl.fcla.edu/fcla/etd/UFE0041091. [Date accessed: June 26, 2011].

Hughes, E. 2000. Biomass co-firing: economics, policy and opportunities. Biomass and Bioenergy. 19: 457–465.

Humphrey, J.; Davey, S.; Peace, A. [and others]. 2002. Lichens and bryophyte communities of planted and seminatural forests in Britain: the influence of site type, stand structure and deadwood. Biology Conservation. 107(2): 165–180.

Ince, P.J.; Kramp, A.D.; Skog, K.E. [and others]. 2011. U.S. forest products module: a technical document supporting the Forest Service 2010 RPA Assessment. Research Paper FPL-RP-662. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 61 p.

Jackson, S.; Rials, T.; Taylor, A.M. [and others]. 2010. Wood to energy: a state of the science and technology report. University of Tennessee and U.S. Endowment for Forestry and Communities Report. Knoxville, TN: University of Tennessee. 56 p.

Jacobson, M.G.; Greene, J.L.; Straka, T.J. [and others]. 2009. Influence and effectiveness of financial incentive programs in promoting sustainable forestry in the South. Northern Journal of Applied Forestry. 33(1): 35–41.

Janowiak, M.; Webster, C. 2010. Promoting ecological sustainability in woody biomass harvesting. Journal of Forestry. 108(1): 16–23.

Johnson, T.G.; Bentley, J.W.; Howell, M. 2009. The South's timber industry—an assessment of timber product output and use, 2007. Resour. Bull. SRS–164. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 52 p.

Jonsell, M. 2007. Effects on biodiversity of forest fuel extraction, governed by processes working on a large scale. Biomass and Bioenergy. 31(10): 726–732.

Joshi, S.; Arano, K.G. 2009. Determinants of private forest management decisions: a study on West Virginia NIPF landowners. Forest Policy and Economics. 11(2): 118–125.

Kilgore, M.A.; Greene, J.L.; Jacobson, M.G. [and others]. 2007. The influence of financial incentive programs in promoting sustainable forestry on the nation's family forests. Journal of Forestry: 184–191.

Kumarappan, S.; Joshi, S.; MacLean, H. 2009. Biomass supply for biofuel production: estimates for the United States and Canada. BioResources. 4(3): 1070–1087.

Lal, P.; Alavalapati, J.; Marinescu, M. [and others]. 2009. Sustainability indicators for woody biomass harvesting. The future of wood bioenergy in the United States: defining sustainability, status, trends and outlooks for regional development volume by Pinchot Institute for Conservation. http://www.pinchot.org/bioenergy_paper. [Date accessed: July 12, 2010].

Lal, P.; Alavalapati, J.; Marinescu, M. [and others]. 2011. Developing sustainability indicators for woody biomass harvesting in the United States. Journal of Sustainable Forestry. 30(8): 736–755.

Liao, X.; Zhang, Y. 2008. An econometric analysis of softwood production in the U.S. South: a comparison of industrial and nonindustrial forest ownerships. Forest Products Journal. 58(11): 69–74.

Lucier, A. 2010. Fatal flaw in Manomet's biomass study. The Forestry Source. September 2010: 4 p.

Manomet Center for Conservation Sciences. 2010. Massachusetts Biomass Sustainability and Carbon Policy Study: Report to the Commonwealth of Massachusetts Department of Energy Resources. Walker, T., ed. Natural Capital Initiative Report NCI-2010- 03. Brunswick, ME: Manomet Center for Conservation Sciences. 182 p.

Mayfield, C.A.; Foster, C.D.; Smith, C.T. [and others]. 2008. Opportunities, barriers, and strategies for forest bioenergy and bio-based product development in the Southern United States. Biomass and Bioenergy. 31(9): 631–637.

Mckendry, P. 2002. Energy production from biomass (part 2): conversion technologies. Bioresource Technology. 83(1): 47–54.

Mendell, B.; Lang, A.H.; Tydor, T. 2010. Economic and regional impact analysis of the treatment of biomass energy under the EPA greenhouse gas tailoring rule. Commissioned by National Alliance of Forest Owners. Athens, GA: Forisk Consulting. 32 p.

Mercer, E.; Lal, P.; Alavalapati, J. 2011. Competitiveness of carbon offset projects on nonindustrial private forest lands in the United States. In: Alig, R.J., ed. Economic modeling of effects of climate change on the forest sector and mitigation options: a compendium of briefing papers. Gen. Tech. Rep. PNW-GTR 837. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station: 119–160.

Milbrandt, A. 2005. A geographic perspective on the current biomass resource availability in the United States. Tech. Rep. NREL/TP–560–39181. http://www.nrel.gov/docs/fy06osti/39181.pdf. [Date accessed: June 16, 2010].

Neary, D.G. 2002. Hydrologic values. In: Richardson, J.; Bjorheden, R.; Hakkila, P. [and others], eds. Bioenergy from sustainable forestry: guiding principles and practice. Dordrecht, The Netherlands: Kluwer Academic Publishers: 190–215.

Neary, D.; Zieroth, E. 2007. Forest bioenergy system to reduce the hazard of wildfires: White Mountains, AZ: Biomass and Bioenergy. 31: 638–645.

Nesbit, T.; Alavalapati, J.R.R.; Dwivedi, P.; Marinescu, M. 2011. Economics of ethanol production using feedstock from slash pine (*Pinus elliottii*) plantations in the Southern United States. Southern Journal of Applied Forestry. 35(2): 61-66.

Oak Ridge National Laboratory. 2008. Bioenergy conversion factors. bioenergy.ornl.gov/papers/misc/energy_conv.html. [Date accessed: June 10, 2010].

O'Laughlin, J. 2010. Accounting for greenhouse gas emissions from wood bioenergy: response to the U.S. Environmental Protection Agency's call for information, including partial review of the Manomet Center for Conservation Sciences' biomass sustainability and carbon policy study. Report No. 31. Moscow, ID: Policy Analysis Group, College of Natural Resources. University of Idaho. 58 p.

Oklahoma Department of Agriculture, Food, and Forestry. 2008. Southern pine beetle threat draws cost-share funds. http://www.ok.gov/~okag/forms/forestry/pinebeetle.pdf. [Date accessed: April 16, 2011].

Pattanayak, S.; Murray, B.; Abt, R. 2002. How joint is joint forest production? An econometric analysis of timber supply conditional on endogenous amenity values. Forest Science. 48(3): 479–491.

Pattanayak, S.K.; Abt, R.C.; Sommer, A.J. [and others]. 2005. Forest forecasts: does individual heterogeneity matter for market and forest landscape outcomes? Forest Policy and Economics. 6(3–4): 243–260.

Pellet Fuels Institute. 2010. Fuel availability. http://pelletheat.org/pellets/fuel-availability/. [Date accessed: June 16, 2010].

Peng, C.; Jiang, H.; Apps, M.J.; Zhang, Y. 2002. Effects of harvesting regimes on carbon and nitrogen dynamics of boreal forests in central Canada: A process model simulation. Ecological Modeling. 155: 177–189.

Perlack, R.D.; Wright, L.L.; Turhollow, A.F. [and others]. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. DOE/GO–102995–2135. Joint report by U.S. Department of Agriculture and Department of Energy. Oak Ridge, TN: Oak Ridge National Laboratory. 58 p.

Prestemon, J.P.; Abt, R.C. 2002. Timber products supply and demand. In: Wear, D.; Greis, J., eds. Southern Forest Resource Assessment. Gen. Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 299–326.

Reijnders, L. 2006. Conditions for the sustainability of biomass based fuel use. Energy Policy. 34(7): 863–876.

Renewable Fuels Association. 2010. Biorefinery Locations. http://www.ethanolrfa.org/bio-refinery-locations/. [Date accessed accessed: January 7, 2010].

Rossi, F.J.; Carter, D.R.; Abt, R.C. 2010. Woody biomass for electricity generation in Florida: bioeconomic impacts under a proposed Renewable Portfolio Standard (RPS) mandate. Final report prepared for Florida Department of Agriculture and Consumer Services, Division of Forestry. Gainesville, FL: School of Forest Resources and Conservation. 98 p.

Sample, V.A. 2009. Ensuring sustainability in the development of wood-based bioenergy in the U.S. South. http://www.pinchot.org/gp/SouthRegionalMeeting. [Date accessed: July 25, 2010].

Schaberg, R.H.; Aruna, P.B.; Cubbage, F.W. [and others]. 2005. Economic and ecological impacts of wood chip production in North Carolina: an integrated assessment and subsequent applications. Journal of Forest Policy and Economics. 7(2): 157–174.

Schmidt, K.M.; Menakis, J.P.; Hardy, C.C. [and others]. 2002. Development of coarse-scale spatial data for wildland fire and fuel managment. RMRS-GTR 87. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 41 p.

Scott, D.; Dean. T. 2006. Energy trade-offs between intensive biomass utilization, site productivity loss, and ameliorative treatments in loblolly pine plantations. Biomass and Bioenergy. 30: 1001–1010.

Searchinger, T.; Heimlich, R.; Houghton, R.A. [and others]. 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change. Science. 319(5867): 1238-1240.

Sendek, P.E.; Abt, R.C.; Turner, R.J. 2003. Timber supply projections for northern New England and New York: integrating a market perspective. Northern Journal of Applied Forestry. 20(4): 175–185.

Shrum, T. 2007. Greenhouse gas emissions: policy and economics. Report prepared for the Kansas Energy Council. Topeka, KS: Kansas Energy Council. 78 p. http://kec.kansas.gov/reports/GHG_Review_FINAL.pdf. [Date accessed: July 22, 2010].

Siry, J.P.; Cubbage, F.; Malmquist, A. 2001. Potential impact of increased management intensities on planted pine growth and yield and timber supply modeling in the South. Forest Products Journal. 51(3): 42–48.

Siry, J.P.; Robison, D.J.; Cubbage, F.W. 2004. Economic returns model for silvicultural investments in young hardwood stands. Southern Journal of Applied Forestry. 28: 179–184.

Smith, T.; Lattimore, B. 2008. Potential environmental impacts of bioenergy harvesting on biodiversity. Forest Encyclopedia Network. http://www.threats.forestencyclopedia.net/t/t450/?searchterm=mitigating. [Date accessed: April 22, 2011].

Speight, M. 1997. Forest pests in the tropics: current status and future threats. In: Watt, A.; Stork, N.; Hunter, M., eds. Forests and insects. London: Chapman and Hall. 406 p.

Spelter, H.; Toth, D. 2009. North America's wood pellet sector. Res. Pap. FPL–RP–656. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 21 p.

Stupak, I.; Asikainen, A.; Jonsell, M. [and others]. 2007. Sustainable utilization of forest biomass for energy—possibilities and problems: policy, legislation, certification, and recommendations and guidelines in the Nordic, Baltic, and other European countries. Biomass and Bioenergy. 31(10): 666–684.

Susaeta, A.; Alavalapati J.; Carter, D. 2009. Modeling impacts of bioenergy markets on nonindustrial private forest management in the Southeastern United States. Natural Resource Modeling. 22(3): 345–369.

Susaeta, A.; Alavalapati, J.; Lal, P.; Matta, J. 2010. Assessing public preferences for forest biomass based energy in the Southern United States. Environmental Management. 45(4): 697–710.

Thiffault, E.; Paré, D.; Bélanger, N. [and others]. 2006. Harvesting intensity at clear-felling in the boreal forest: impact on soil and foliar nutrient status. Soil Science Society of American Journal. 70: 691–701.

Thiffault, E.; Pare, D.; Brais, S.; Titus, B. 2010. Intensive biomass removals and site productivity in Canada: a review of relevant issues. Forestry Chronicle. 86(1): 36–42.

Thor, M.; Stenlid, J. 2005. *Heterobasidion annosum* infection of *Picea abies* following manual or mechanized stump treatment. Scandinavian Journal of Forest Research. 20: 154–164.

United States Department of Agriculture (USDA) Forest Service. 2005. A strategic assessment of forest biomass and fuel reduction treatments in Western States. RMRS-GTR-149. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 17 p.

Van Loo, S.; Koppejan, J. 2008. The handbook of biomass combustion and cofiring. London, UK: Earthscan. 442 p.

Walmsley, J.; Godbold, D. 2010. Stump harvesting for bioenergy—a review of the environmental impacts. Forestry. 83(1): 17–38.

Walsh, M.E. 2008. U.S. cellulosic biomass feedstock supplies and distribution. http://ageconsearch.umn.edu/bitstream/7625/2/U.S.%20Biomass%20Supplies.pdf. [Date accessed: July 5, 2010].

Wear, D.; Abt, R.; Alavalapati, J. [and others]. 2010. The South's outlook for sustainable forest bioenergy and biofuels production. The Pinchot Institute Report. 20 p.

Wear, D.; Greis, J.; Walters, N. 2009. The Southern Forest Futures Project: using public input to define the issues. Gen. Tech. Rep. SRS–115. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

Zhu, J.Y.; Pan, X.J. 2010. Woody biomass pretreatment for cellulosic ethanol production: technology and energy consumption evaluation. Bioresource Technology. 100(13): 4992–5002.

APPENDIX B. Total Wood Demand for Energy Estimation

This appendix accompanies chapter 10. Estimation of the woody biomass required for electricity production began with Energy Information Administration (2010) data on electricity generation, in billion kilowatt hours (kWh), for the electricity grids that supply customers in the Southern United States. The grid-based sales data is available only until 2035, but we extrapolated it to 2050 by applying the average growth rate calculated over the five preceding years. Determining the amount of electricity consumed in the 13 Southern States is challenging because the electric grid networks do not track the volume of power flowing to or from individual areas, nor do they break out the electricity sales information by States.[1]

We assumed that a fixed percentage of individual grid electricity caters to the South (Galik and others 2009, Rossi and others 2010) and based estimates of that percentage on expert opinions. Our underlying assumption was that the electricity demand storyline will not drastically change, with little alterations in percentages.

The Florida Reliability Coordinating Council and Electric Reliability Council of Texas grids only serve customers in the South, so we assumed that all of their sales are within the South. Other electric grids cater to customers outside the South as well:

The Southeast Reliability Corporation serves customers throughout Missouri, Alabama, Tennessee, North Carolina, South Carolina, Georgia, and Mississippi; as well as portions of Iowa, Illinois, Kentucky, Virginia, Oklahoma, Arkansas, Louisiana, Texas, and Florida. To account for supplies going outside the South—most of Missouri and portions of Iowa and Illinois—we subtracted 16 percent of the grid total electricity.

The Southwest Power Pool serves customers throughout Kansas as well as portions of New Mexico, Texas, Oklahoma, Arkansas, Louisiana, Missouri, and Nebraska. We assigned 36 percent of the grid's output to the Southern States—Texas, Oklahoma, Arkansas, and Louisiana.

An East Central Area Reliability Coordination Agreement state, now merged into Reliability First Corporation, serves portions of Kentucky and Virginia. We assigned 18 percent of the grid's output to those States.

Western Texas also receives some electricity from the Western Electricity Grid. Rather than apportioning part of the Western Grid supply, we inflated the electricity supply of the major supplier in the State (Electric Reliability Council of Texas) by 6 percent.

Using the percentage apportioning described above, we scaled data on the total U.S. annual electricity sales outlined in Energy Information Administration (2010) reference case scenario to the Southern States.

We estimated the share of woody biomass-based electricity, using the same data source (Energy Information Administration 2010) for the electricity grids. These data are broken down by the type of renewable energy—including conventional hydroelectric, geothermal, wood and other biomass, biogenic municipal waste, wind, photovoltaic, and solar thermal sources; but excluding ethanol, net electricity imports, and nonmarketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters—and scaled down according to the percentage factors used to derive total output for the South. Using total electricity demanded, total renewable electricity, and total woody and other biomass-based electricity data, we derived the share of renewables in the total electricity portfolio of the region, as well as the share of wood-based biomass electricity within the renewables. Following Galik and others (2009), we assumed that all energy from wood and other biomass sources outlined by the Energy Information Administration (2010) is completely composed of wood. The woody biomass demand specified as electricity in billion kWh was converted to woody biomass in thermal energy terms of trillion Btu. Following Rossi and others (2010), we used a conversion factor of 13,648 Btu per kWh, which is the standard electricity to thermal energy conversion factor (3,412 Btu per

[1] Personal communication, 2010. R.J. Robertson, Manager, Customer Relations. Southwest Power Pool, 415 North McKinley, #140 Plaza West, Little Rock, AR 72205; and Teresa Glaze, Data Analyst, SERC Reliability Corporation, 2815 Coliseum Centre Drive, Suite 500, Charlotte, NC 28217.

kWh) at a 25 percent level of efficiency. This is congruent with the Wiltsee (2000) study of biomass-fuelled power plants, which reported the typical higher heating value to be approximately 14,000 Btu per kWh (24.4 percent efficiency).

To account for conversion efficiency increases resulting from factors such as increased use of co-firing with coal in the future, replacing older combustion steam turbines with gasification combined cycle plants, and technological advances to all types of biomass power plants, we assumed a gradual increase in thermal efficiency after 2020 to a maximum of 40 percent in 2050. We converted Btu values to mass in green tons by applying a conversion factor of 8.6 million green tons per Btu outlined by the Forest Service (2004) for green wood (50 percent moisture content). Next we needed to allocate how much of the total biomass used for energy is sourced from softwoods versus hardwoods. This is challenging as weight-to-volume conversion factors vary with stem size and specific gravity of species. Galik and others (2009) estimated conversion factors for trees of average diameters based on Timber Mart-South 2007 data. We followed their conversion factors—34.44 green tons per thousand cubic feet for softwoods and 35.98 green tons per thousand cubic feet for hardwoods.

ESTIMATING DEMAND

Wood-Based Liquid Fuels

Estimation of the woody biomass required for liquid fuels production began with Energy Information Administration (2010) projections of energy consumption by sector and source. We used this information to determine the share of cellulosic ethanol with respect to the total domestic ethanol production. While extrapolating ethanol production from 2036 to 2050, we pegged the corn and starch ethanol production value at the 2035 level and assumed that increased ethanol production will come from cellulosic sources alone. This is in sync with current Renewable Fuel Standard target of pegging corn and starch ethanol production at a fixed level and allows for increase in ethanol production through cellulosic sources alone, although the Energy Information Administration (2010) projections assume that the Renewable Fuel Standard target of cellulosic ethanol will not be met by 2022.

We estimated total domestic cellulosic ethanol production (in million barrels per day) based on percentage share data on estimates of liquid fuels supply and disposition, and added data for other biomass-derived liquids such as pyrolysis oils, biomass-derived Fischer-Tropsch liquids, and renewable feedstocks used for the production of green diesel and gasoline, gathered from the same source, to get total liquid fuels that can be produced from wood or other cellulosic sources (Energy Information Administration 2010).

We scaled cellulosic liquid fuels demand at the national level down to southern levels based on the assumption that 55 percent of the national demand will be met by the 13 Southern States. Because wood is a high-volume low-value product, transportation costs limit its transport to conversion plants far from harvesting areas. In this light, 55 percent is conservative, as 57 percent of wood harvesting occurs in the South (Hanson and others 2010).

A suite of feedstocks (including wood, paper and pulp liquors, algae, switch grass, and agricultural residue) can be used to produce cellulosic ethanol or other bio-oils. Because the future of liquid fuel from biomass sources is uncertain and we do not know how much cellulosic ethanol and other bio-oils will come from wood sources, we assumed that 30 percent of the total cellulosic fuels and bio-oils are from wood. We converted barrel-per-day demand to gallons per day according to Oak Ridge National Laboratory (2010) protocols, which defined 1 barrel as 42 gallons. We converted daily consumption data to annual levels by multiplying by a factor of 365.242 and converted gallons of ethanol and bio-oils to green tons of wood using an ethanol yield calculator (http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html), establishing that a green ton of softwoods produces 40.75 gallons, 50.4 gallons for hardwoods. We further converted the wood demand in thousand cubic feet by applying the volume-to-weight conversion factors developed by Galik and others (2009).

Wood Pellets

The U.S. wood pellet industry is already established, in contrast to the wood electricity and wood fuels industries (Alavalapati and Lal 2009, Spelter and Toth 2009). However, to a large extent, it is being driven by European demand (Gold 2009). This along with the use of wood pellets for domestic heating rather than grid electricity might result in incomplete accounting by the Energy Information Administration (2010), where renewable electricity production estimates are based solely on electricity grid sales. This prompted us to account for wood pellet demand separate from wood based electricity demand. Spelter and Toth (2009) estimated southern pellet plant capacity to be 1.85 million tons in 2009; based on their assessment that U.S. plants operate at an average efficiency of 66 percent, we estimated the demand for wood for pellets in the southern region to be 1.22 million tons. Because many States are encouraging the use of renewables, domestic demand is likely to increase in future. To account for expected demand increase in future, we assumed a 0.5-percent annual increase in the capacity of pellet plants from 2011 onwards. The current capacity utilization of U.S. pellet plants is lower than countries like Canada, which have utilization efficiency of 81 percent. Spelter and Toth (2009) attributed this to reasons such as newer plants, normal startup problems, and limits

on fiber availability. However, they also say that as pellet plants become older, the U.S. capacity utilization is expected to increase. To account for technological advancements, we assumed that overall capacity utilization increases by 1 percent per year from 2015 until it reaches 85 percent.

Harvesting Residues and Urban Wood Waste

Current literature (Perlack and others 2005, Galik and others 2009, Energy Information Administration 2010) indicates that harvesting residues—discarded tree tops and limbs generated during the harvesting process—currently being left on the ground can be used as woody biomass-based energy feedstocks. Recent analyses (Galik and others 2009, Rossi and others 2010) suggest that harvesting residues could be used to avoid diverting some merchantable timber for energy production. Rossi and others (2010) also argue that the projections of woody biomass demand for energy production need to be scaled down further to account for urban wood waste. For this reason, we dropped urban wood waste from the total amount of woody biomass consumption. This essentially gives us the merchantable timber that will be required for energy production (total woody biomass minus urban wood waste). Note that the residue from additional harvesting was handled endogenously. The model calculates softwood and hardwood harvesting residues along with the merchantable timber that can be harvested in a particular year. For each year, the amount of harvesting residues that can be made available is estimated along with the harvest levels of softwood and hardwood pulpwood and sawtimber. Because it ignores urban wood waste, we netted out urban wood waste from total woody biomass consumption and fed the remainder into the model.

The harvest residue that can be used for energy production depends on total harvest as well as the residue utilization factor (the percentage of harvest residue that can be converted to energy). Increased harvesting efficiency can reduce the availability of forest residues (Grushecky and others 2007). Rather than having a constant harvesting residue utilization factor—40 percent for Walsh and others (2008), 45 percent for Rossi and others (2010), and 50 percent for Galik and others (2009)—we assume 45 percent in 2010, increasing to 67 percent in 2025, and remaining pegged at this level until 2050. We believe that this trend characterizes the effects of current harvest efficiencies and technology improvements along with potential developments of the forest residues market. Because forest residue removal also has the potential for adverse impacts on site productivity and biodiversity (Lal and others 2009), some State biomass harvesting guidelines are aimed at retaining of 10 to 33 percent forest residues on harvesting sites (Lal and others 2011). Consequently, we assume that not more than 67 percent of harvest residues are removed and utilized for energy production.

Total harvest information for different time periods is estimated through an auxiliary Subregional Timber Supply model, (Abt and others 2000), which calculates gross harvest residues. The modified model uses residual factors (Johnson and others 2009) to estimate softwood and hardwood harvesting residues produced for different woody biomass consumption scenarios. For the forest survey units in this study, the harvesting residual factors for softwood ranges from 0.049 to 0.161 (per cubic foot of removals) for growing stock, and 0.091 and 0.357 for nongrowing stock, compared to 0.106 to 0.247 for growing stock and 0.1945 and 0.3783 for nongrowing stock for hardwoods.

The subregional supply model run allocates harvest residues based on species (hardwood versus softwood) rather than to hardwood and softwood products (sawtimber versus nonsawtimber). To distribute residues to the four products, we used average product shares of these products as initial parameter values and calculated the average product shares based on the Timber Product Outputs data (Bentley 2003; Johnson and others 2006, 2008, 2009). We estimated the residues at 55.51 percent for softwood sawtimber, 44.48 percent for softwood nonsawtimber, 39.74 percent for hardwood sawtimber, and 60.25 percent for hardwood nonsawtimber.

Wiltsee (1998) estimated per capita urban wood waste at 0.203 green tons per year, which we used—along with the yearly estimates of future population of the Southern States through 2050 from the U.S. Census Bureau States Interim Population Projections by Age and Sex data sets (http://www.census.gov/population/www/projections/projectionsagesex.html)—to calculate the annual amount of urban wood waste generated in the region. Because some urban wood waste will not be diverted for energy use, we scaled the per capita urban wood waste estimation by a utilization factor of 60 percent (Carter and others 2007).

ALLOCATING MERCHANTABLE TIMBER INTO FOUR PRODUCTS

To determine the percentage share within a species group, we allocated woody biomass requirement (minus harvesting residues) only to the pulpwood market, as sawtimber and other higher value forest resources might be too expensive to be used for bioenergy production. The nonsawtimber-based feedstock preference can also be observed in a recent study by Rossi and others (2010) in Florida, which assumed that 88 percent of the total timber diverted for energy comes from nonsawtimber sources. However, Perlack and others (2005) outline the possibility that high oil prices and low timber prices may create conditions whereby pulpwood or even small sawtimber resources could be used for bioenergy. We assumed that nonsawtimber will be used for energy production earlier than high value sawtimber. However, at

higher level of woody biomass consumption, we determined how much of the woody biomass requirement exceeds what can be met by nonsawtimber. We posit that this extra requirement of biomass (over and above the harvest levels depicted by the model runs) is sourced by displacing softwoods and hardwoods sawtimber from forest industries.

The subregional supply model utilizes diameter distributions for each subregion, owner, management type, and age class to calculate product removals and inventory volumes by age class. We modified age class in the subregional supply model from a five-year period to annual levels so that the supply response could be consistent with consumption data. Furthermore, the model requires a specific cull factor and a diameter range that determines how much volume (in each product category) contributes to nonsawtimber. We used the cull factor outlined in Abt and others (2009, 2010) and demarcated sawtimber versus nonsawtimber based on diameter at breast height (d.b.h.) definitions from the Forest Service Forest Inventory and Analysis program: 5–8.9 inches for softwood nonsawtimber, 5–10.9 inches for hardwood nonsawtimber, >9.0 inches for softwood sawtimber, and ≥11.0 inches for hardwood sawtimber. Trees <5 inches d.b.h. are considered to be saplings.

The modified subregional supply model requires that consumption be input according to the softwood and hardwood categories specified by the user. We apportioned total woody biomass consumed (both for energy and for traditional forest industry requirements) for a particular scenario among the hardwood and softwoods as the starting point. Looking at roundwood output data for the past decade (Bentley 2003; Johnson and others 2006, 2008, 2009), we observed that the softwoods comprise approximately 70 percent of the total timber output, compared to 30 percent for hardwoods.

As most of the technology for woody bioenergy production is in nascent stage and no species group has been established as favored, we followed this generic timber output trend and parameterized the initial model run by assuming that 70 percent of wood used for energy or by industry is sourced from softwood, and the remaining 30 percent is from hardwoods.

Effect of Bioenergy Demands and Supply Response on Markets, Carbon, and Land Use

Karen L. Abt, Robert C. Abt, and Christopher Galik

Abstract: An increase in the demand for wood for energy, including liquid fuels, bioelectricity, and pellets, has the potential to affect traditional wood users, forestland uses, management intensities, and, ultimately, carbon sequestration. Recent studies have shown that increases in bioenergy harvests could lead to displacement of traditional wood-using industries in the short run and intensive management, land use change, and sawtimber market impacts in the long-run. We simulate timber markets, as well as land use response and carbon outcomes resulting from projections of both traditional and bioenergy wood use in Alabama, Georgia, and Florida under differing levels of market supply responses. Increased logging residue recovery had a moderating effect on prices, although increased planting response led to higher carbon sequestration, and smaller effects on prices. Increased forest productivity led to lower prices, but also led to reduced timberland and thus lower forest carbon sequestration. Supply responses will be crucial to moderating market responses to increases in bioenergy wood demands. FOR. SCI. 58(5):523–539.

Keywords: woody biomass, timber supply, timber demand, logging residue, carbon sequestration

THE POTENTIAL FOR INCREASED USE OF WOOD in producing energy has added uncertainty to forest management and timber markets. Although the demand for wood for bioenergy is primarily policy-driven at this time, changes in the prices of fossil fuels could make the use of wood for energy a viable market alternative in the production of liquid fuels or electricity. Regardless of the impetus, however, increasing demands for wood will influence both the existing demand from traditional wood users as well as the potential supply responses. In this analysis, we use a market model of supply and demand, combined with biomass demands developed by Forisk Consulting (Brooks Mendell, pers. comm., Jan. 17, 2011) to address potential market responses. We evaluate how markets, land use, and on-site forest carbon are affected by supply responses. The potential supply responses we evaluate are logging residue recovery rates, increased pine plantation growth, and increased planting response to stumpage prices.

Typical approaches to evaluating the wood bioenergy markets include the following: assessments of potential available woody biomass (Perlack et al. 2005, Gan and Smith 2006, Biomass Research and Development Board [BRDI] 2008, Perez-Verdin et al. 2009) that do not include models of biomass demand; market models of both supply and demand, using policy-based biomass demands (Galik et al. 2009,Rossi et al. 2010, Abt et al. 2010a, 2010b, Ince et al. 2011); and facility location evaluations, often including optimal plant size in addition to plant locations (Wu et al. 2011). Carbon impacts of this changing market have also been assessed, focusing on national (Gan and Smith 2006) or regional implications (Abt et al. 2010b), or assessing the changes in carbon resulting from biological changes without including potential market responses (Manomet Center for Conservation Sciences 2010, Biomass Energy Resource Center 2012).

The current low level of logging residue recovery (LRR) will probably increase to supply the bioenergy market. The level of LRR is addressed in most analyses of woody bioenergy demand, in part because residues are specified in some federal and state policies as the only type of woody biomass that qualifies as renewable (Bracmort and Gorte 2009). Depending on the temporal scale chosen, carbon accounting of forest residues is also a fairly straightforward exercise. Recent studies suggest that the use of LRR for bioenergy may lead to a net increase in carbon emissions in the near term, but that the emission differential falls over time (Repo et al. 2011, Domke et al. 2012). Other studies (e.g., Abt et al. 2010b) assume that the long-term differential is negligible, implicitly treating the pool as carbon neutral.

Existing forest landowners probably will also increase their investments in intensive pine plantation management if prices increase. A recent summary by Munsell and Fox (2010) provides support for the potential benefits resulting from increased management of pine plantations. The various treatments, including tree improvement, genetics, tillage, fertilizer, and competition control, are shown to be economically beneficial to forest landowners (Allen et al. 2005), technologically possible (Fox et al. 2007), and sustainable (Fox 2000).

Land in timber production has been shown to increase based on relative changes in agriculture and forest rents

Manuscript received May 1, 2011; accepted April 2, 2012; published online May 10, 2012; http://dx.doi.org/10.5849/forsci.11-055.

Karen L. Abt, Southern Research Station, USDA Forest Service, PO Box 12254, Research Triangle Park, NC 27709—Phone (919) 549-4094; kabt@fs.fed.us. Robert C. Abt, North Carolina State University—bob_abt@ncsu.edu. Christopher Galik, Duke University—christopher.galik@duke.edu.

Acknowledgments: We thank Brooks Mendell and Amanda Lang, Forisk Consulting, for providing the bioenergy announcement data. We also thank Dan Koehler, La Capra Associates, Jianbang Gan, Texas A&M, and two anonymous *Forest Science* reviewers for their helpful reviews and comments.

This article was written by U.S. Government employees and is therefore in the public domain.

ED_000419-0007990

(Hardie et al. 2000). In this analysis, we use the Hardie et al. (2000) empirical model based on endogenous timber price changes, while holding agriculture rents constant. If timber acreage increases because of timber price increases, we assume that all gains are in pine plantations, although natural forest types remain constant. For this analysis, if timberland is decreasing, losses are distributed proportionally across all broad management types (pine plantation, natural pine, oak-pine, upland hardwoods, and lowland hardwoods).

In the following, we discuss the methods we use to evaluate the potential supply responses to meet varying bioenergy wood demands in a subregion of the Southeastern Unites States, Alabama, Florida, and Georgia, which is the core of the existing southern forest industry and also has been a focus of the evolving bioenergy industry. We develop demands for both traditional and emerging bioenergy industries. The effects on prices, inventories, and harvest levels, as well as impacts on land use, traditional industries, and carbon sequestration are discussed. The analysis of carbon outcomes is limited to forest carbon inventory within the three states only. It does not include impacts of forests outside these states nor changes in emissions associated with wood products production or substitutes.

Methods and Data

Below we describe our timber market region, describe the Sub-Regional Timber Supply (SRTS) model used in the simulations, describe the scenario development, and discuss carbon sequestration calculations.

Timber Market Region: Alabama, Florida, and Georgia

Alabama, Florida, and Georgia have an extensive forest resource base with a concentration of productive pine plantations. More than 33% of the timberland in this region is in privately owned pine plantations (USDA Forest Service 2011) The forest resource currently supports a large forest product industry that consumed more than 90 million metric tons annually from 1989 to 2007 (Figure 1) (USDA Forest Service 2009). The resource base and logging residue availability have also been attractive to the emerging bioenergy industry. Of the announcements of wood-using bioenergy facilities recorded by Forisk Consulting for the southern states, more than 60% of total announced demands in the South were in Alabama, Florida, and Georgia. In the last decade, however, lower prices have led to reduced planting in Georgia and Florida, which will affect future timber supply (Figure 2) (USDA Forest Service 2011). The availability of logging residue is also being affected by the recent drop in wood consumption shown in Figure 1.

Although this region is dominated by pine forests, hardwood forests are also an important component of the forest landscape. In these states, hardwood utilization is dominated by pulpwood, but hardwood pulpwood consumption has been less than 20% of total pulpwood consumption in the last decade (USDA Forest Service 2009). Because hardwoods are not managed intensively in this region, there is no history of management intensification response due to higher prices. Higher prices do tend to keep more land in hardwood forests, and this effect is captured in our analysis.

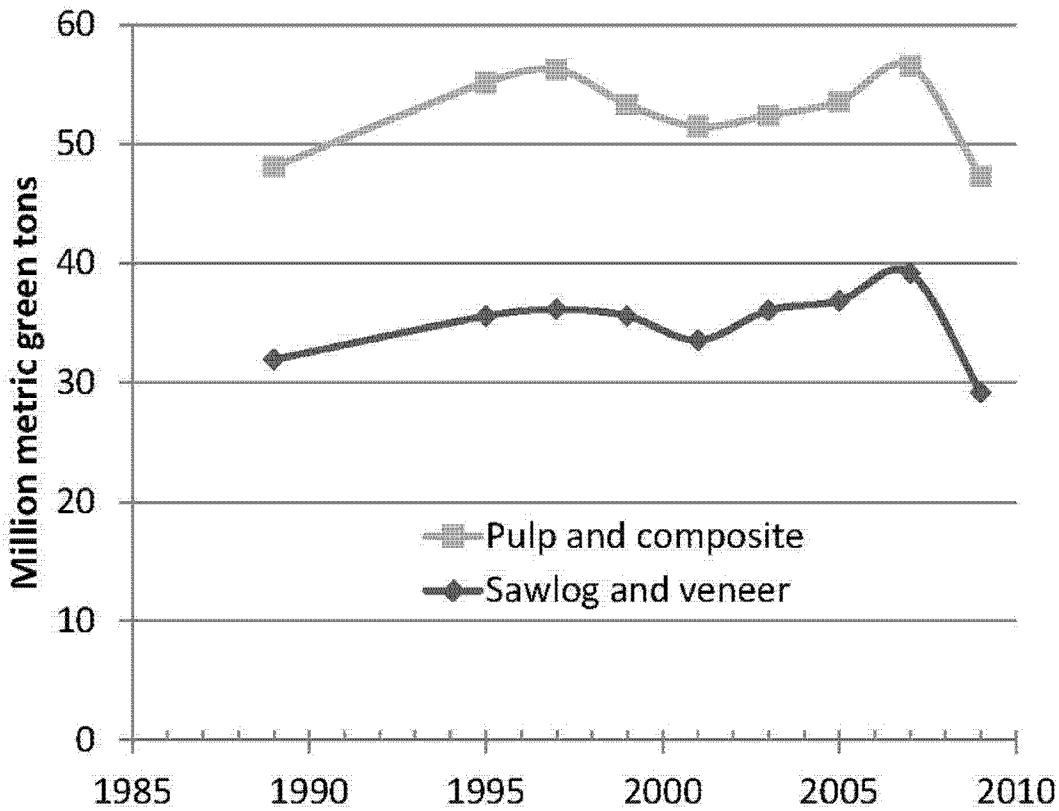


Figure 1. Historical removals for two softwood product groups from 1985 to 2009 for Alabama, Florida. and Georgia (USDA Forest Service 2009).

ED_000419-0007991

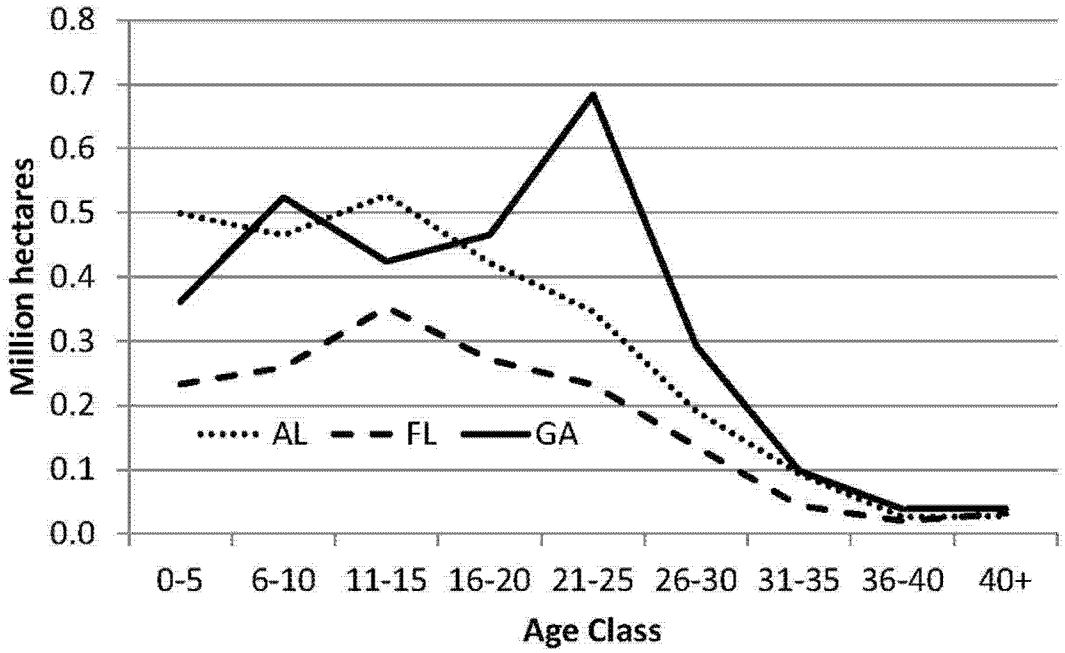


Figure 2. Plantation area by age class from the most recent FIA surveys for Alabama, Florida, and Georgia (USDA Forest Service 2011).

Although hardwood harvests generate more logging residue per unit volume, pine utilization dominates these markets and is the focus of the supply response discussion below.

Modeling Approach

We used the SRTS model to conduct a partial equilibrium analysis of stumpage markets in the region. The model uses the USDA Forest Service Forest Inventory and Analysis (FIA) (USDA Forest Service 2011) data set of inventory, growth, removals, and acreage by forest type, private ownership category, species group, and age class for multicounty areas (FIA survey units). A supply function with assumed price elasticity of 0.3 and inventory elasticity of 1.0 was equilibrated with a demand function with price elasticity of -0.5. Previous research by Pattanayak et al. (2002) concluded that there is consensus in the literature that both the supply and demand price response is inelastic (meaning that a large change in price is needed to induce a small change in harvest), although the precise values of these elasticities vary by study.

Once the equilibrium price and quantity of each of the four products were projected for a year, the model used a goal program to determine from which owners and management types the product harvest would come. The goal program reconciles product volumes with observed harvest patterns across forest types and age classes. The harvest was then passed to the biological accounting module, and inventory was updated for the next period's equilibrium calculation. The accounting module tracks inventory by 5-year age classes for the five southern forest types (pine plantations, natural pine, oak-pine, upland hardwoods, and bottomland hardwoods) and for two ownership classes (corporate and other private). Further details of the SRTS model can be found in Abt et al. (2009).

In this analysis, we evaluate four product types: softwood pulpwood, softwood sawtimber, hardwood pulpwood, and hardwood sawtimber. The model grows and harvests trees in response to demands for pulpwood and sawtimber, where the term *pulpwood* is used to describe the growing stock volume in softwood trees of <9 inches dbh or hardwood trees of <11 inches dbh. In addition, a portion of trees in larger diameter classes, which includes top volume and cull, was added to pulpwood volume. Softwood and hardwood volumes in larger diameters, net of this cull proportion, were considered sawtimber. The amount of harvest that was considered logging residue was calculated based on TPO removal proportions (Table 10 in Johnson et al. 2009) by state.

Scenario Development

Traditional Wood Demand

Demand represents the potential consumption of wood at different prices. To develop demand scenarios over time we project consumption of wood in various uses at existing prices. This would represent future consumption only if supply were unconstrained. We then use these demand scenarios to shift the product demand curve in the model. This demand interacts with a supply curve, which is based on current year product inventories and econometrically estimated supply-price relationships. The resulting price and harvest from supply-demand equilibrium is reported as the market outcome. The change in inventory resulting from the harvest and annual growth is also presented.

The projected demand for timber from traditional wood processing for four product types is shown in Figure 3. The 2007–2010 recession can be seen to have had an effect by reducing demand and is followed by a recovery through 2018. We used downscaled national observations of paper and wood products industry value of shipments (US Department of Commerce, Bureau of the Census 2011) to

ED_000419-0007992

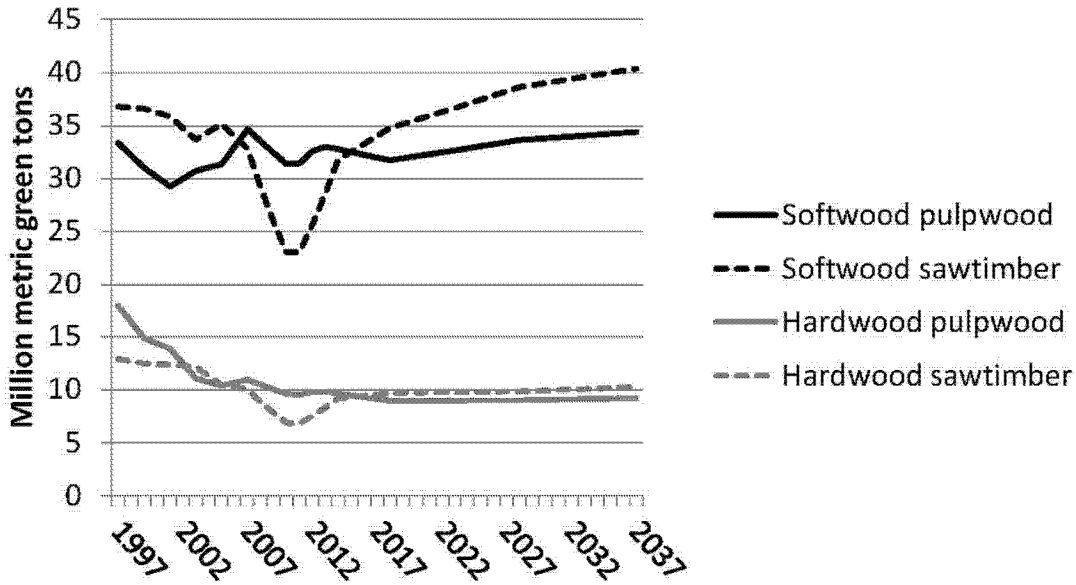


Figure 3. Historical traditional demand for four product groups from 1997 to 2007 and projected traditional demands for 2008 to 2037 for Alabama, Florida, and Georgia.

extend the 2007 timber product output data (USDA Forest Service 2009) to 2010. We then used the Bureau of Labor Statistics 2008–2018 forecast at the national industry level for total industry output (Woods 2009), also downscaled to the state level. Then, assuming a softwood-hardwood mix consistent with state historical trends, we partitioned the changes in industries year-over-year to each of the four products out to 2018. This assumes that the change in value of shipments translates directly to a change in input demand. Beyond 2018, we assume decade-over-decade increases of 10 and 5% for sawtimber and 5 and 2.5% for pulpwood for the second and third decades of the projection, respectively.

Because some policies encourage the use of logging residues and others allow only the use of logging residues, the level of projected traditional wood demand is important in any assessment of the impact of woody bioenergy demand on timber markets. A lower level of timber demand from pulp and paper mills and sawmills, for example, will lead to lower harvest levels and fewer available logging residues. If only residues are allowed to qualify as renewable, then the woody bioenergy industry is explicitly tied to the future of the traditional wood industries. However, if roundwood is used for bioenergy, then the market outcome is more complicated. A lower level of traditional harvest could lead to fewer available residues (which could raise the price of residues and set a physical upper limit on residue supply) but could also lead to higher inventory levels and lower roundwood prices, which would favor increased roundwood utilization for bioenergy.

Bioenergy Wood Demand

Because bioenergy is an emerging industry, econometric relationships have not been estimated for either supplies or demands. The current biomass energy literature focuses on projected consequences of bioenergy policy on bioenergy demands. Examples include Ince et al. (2011), Alavalapati et al. 2011, the U.S. Billion-Ton Update (US Department of Energy 2011), and US Energy Information Administration policy assessments (US Energy Information Administration 2007). For this analysis, we used a database of announced facilities in the region that would process woody biomass into electricity, wood pellets, and liquid fuels. Forisk Consulting has developed a methodology to project medium-term demand for woody biomass based on an evaluation of viable technologies and the status of the announcements (Forisk Consulting (Brooks Mendell, pers. comm., Jan. 17, 2011)).

Forisk Consulting gathers information on all announced facilities by type and location and then researches the level of commitment made to the facility. These announcements include facilities for the production of liquid fuels, wood pellets, and electricity. Forisk Consulting assesses the announcements for the projected start-up date and includes announcements out to 2020. We use the timber demands from all announced facilities as the bioenergy demand in the region (Figure 4). The start-up dates result in a steep increase in demand in early years and then a leveling off in later years, which will probably be smoothed to a more linear increase as projects are delayed or ended and new projects are announced. A higher level of bioenergy demand could result if the technology for cellulosic ethanol develops and wood-derived fuel is used to meet the Renewable Fuels Standard (US Energy Information Administration 2007) or if the United States adopts a carbon reduction policy or a renewable electricity standard. Conversely, a lower level of bioenergy demand could result if the technology for commercial cellulosic ethanol does not develop, if additional state-level renewable energy standards are not adopted, or if the price of nonrenewable energy falls.

Forisk Consulting provides estimates of actual (2008–2010) and potential (2011–2020) bioenergy demand. We assumed that the level will increase at a rate of 10% per decade for the following two decades of the projection. In

ED_000419-0007993

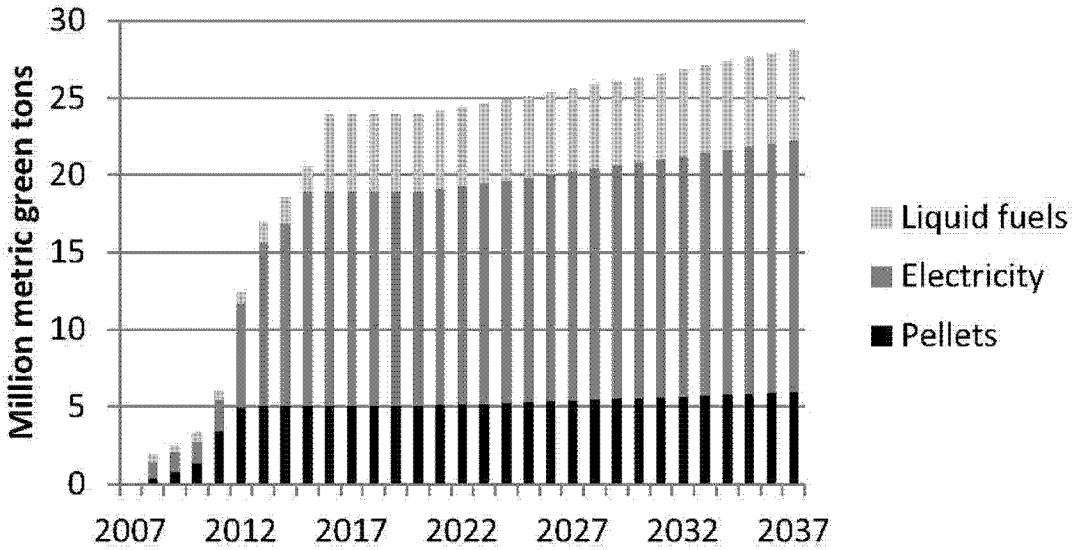


Figure 4. Bioenergy demand from announced facilities for liquid fuels, pellets, and electricity production for Alabama, Florida, and Georgia from 2007 to 2037 (adapted from Forisk Consulting).

addition, although Forisk Consulting separates the announcements by end use, they do not estimate how the various uses will use hardwood and softwood species. We use their aggregate woody bioenergy demand value in metric tons (Figure 4) as our bioenergy demand.

We implemented bioenergy demand by calculating available logging residue from existing harvests and assumed that these residues would reduce bioenergy demand for roundwood. The utilization of residues will depend on the mix of bioenergy consumers (e.g., liquid fuels, pellets, and electricity) and the technologies they use. There are also cost, logistics, and logging capacity questions associated with residue supply. To the extent that these factors constrain residue utilization below our assumptions, our estimates of roundwood market impacts are conservative and vice versa.

Residue availability was based on two calculations. The first is an estimate of residue production from harvest operations. The second is LRR over time, which is discussed below under supply responses. For residue production, we used the state-level data recorded in Table 10 in Johnson et al. (2009) to estimate growing stock and nongrowing stock logging residues per ton of growing stock harvest. Table 10 estimates were adjusted to remove stump volumes, which are included in the Forest Service definition of residue but are not usually considered recoverable. Although utilization standards may evolve over time, we held these residue production rates constant over the projection.

Although the above procedure gives us supply estimates of logging residue by size class and species group, our bioenergy demands are not specific to species or size classes. For these projections, we assumed that bioenergy demand would follow the current pulpwood harvest allocation between pine and hardwood. As noted above, this assumes that approximately 80% of bioenergy demand in the region would come from pine.

The procedure for adding bioenergy demand to traditional demand was the following. The Forisk Consulting database was split into hardwood and pine demand based on current pulpwood harvest. A portion of this demand was met by logging residue based on the availability and the LRR factor for that species group and year. After residue utilization was deducted, the remaining bioenergy demand quantity was used to shift the current year pulpwood demand curve. Because demand and supply are price-inelastic in these markets, demand shifts lead to larger price changes than harvest changes.

The difference between the demand shift and the resulting market equilibrium harvest change for both industries is what we call "displacement." If we had information on the demand price elasticity of emerging bioenergy demand, it would be possible to simulate the change in the price responsiveness of the combined (existing and bioenergy) industry demand. Because we do not have this information, however, we compare this total displacement quantity to the demand quantities in bioenergy and existing pulpwood consumer. Three potential outcomes could occur.

First, if both industries had the same demand price response, the displacement would be proportional, e.g., demand might be reduced by 20% in each sector because of higher prices. Second, if bioenergy were more price-inelastic (less price-responsive) than traditional industries, the higher market prices would affect the existing wood consumers disproportionately; i.e., a larger than proportionate share of displacement would be due to reduced consumption from the existing industry. Price-inelastic bioenergy demand would be consistent with the view that these demands are policy-driven and that some power markets are regulated so that costs may be passed through to power consumers.

Third, if bioenergy demand were more price-responsive (less price-inelastic) than existing wood consumers, higher wood prices would have a larger impact on bioenergy consumption, and a larger than proportionate share of displacement would be due to reduced consumption by the

ED_000419-0007994

bioenergy sector. This view would be consistent with bioenergy firms updating their feedstock price expectations as markets evolve so that fewer announcements become actual facilities. Availability of renewable or carbon-friendly substitute feedstocks at relatively lower prices could also lead to greater bioenergy demand response to wood prices.

For these projections, we assumed that the price elasticity of wood demand did not change with the addition of bioenergy demand, so that the difference between the demand shift due to bioenergy and the resulting harvest is based on a demand price elasticity of -0.5. In our results we show the proportion of bioenergy or pulpwood demand that this displacement represents. This gives some perspective to how changes in the allocation of displacement would affect the sectors.

Supply Response

Three potential supply responses were evaluated: increased LRR, increased plantation growth, and increased timberland area response. For LRR and growth responses, there are no empirical data to determine market response to demand/price changes. Thus, we make assumptions about the rate of adoption of these responses. For timberland, the model calculates endogenous planting response (Hardie et al. 2000) as described in the introduction, but these responses are sensitive to the definition of forest rent, which we explore below.

We evaluated two end levels of LRR, 33% and 66%, with increases from zero to this level over the first 5 years of the projection. These recovery rates are applied to all harvests, implying that we expect some harvests to be recovered at a higher rate and some at a lower rate to reach this regional average on all harvests. The higher level, 66%, is similar to levels assumed to be the operational maximum level of LRR (Perlack et al. 2005, BRDI 2008) on individual pine stands. We assume that the adjustment process will not be immediate because the logging sector will need to adjust equipment, transportation, and employment capacity to accommodate the new markets.

The initial hectares of pine plantations are derived from the FIA database (USDA Forest Service 2011). Timberland area is projected for each scenario based on Hardie et al. (2000) as a function of pine sawtimber prices. Other inputs are used in Hardie et al. (2000), such as agricultural rents and county population forecasts. Agricultural rents are held constant and the loss of rural land to urbanization is based on the county-level population forecasts used in the Southern Forest Resource Assessment (SFRA) (Prestemon and Abt, 2002). The timber price used in the land use forecast is the previous year's SRTS model output, so that the response of planting in time t is made in response to the modeled softwood pulpwood and sawtimber prices in time $t - 1$. In this analysis, overall timberland change was initially tied primarily to pine sawtimber prices, as developed in the Hardie et al. model. When timberland increases, the increases are assumed to occur in pine plantations, although decreases in timberland are assumed to be proportional across all five management types. To better reflect biomass market impacts on forest rents, we modified the rent calculation to reflect income from both pulpwood and sawtimber price changes using a net present value calculation. Our calculation takes into account the price and timing differential in these products. This calculation continues to put the primary weight on sawtimber prices, but in times of lower sawtimber prices and high pulpwood prices, a larger proportion of rent is based on pulpwood price.

Current growth rates in the model are developed from regression equations for each management type and physiographic region. These rates represent averages across large areas, and different owners. To model increased growth that is likely to occur on some stands, but not all, due to increases in fertilization, thinning, or genetic selection, we augmented the growth rates on new plantations beginning in 2008, rising to a regionwide average increase of 25% by 2037. Again, assuming a regionwide average of 25% implies that although some individual stands could have growth rates higher than 25% over 30 years, some stands will also have lower growth rates. An earlier study, the SFRA (Prestemon and Abt 2002), used an assumed increase of 50% in growth over 50 years compared with our 25% growth increase over 30 years.

Scenarios

We simulated six scenarios to evaluate the consequences of the three potential supply responses individually or in combination (Table 1). The scenarios include (1) a baseline including only traditional demands, no new bioenergy demands, and no additional supply responses; (2) BIO 1 added bioenergy demand and a supply response of a 33% LRR; (3) BIO 2 doubled the residual supply response by assuming a 66% LRR; (4) BIO 3 added a potential increase in planting response by including pine pulpwood prices in the timber rent calculation; (5) BIO 4 added a 25% increase in growth on new plantations but did not include pulpwood in the rent calculation, and (6) BIO 5 added both the increased planting response of BIO 3 and the increased growth on new plantations of BIO 4.

Carbon Sequestration Calculations

We converted SRTS inventory projections into estimates of on-site forest carbon through the use of FIA-derived ecosystem-level equations (Foley et al. 2009, as based on Smith and Heath 2002 and Smith et al. 2006). These provide carbon estimates for each of the five management types by age class included in the SRTS model. For each year of SRTS output, we calculated the total amount of carbon contained in live tree, dead tree, understory, down deadwood, and forest floor carbon pools across all forested acres in each of the five management types.

Note that this analysis accounts only for changes in forest carbon and is not a complete carbon accounting of the greenhouse gas (GHG) effects, which would require a assessment of fossil fuel substitution and a life cycle analysis of bioenergy GHG emissions (see, e.g., Mann and Spath 2001). We also take a simplified approach to LRR carbon accounting, assuming a negligible difference between near-term use of residues for bioenergy and their long-term

ED_000419-0007995

Table 1. Definition of baseline and bioenergy demand scenarios with varying supply responses.

Scenario	Supply response		
	Residue recovery	Increased planting response	Growth increase
Baseline: traditional demand only (no bioenergy demand or supply response)	NA	Timber rent based on pine sawtimber prices	None
BIO 1: traditional + bioenergy demand; 33% LRR	33%	Timber rent based on pine sawtimber prices	None
BIO 2: traditional + bioenergy demand; 66% LRR	66%	Timber rent based on pine sawtimber prices	None
BIO 3: traditional + bioenergy demand; 66% LRR; increased planting response	66%	Timber rent based on pine pulpwood and sawtimber prices	None
BIO 4: traditional + bioenergy demand; 66% LRR; 25% growth increase	66%	Timber rent based on pine sawtimber prices	25% on new planting by end of projection
BIO 5: traditional + bioenergy demand; 66% LRR; increased planting response; 25% growth increase	66%	Timber rent based on pine pulpwood and sawtimber prices	25% on new planting by end of projection

NA, not applicable; LRR, logging residue recovery.

decomposition on the ground. We therefore exclude carbon stored in harvest residues from our estimates of forest carbon, because the pool is effectively canceled out by including it in both the bioenergy and baseline scenarios. Other research has explored the effect of displaced fossil emissions on net GHG balance (e.g., Abt et al. 2010b); therefore, this analysis is limited to the carbon implications of shifts in timberland and inventory only. Finally, we evaluate only the three states listed above, and do not include impacts on forests outside these states, nor do we include any changes in emissions associated with the production of wood products or their substitutes. Our analysis focuses on the net forest carbon impacts of increased demand for bioenergy and a set of expected supply responses to this demand.

Results and Discussion

The results are presented in Figures 5–12. Figure 5 shows softwood pulpwood market responses from 2007 to 2037, and Figure 6 shows softwood sawtimber responses for that same period. There are few impacts on the hardwood market, both because of the initial effect of changes in demand, based on the proportion of the market fulfilled by hardwoods, and because the hardwood forest types are not typically intensively managed to improve growth nor are they planted. Plantation acres over time are shown in Figure 7 for all six scenarios, and Figure 8 shows the land use changes by planted and natural forest types over the projection by scenario. Figure 9 shows the bioenergy feedstocks from forests including residue use, harvest change, and harvest displacement, and Figure 10 illustrates the range of how total displacement of demand could affect the two industries. Figures 11 and 12 show the three-state forest carbon storage from 2007 to 2037, with Figure 11 showing the total and Figure 12 showing the storage by both natural and planted forest types. Each of the figure and scenario results is discussed in more detail below.

Softwood pulpwood markets respond, as expected, more than the other three product types because any bioenergy demand not met through residue recovery is assumed to be met by using pulpwood. The baseline pulpwood projection (Figure 5a) shows a decline in price from 2007, with an eventual recovery, although prices never return to the 2007 level. Although acres of young stands are affected by reduced planting, this effect is offset by the "cull" proportion of the growing sawtimber inventory. Removals and inventory stay fairly steady throughout the projection. When bioenergy demand is introduced, but supply response is limited (BIO 1, with only a 33% LRR) (Figure 5b), pulpwood prices rise through the end of the projection, with 2037 97% higher than 2007. Pulpwood inventory rises during the recession, but quickly falls to hover below the 2007 level, and removals show a rise after the recession, but then level off, consistent with our expectations of a market with inelastic price response.

Doubling the logging residual recovery rate to 66% (Figure 5c) reduces the impact on the pulpwood market, with prices rising only by 70% over 2007 levels and smaller effects on both inventory and removals. Adding an enhanced response of planting to pulpwood prices over the 30 year projection moderates the market effects, again leveling off the rising trend so that the projected 2037 value is now only 63% higher than the 2007 value (Figure 5d, BIO 3). Under a supply response of high LRR and an increased growth rate on new plantations (Figure 5e, BIO 4), prices rise as in BIO 2 and BIO 3 through 2023 but then begin to moderate as the new growth on plantations begins to influence the inventory values. Inventory increases, removals increase, and prices fall after 2023, with prices projected at only 32% higher in 2037 than in 2007. Figure 5f shows the combined supply response of 66% LRR plus 25% growth increase plus the increased planting response (BIO 5) and has the lowest price level in 2037 of all of the bioenergy scenarios (at 127% of the 2007 level). An increase in the LRR reduces the overall effect of the bioenergy demands; increased plantation response to pulpwood prices leads to a moderating of price increases and increased growth on plantations leads to a reversal of the rising trend in prices.

Figure 6 shows the response of the softwood sawtimber market to the six supply response scenarios.

Pulpwood and sawtimber are linked in the model through product definitions because a percentage of the sawtimber

ED_000419-0007996

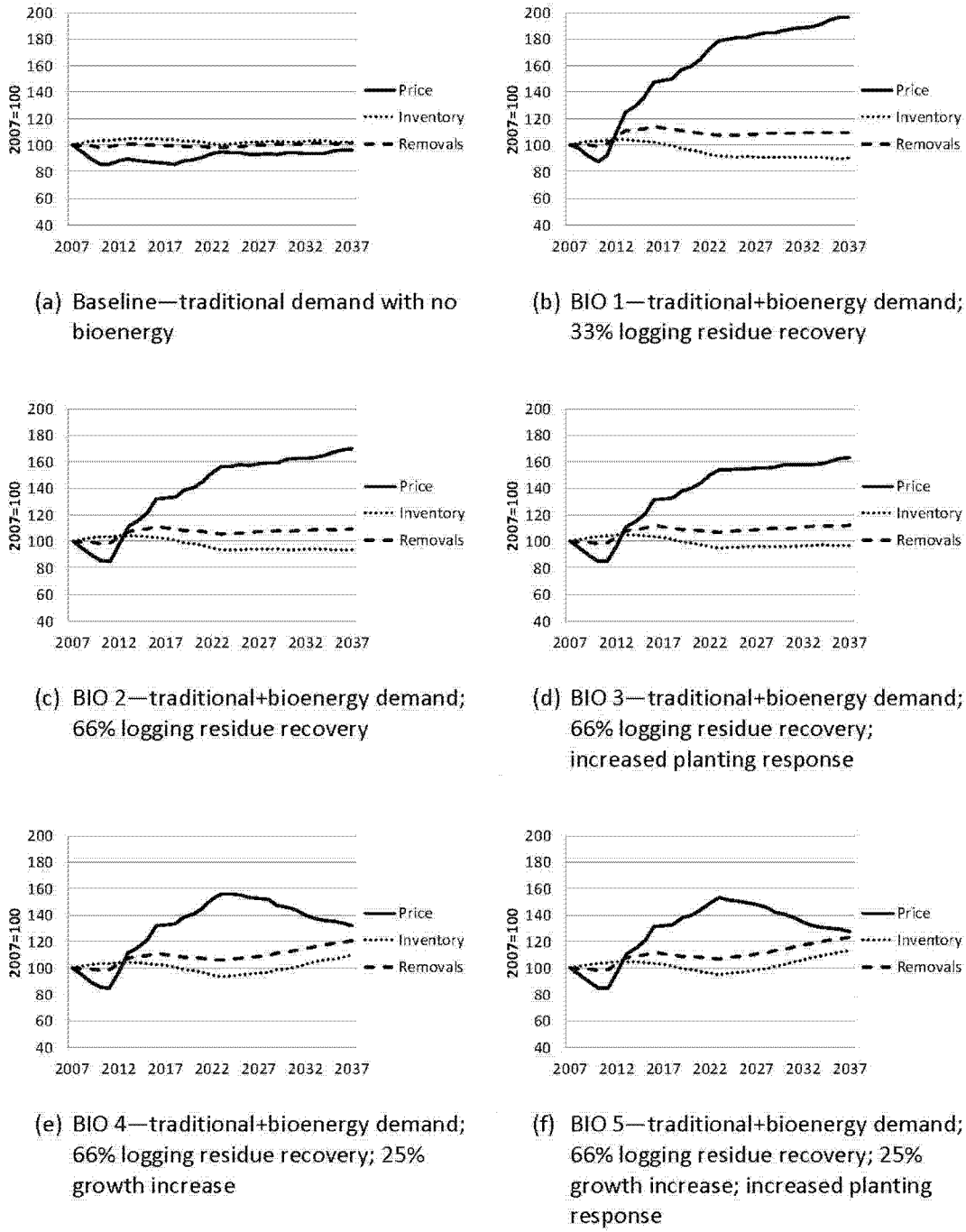


Figure 5. Softwood pulpwood: comparison of prices, inventory, and removals from simulations of the baseline and five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

size class is classified as pulpwood, and increased harvest of pulpwood reduces ingrowth into the sawtimber category [1]. Sawtimber harvests are a key component of logging residue production. Because sawtimber prices are currently at about three times the level of pulpwood prices [2], we do not expect that sawtimber will be used to provide bioenergy over the projection period. Even in the lowest supply response scenario (BIO 1), pulpwood prices rise only to about double their current level, not high enough to induce the use of sawtimber for pulpwood or biomass except at the margin.

The baseline (Figure 6a) shows a large and long-lasting effect of the recession on softwood sawtimber markets, with a return of prices to 2007 levels not projected until 2027. This is a result of only our traditional demand projection and the buildup in sawtimber inventories, because bioenergy demand is not included in the baseline projections. Inventory levels rise sufficiently in the early years to allow removals to recover with slower recovery in price levels. In the scenario with the largest harvesting impact (BIO 1, the smallest supply response of the five we examined), prices rise more rapidly, returning to 2007 levels 4 years earlier and continuing at a higher rate of increase through the end

ED_000419-0007997

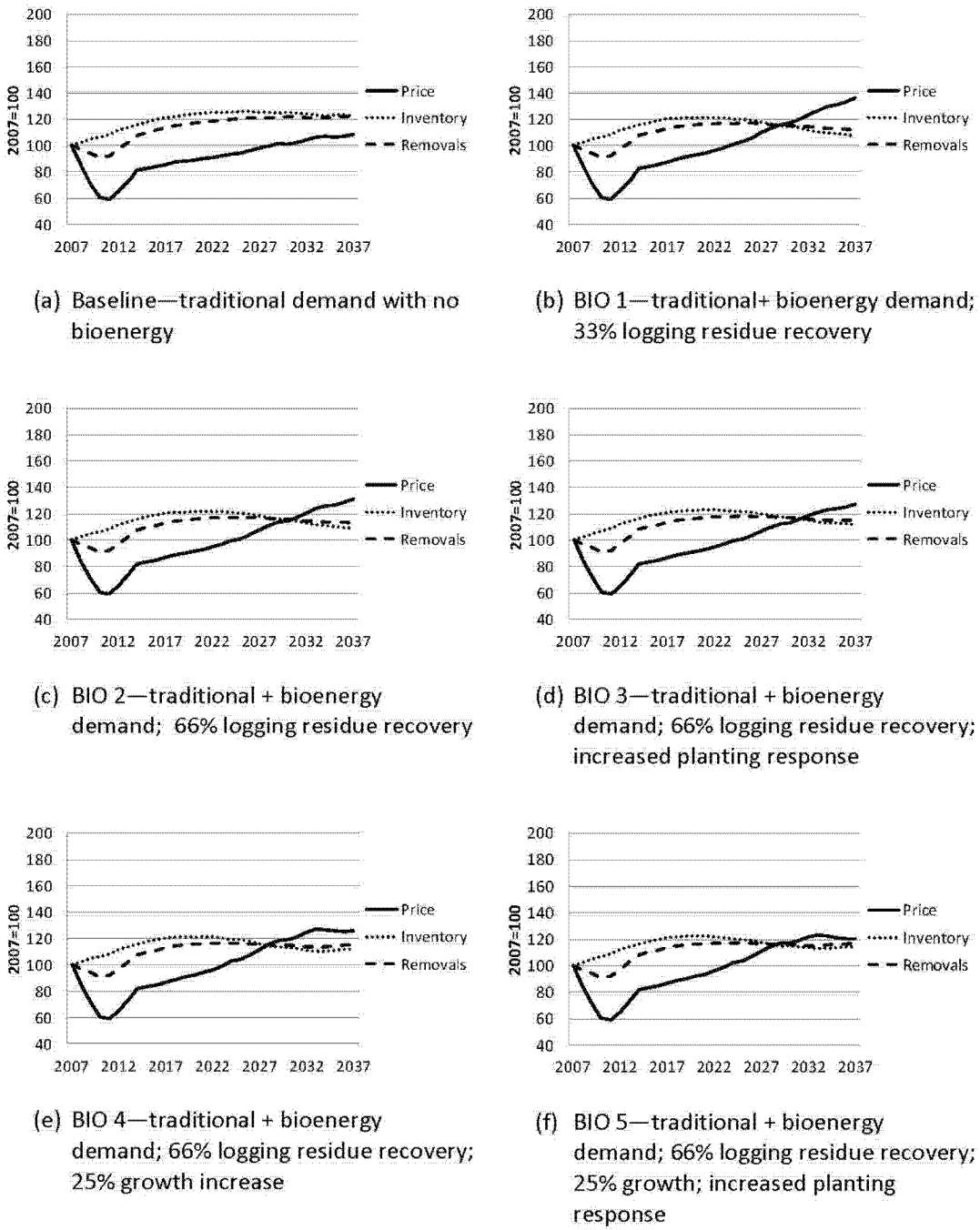


Figure 6. Softwood sawtimber: comparison of prices, inventory, and removals from simulations of the baseline and five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

of the projection (Figure 6b, BIO 1). Correspondingly, the levels of removals and inventory begin to decline somewhat toward the last decade of the projection.

Doubling the residue recovery rate has effects similar to the effects on the pulpwood market, although not as dramatic because as noted above this market is assumed to not be directly affected by the changes in roundwood demand caused by the changes in residue recovery rates (Figure 6c, BIO 2). The year in which price returns to the 2007 level is delayed by more than a year, and the ending price increase is only 31% compared with 36% in BIO 1. Addition of the increased response of planting to pulpwood prices further moderates the increase (Figure 6d, BIO 3) to 27% above 2007 levels. The addition of a 25% growth increase, shown in Figure 6e (BIO 4), instead of the change in planting response, results in very similar outcomes, and combining both growth and planting responses leads to the least increase in prices over the projection, similar to the response of the pulpwood market discussed above (Figure 6f, BIO 5).

Although not displayed in detailed figures, the scenarios included projections for the hardwood pulpwood and hardwood sawtimber markets. Overall, these markets were little affected by most of the scenarios, in part because hardwoods comprise a smaller portion of the overall timber markets in these three states but largely because the supply

ED_000419-0007998

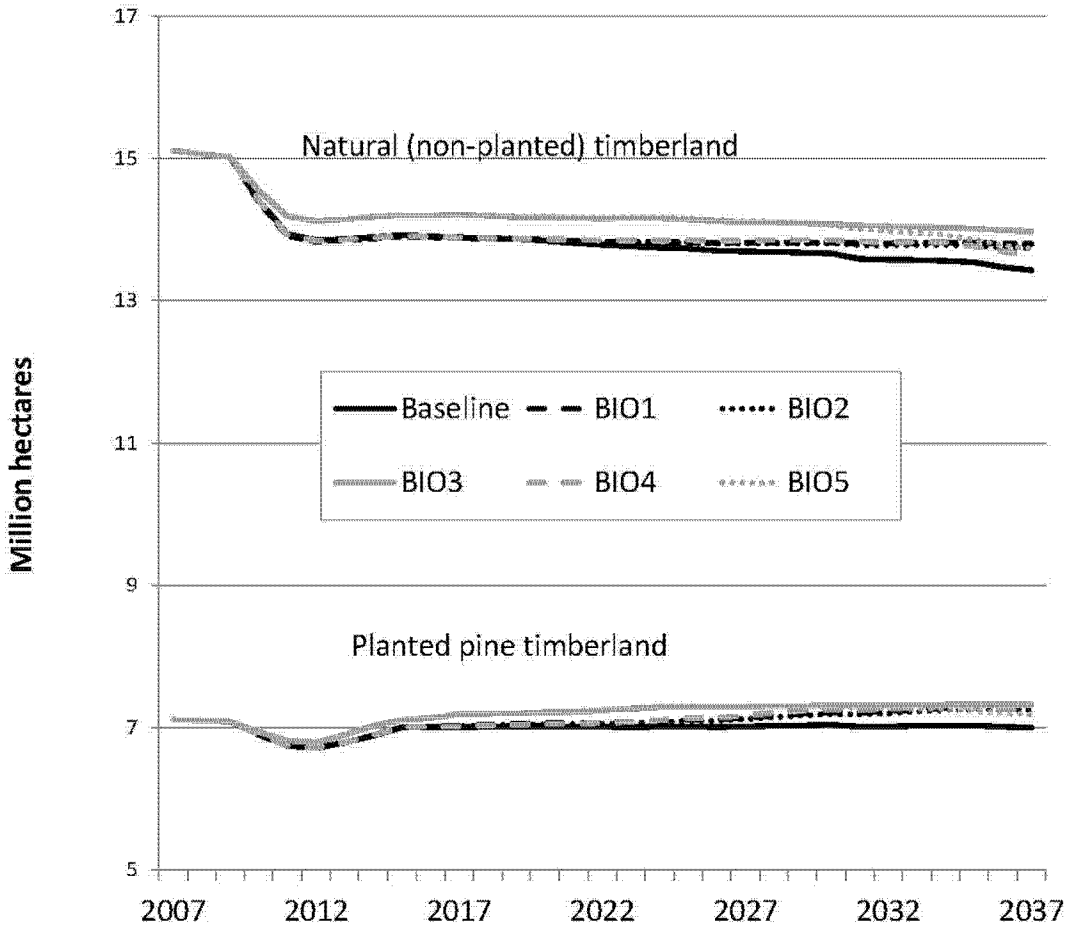


Figure 7. Area of planted and natural timberland from simulations of the baseline and five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

responses of growth increase and planting response do not affect hardwoods. Only the change in LRR had noticeable effects on the hardwood simulations.

The baseline projections for hardwood pulpwood show a continuation of the rises in hardwood inventory and corresponding declines in prices. Removals recover from the recession in 2023. Adding bioenergy demands and the 33% LRR leads to a spike in price as demands increase, but then price smooths out, ending at 30% over 2007 levels, although both inventory and removals are also above 2007 levels because of increased growth in the hardwood inventory. The doubling of LRR to 66% removes the large price increase, with prices recovering only to 90% of the 2007 levels. None of the other supply responses change the hardwood pulpwood projections noticeably. For hardwood sawtimber, the baseline reflects the recession and recovery, with prices slightly below 2007 levels, but inventory and removals slightly higher. The addition of bioenergy demand keeps prices slightly higher, but there are few other changes over the supply response scenarios. Because hardwoods are not expected to have increased growth or to be planted in substantial numbers, these results are expected.

Overall changes in both pine plantation and natural timberland area for the three states over the projection period for the six scenarios are shown in Figure 7. Although the differences are small relative to overall timberland area, Figure 8 provides more detail on the changes in pine plantations. After the recession, the baseline plantation area returns to a stable level approximately 0.1 million ha below the 2007 value of 7.1 million ha. This is partially due to an assumption that plantation gains occur at the extensive margin, but it is primarily due to low pine sawtimber prices for much of the projection period. All of the bioenergy scenarios lead to higher planting, resulting from the increases in pulpwood and/or sawtimber prices as a result of the new bioenergy demands. The variation results from the differing supply responses and their effects on pulpwood and sawtimber prices. Increasing the planting responsiveness to pulpwood prices leads to higher projected land area in plantations (BIO 3 and BIO 5), with the addition of growth tempering the increase in area as a result of the lower softwood product prices. Total timberland acres decreased 8% in the baseline and 5–6% in the bioenergy scenarios. These results have less plantation area increases than prior regional assessments including the SFRA (Prestemon and Abt 2002) and more recently the Southern Forest Futures Project (Huggett et al. 2011). SFRA was conducted when the relevant policy questions were related to how the southern resource would respond to anticipated higher demands for wood products. Those studies suggested an expansion of the plantation base consistent with current plantation acreage. The Southern Forest Futures Project is based

ED_000419-0007999

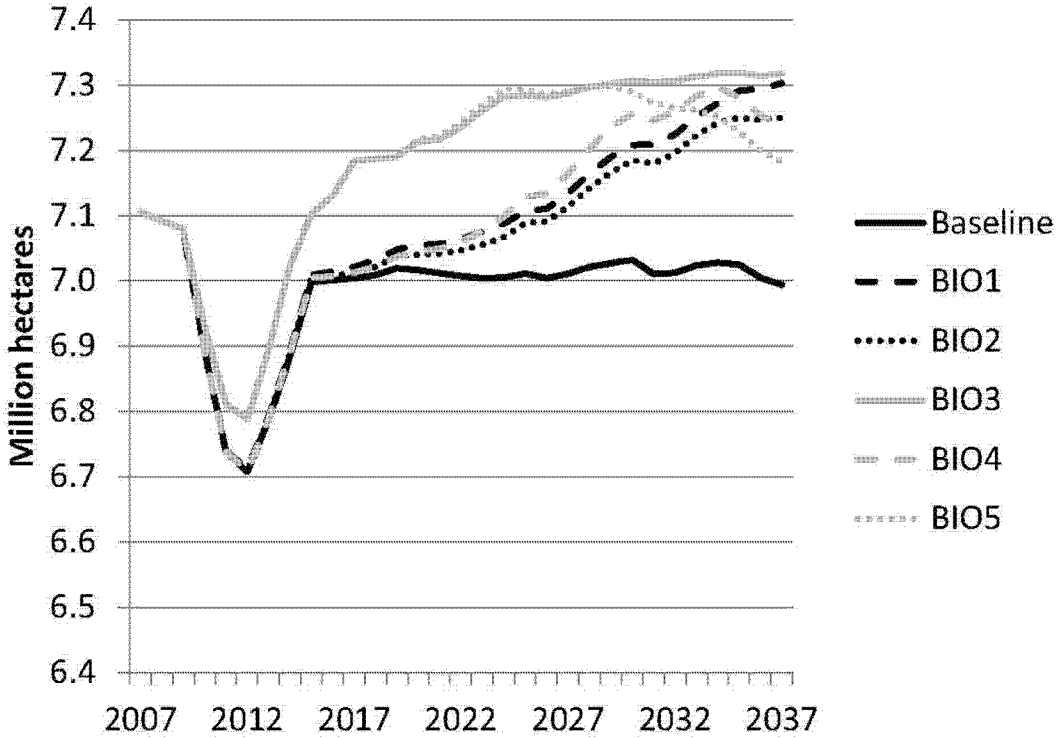


Figure 8. Detailed area of planted pine timberland from simulations of the baseline and five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

on demand scenarios derived from Intergovernmental Panel on Climate Change global change scenarios and uses transition matrices and planting rates consistent with price scenarios embedded in a set of cornerstone solutions. Each of these scenarios project higher acreage of plantations than we do, but the study does not include the current recession, which dominates the short-term outlook in this study.

The harvest outcomes and residue recovery assumptions are reflected in the projected bioenergy feedstocks seen in Figure 9, which shows the portion of bioenergy demand met by softwood and hardwood used residues, new harvest, and displacement. As defined above, displacement is the difference between expected demand with no price change and equilibrium harvest that incorporates supply. Only in BIO 1 (Figure 9a), which has the smallest supply response (33% LRR), does hardwood harvest change and displacement play a role; otherwise hardwood residues fulfill most of the demand for hardwoods. In Figure 9b–e, softwood residues show steep increases in the beginning of the projection as LRR rises to 66% in 2012 (BIO 2–5). Actual levels fluctuate in concert with harvest levels. After depletion of available residues, pulpwood harvest increases, but inelastic supply implies that equilibrium harvest will be significantly smaller than the demand increase. Planting has a small influence on the feedstocks (Figure 9c), but the impact does not occur until a decade after the biomass demand enters the pulpwood market (BIO 3). The planting impact is muted because low sawtimber prices dominate the rent calculation even when pine pulpwood prices are included. There are larger, more immediate, cumulative impacts from assumed growth increases (Figure 9d, BIO 4). Higher supply leads to increased pine harvest and less displacement. Because planting response is linked to price changes, but growth responses are not, increased growth lowers the price impetus for increased planting. The combined effect (Figure 9e, BIO 5) is much smaller than the sum of the separate effects (Figure 9c and d).

The impact of displacement depends on the relative demand price elasticities for wood by the bioenergy and pulpwood sectors. Figure 10 shows the relationship between pine pulpwood and bioenergy demand projections and the resulting harvest change. In Figure 10a, which has the lowest supply response (BIO 1), the price effect on reduced wood consumption is more than 80% of original biomass demand. In other words, if all of the reduction in sector demand was allocated to the bioenergy industry, less than 20% of announced bioenergy capacity would be built. Alternatively, if the entire displacement was fully absorbed by the pine pulpwood industry, there would be a 40% reduction in projected sector demand. Figure 10b shows the direct impact of LRR increases (BIO 2), and although the effect is immediate, it does not change the path of displacement. Figure 10c and d (BIO 3 and BIO 4) shows the reduction in displacement over time associated with planting responses and growth responses, respectively, and Figure 10e shows the combined responses (BIO 5). These figures also illustrate that although increased harvest directly affects pine pulpwood displacement, the additional residues from increased harvest allow bioenergy displacement to decline faster for a given supply response. With the assumption of similar demand-price responses, both industries would experience a 28% reduction from expected demand based on supply price effects at the end of the projection in the low supply response BIO 1 scenario (Figure 10a). In the high

ED_000419-0008000

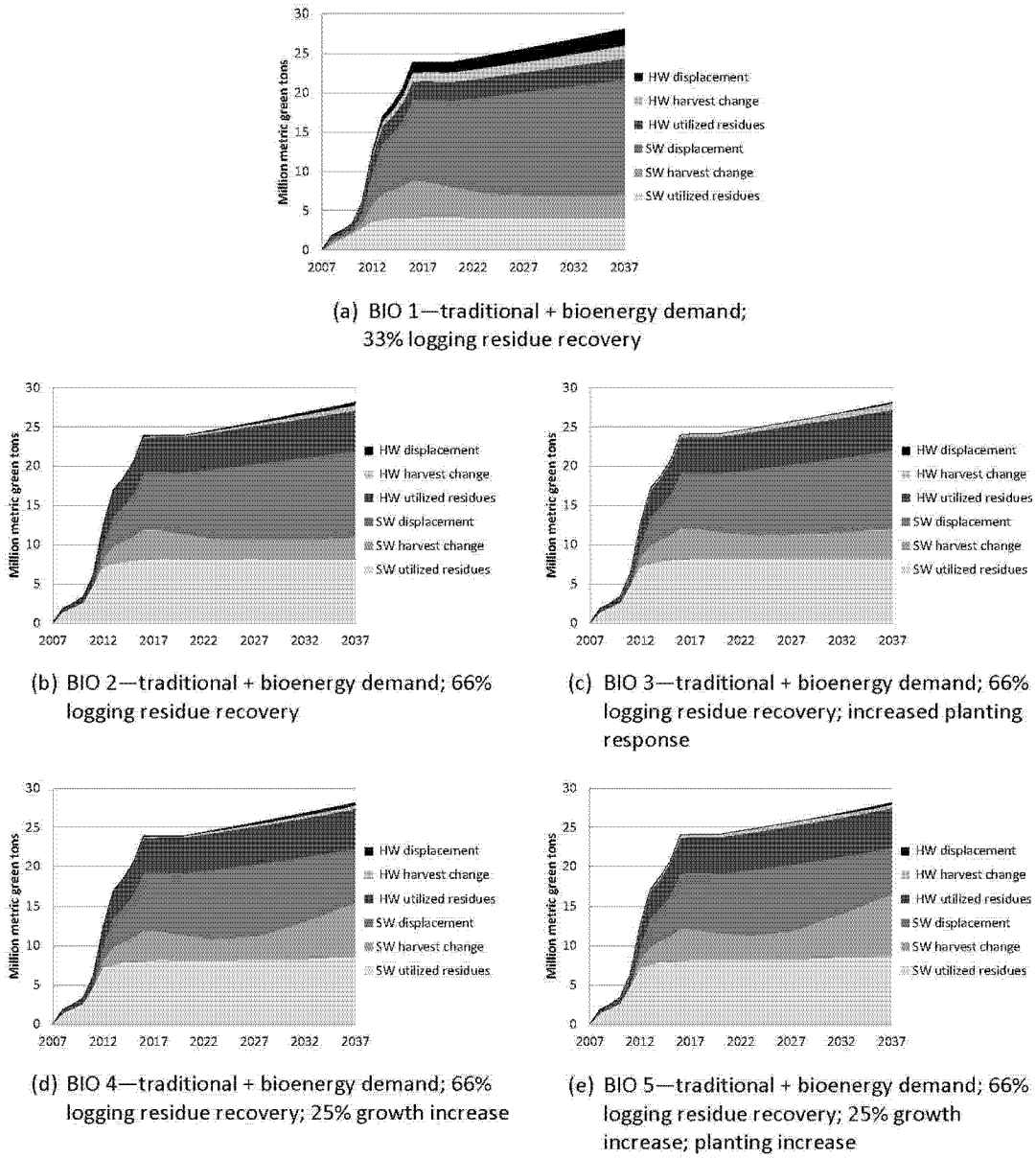


Figure 9. Wood use for bioenergy feedstocks from simulations of five bioenergy supply response scenarios showing displacement, new harvest, and used residues by species group for Alabama, Florida, and Georgia from 2007 to 2037.

supply response BIO 5 scenario (Figure 10e), with similar price responses between the sectors, displacement would peak at 19% in 2022 but decline to 12% by the end of the projection when increased growth and planting rates are incorporated into pulpwood supply.

Forest carbon stock is driven by growth, removals, age class distribution, and land use change. The market impacts were concentrated in pine plantations, but they represent only 26% of the initial carbon stock, although the hardwood types (oak-pine, upland hardwood, and lowland hardwood) represent 57%. Figure 11 shows the aggregate on-site forest carbon inventory across all forest types by scenario by year. The total carbon impacts indicate that scenarios where forest rent included pine pulpwood and had net carbon increases over the baseline scenario. Scenarios that linked forest rents only to pine sawtimber prices showed net reductions because the increased harvest was not offset by additional planting or reduced loss of natural stands to agriculture due to higher bioenergy demand. The difference between BIO 1and BIO 2, which reflects only higher residue utilization, in BIO 2, shows BIO 2 with small but cumulative carbon advantage over time. This effect is slightly overstated as the reduction in the transient carbon stock in residuals is not estimated. The advantage here is due to decreased harvest of roundwood only. Note the scale in Figure 11: the maximum carbon disadvantage over the baseline is approximately 2% in BIO 4 in the second decade and the maximum carbon advantage over the baseline is approximately 1.5% in BIO 3 and BIO 5 in the first decade.

Differences between carbon impacts from plantation growth rate increases (BIO 4 and BIO 5) and land use effects due to forest rents (BIO 3 and BIO 5) are best understood by examining the differential impacts on planted and natural stands shown in Figure 12. As modeled here,

ED_000419-0008001

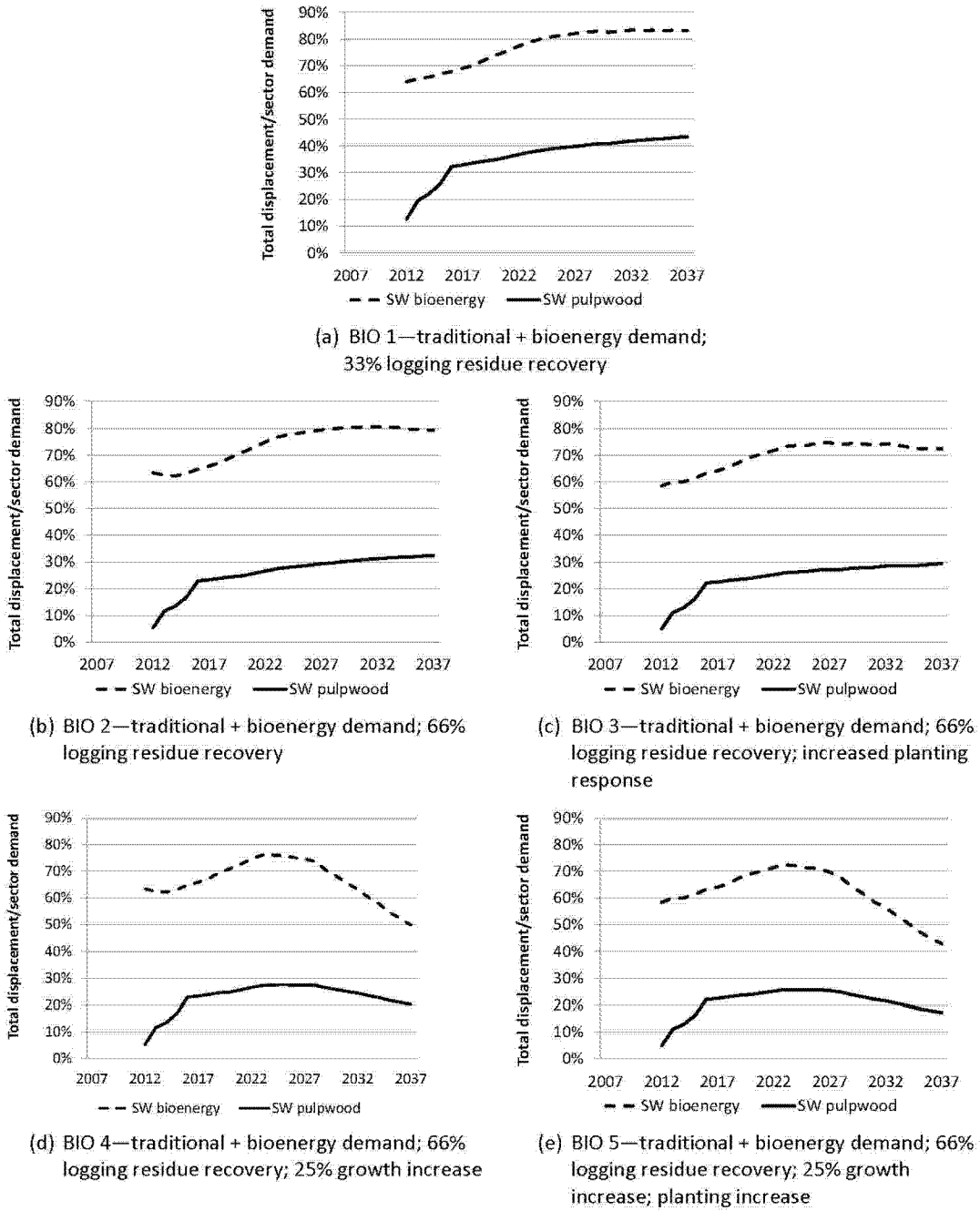


Figure 10. Range of displacement possible for bioenergy sector and traditional sector resulting from assumptions that all displacement will fall on selected sector from simulations of five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

land use change responds to price, but the growth increase is not price-responsive, which might correspond to a continued trend in genetic improvement. Figure 12 shows that the carbon differences among scenarios are driven primarily by differences in natural stand carbon. Over time, market responses tend to offset changes in supply or demand on plantations. During the recession, fewer acres were both harvested and planted. Although decreased prices led to a loss of plantation acres, the decreased harvest allowed total inventory and carbon to increase slightly. Higher demand leads to increased harvest and price, which reduces the inventory and carbon stock but leads to more planting and intensive management. As shown in Figure 12, this allows carbon stocks in the plantations with increasing growth rates to exceed baseline carbon by the end of the projection. Planting responses in these scenarios are depressed by continued low pine sawtimber prices. Pine sawtimber is the only rent driver in BIO 1, BIO 2, and BIO 4 but has a greater influence than pine pulpwood prices in all scenarios.

The natural stands are also affected by price in the model. When forest rents rise, the timberland increase relative to agriculture is attributed to pine plantations. With increased rents, however, there may also be less conversion of natural stands to agriculture. No scenario increased timberland at the agriculture margin enough to offset the effect

ED_000419-0008002

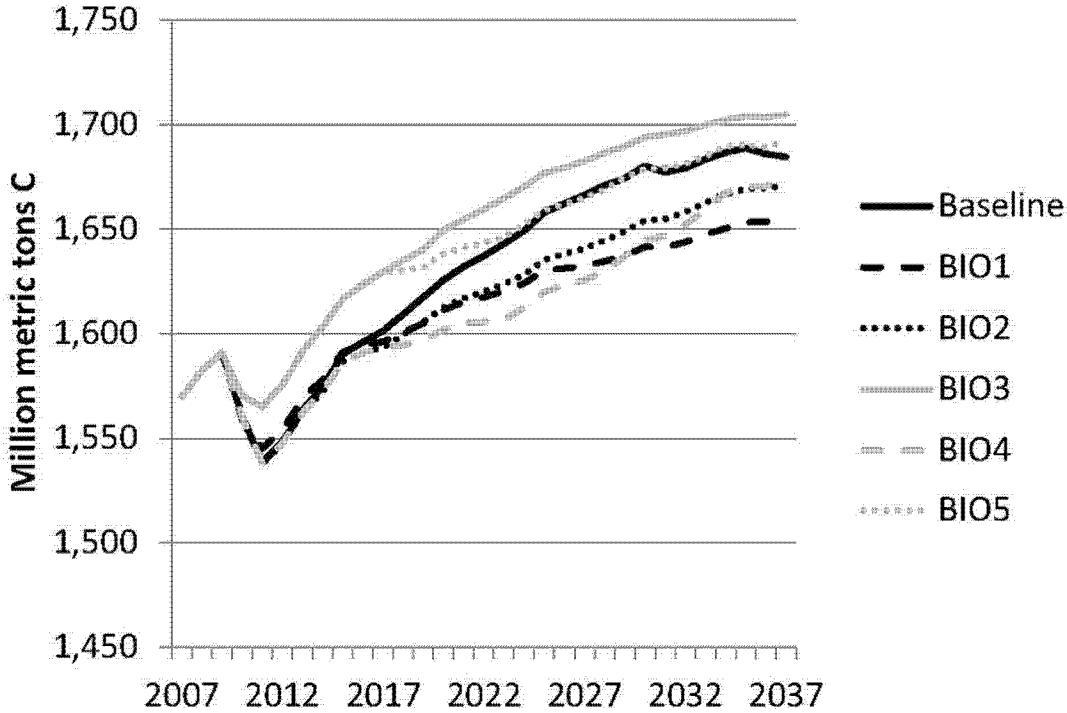


Figure 11. On-site carbon sequestration from simulations of five bioenergy supply response scenarios for Alabama, Florida, and Georgia from 2007 to 2037.

of urbanization, but compared with the baseline run, reduced loss of natural stands has a significant carbon effect. Scenarios BIO 3 and BIO 5, which use forest rents that include biomass price effects on pine pulpwood, lead to less loss in all forestland and an increase in plantations to prerecession levels as described above. This advantage appears before the biomass markets begin because pine pulpwood prices are less affected by the recession in the prebiomass market period. The BIO 5 scenario, which also includes the higher plantation growth rate, however, begins to lose some of this advantage over time as higher pulpwood inventories lower prices and rents, which lower replanting rates. Scenarios BIO 1 and BIO 4 reduce the carbon stock in natural stands relative to the baseline. In BIO 1 with low residue utilization, natural hardwood stands are harvested to meet bioenergy demand. BIO 4 includes plantation growth increases, but forest rent is linked to only pine sawtimber so that natural timberland is decreasing faster than in other scenarios at the end of the projection.

Conclusions

Regardless of the forces that create new bioenergy wood demands, there will be impacts on traditional wood-using industries. The magnitude of these impacts, however, will depend on both the level of demand and the level of supply response. The time path and market consequences of the growth and planting responses are quite different, so that although these are the primary levers by which management can influence supply, the scale, timing, and market impacts of all three responses lead to different land use and carbon outcomes. If demand stays at a level coincident with announcements of facilities and if logging residue recovery rates can average 66% or higher across the region, then market results indicate that the price effect may displace up to 28% of projected demand in the low supply response scenarios or 12% of projected demand in the high supply response scenarios. How this displacement is distributed depends on the wood demand price responsiveness of the emerging industry relative to that of the existing industry.

Higher product prices are linked to land use through the planting response function such that an increase in prices will lead to an increase in new pine plantations. Thus, in scenarios in which prices increase, there is more timberland area than occurs under the baseline scenario without bioenergy demand. This, in turn, leads to a higher level of carbon sequestration in the standing forest than occurs under the baseline. Growth increases, assumed at a regional average of 25% on new pine plantations, lead to an increase in inventory volume that will have a moderating effect on pulpwood prices in the simulations. The regional carbon outcome is lower in the scenario with growth increases than in the scenario with only increased planting response. In all scenarios, including the baseline, the three-state forest carbon sequestration is higher at the end of the projection than in 2007, because carbon in aging existing stands accrues at a faster rate than what is expected to be lost through harvest or conversion to other land uses.

One crucial assumption regarding the market effects of bioenergy demands is the projection of the traditional industries. We modeled as if traditional demand for stumpage would continue to increase at a rate of about 1% per year for sawtimber and 0.5% per year for pulpwood for the second decade and half that for the third decade of the projection. Under an alternative assumption that demands from these industries fall in the absence of bioenergy demands, then prices will fall, potentially leading to declines in timberland

ED_000419-0008003

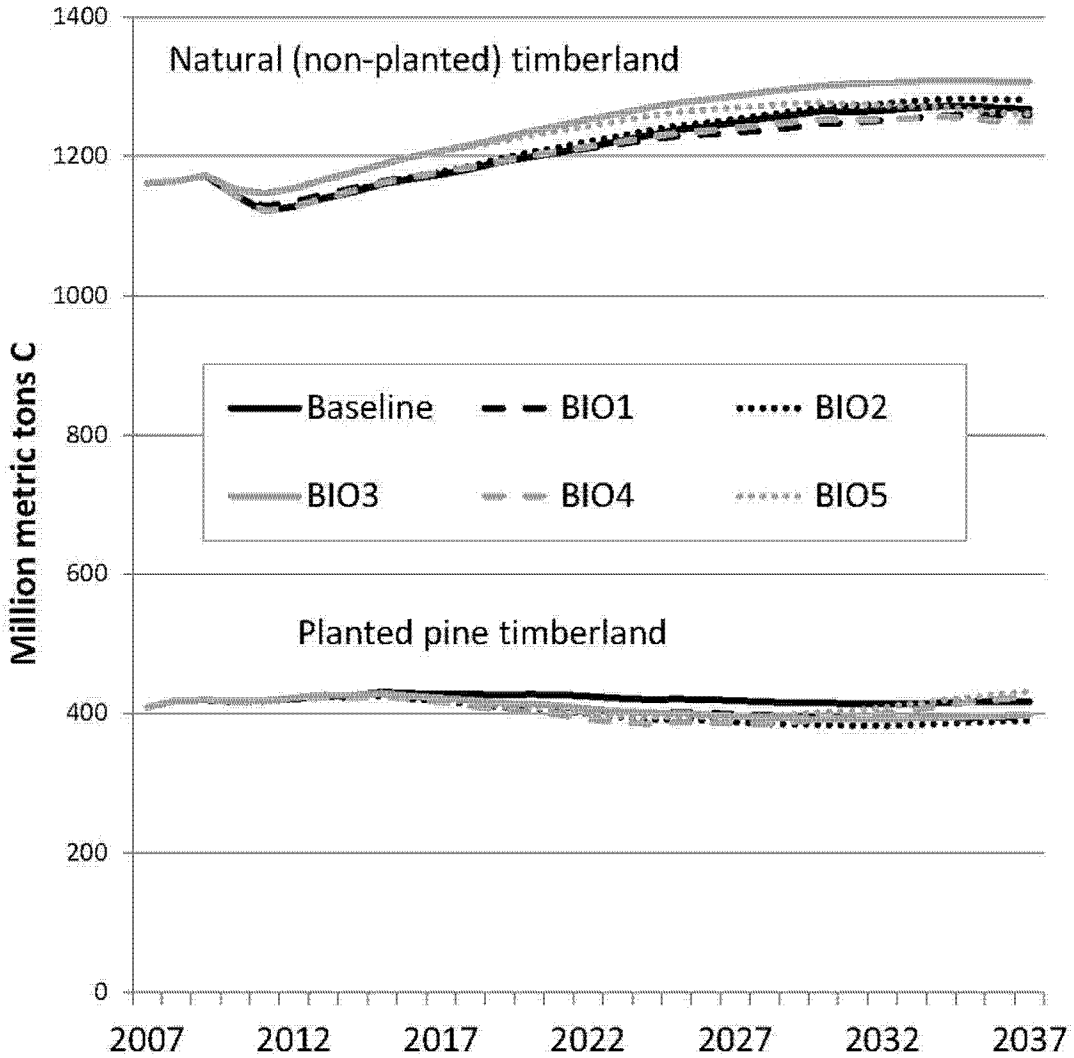


Figure 12. On-site forest carbon sequestration from simulations of five bioenergy supply response scenarios for planted and natural stands for Alabama, Florida, and Georgia from 2007 to 2037.

area and thus in sequestered carbon. Adding in the new bioenergy demands, however, means that declines in traditional harvest will reduce feedstocks available from logging residues, regardless of recovery rates. This, in turn, will lead to higher harvests of pulpwood for bioenergy with resulting price increases for pulpwood and thus smaller declines in timberland area and higher forest carbon sequestration in these three states.

Additional research is needed on the price responsiveness of several of the relationships modeled in the scenarios for which we made assumptions, including residue recovery response to prices, plantation productivity response to prices, and changes in pine plantation conversion from other forest types. Finally, improved carbon accounting would better account for carbon stored in end-use wood products, the carbon dynamics of residue recovery or decay over time, and emissions attributable to shifts in harvest activity outside of the three-state-region. Although we do not expect the inclusion of these components to change the magnitude or direction of our results, it would add additional detail to our estimates and allow for increased scrutiny of those scenarios yielding marginal carbon benefits (e.g., BIO 5).

These results also illustrate the importance of the recovery of pine sawtimber demand in this region. Although a relatively modest plantation growth increase is sufficient to stabilize prices and restore inventories given bioenergy demand examined here, the key forest rent driver of supply response, pine sawtimber price, may be largely unaffected by bioenergy demand in the near term. These factors imply that increased pine pulpwood demand in the absence of pine sawtimber market recovery will increase pressure to use small sawtimber to meet these demands. Further research is needed to investigate how price-sensitive product definitions would affect these results.

Endnote

[1] An increase in the demand for residues for wood energy has the potential to result in an increased harvest of roundwood, dependent on a complementary relationship between residues and roundwood (either sawtimber or pulpwood), such that an increase in the price of residues (from zero to a positive value) would lead to an increased harvest of either sawtimber or pulpwood. Using a theoretical stand-level model of soil expectation value, a new product such as residues could lead to a small decline of the optimal rotation age, depending on the presence of other costs and the production rates of residues from the different

ED_000419-0008004

products (all else held constant). Whether this leads to an increase or decrease in aggregate harvest volumes is dependent on these optimal stand decisions, the number of stands affected, and the ultimate effects on market prices from changes in stand management. We are not aware of any research on the complementarity between roundwood and residues, and little research on the complementarity of the pulpwood and sawtimber. The results from these latter studies (Newman 1987, Newman and Wear 1993, Prestemon and Wear 2000, Polyakov et al. 2010) provide mixed results on complementarity between forest stumpage products.

[2] According to Timber-Mart South, fourth quarter average southwide prices for pine sawtimber were $23.54/ton and for pine pulpwood were $8.20/ton (Timber Mart South 2012).

Literature Cited

ABT, R.C., K.L. ABT, F.W. CUBBAGE, AND J.D. HENDERSON. 2010a. The impact of bioenergy demands on southern forests: A case study of North Carolina. *Biomass Bioenergy* 34:1679–1686.

ABT, R.C., F.W. CUBBAGE, AND K.L. ABT. 2009. Projecting southern timber supply for multiple products by subregion. *For. Prod. J.* 59(7/8):7–16.

ABT, R.C., C.S. GALIK, AND J.D. HENDERSON. 2010b. *The near-term market and greenhouse gas implications of forest biomass utilization in the Southeastern United States.* Climate Change Policy Partnership, Duke University, Durham, NC. 49 p

ALAVALAPATI, J.R.R., P. LAL, A. SUSAETA, R.C. ABT, AND D.N. WEAR. 2011. Forest Biomass-based energy. Chapter 10 in *Southern forest futures project,* Wear, D.N., and J. Greis. (eds.). 155 p. Available online at www.srs.fs.usda.gov/futures/reports/draft/Frame.htm; last accessed on Mar. 5, 2012.

ALLEN, H.L., T.R. FOX, AND R.G. CAMPBELL. 2005. What is ahead for intensive pine plantation silviculture in the south? *South. J. Appl. For.* 29(2):62–69.

BIOMASS ENERGY RESOURCE CENTER. 2012. *Biomass supply and carbon accounting for southeastern forests.* Biomass Energy Resource Center, the Forest Guild, and Spatial Informatics Group, Montpelier, VT. 132 p.

BIOMASS RESEARCH AND DEVELOPMENT BOARD. 2008. *Increasing feedstock production for biofuels: Economic drivers, environmental implications, and the role of research.* Available online at www.usbiomassboard.gov/pdfs/8-increasing-biofuels-feedstock-production.pdf; last accessed on Apr. 23, 2012.

BRACMORT, K.S., AND R.W. GORTE. 2009. *Biomass: Comparison of definitions in legislation.* Congressional Res. Serv. Rep. R40529, Washington, DC. 12 p.

DOMKE, G.M., D.R. BECKER., A.W. D'AMATO, A.R. EK, AND C.W. WOODALL. 2012. Carbon emissions associated with the procurement and utilization of forest harvest residues for energy, northern Minnesota, USA. *Biomass Bioenergy* 36:141–150.

FOLEY, T., D. DEB. RICHTER, AND C.S. GALIK. 2009. Extending rotation age for carbon sequestration: A cross-protocol comparison of North American forest offsets. *For. Ecol. Manage.* 259:201–209.

FOX, T.R. 2000. Sustained productivity of intensively managed forest plantations. *For. Ecol Manage.* 138(1–3):187–202.

FOX, T.R., E.J. JOKELA, AND H.L. ALLEN. 2007. The development of pine plantation silviculture in the southern United States. *J. For.* 105:337–347.

GALIK, C.S., R.C. ABT, AND Y. WU. 2009. Forest biomass supply in the southeastern united states—Implications for industrial roundwood and bioenergy production. *J. For.* 107(2009):69–77.

GAN, J., AND C.T. SMITH. 2006. Availability of logging residues and potential for electricity production and carbon displacement in the USA. *Biomass Bioenergy* 30:1011–1020.

HARDIE, I.W., P.J. PARKS., P. GOTTLIEB, AND D.N. WEAR. 2000. Responsiveness of rural and urban land uses to land rent determinants in the U.S. South. *Land Econ.* 78(4):659–673.

HUGGETT, R.J. JR., D.N. WEAR, R. LI, J. COULSTON, AND S. LIU. 2011. Forecasts of forest conditions. Chapter 5 in *Southern forest futures project*, Wear, D.N., and J. Greis. (eds.). 71 p. Available online at www.srs.fs.usda.gov/futures/reports/draft/Frame.htm; last accessed on Mar. 5, 2012.

INCE, P.J., A.D. KRAMP, K.E. SKOG, D. YOO, AND V.A. SAMPLE. 2011. Modeling future U.S. forest sector market and trade impacts of expansion in wood energy consumption. *J. For. Econ.* 17(2):142–156.

JOHNSON, T.G., J.W. BENTLEY, AND M. HOWELL. 2009. *The South's timber industry—An assessment of timber product output and use, 2007.* US For. Serv. Resour. Bull. SRS–164. Southern Research Station, Asheville, NC. 52 p.

MANN, M.K., AND P.L. SPATH. 2001. A life cycle assessment of biomass cofiring in a coal-fired power plant. *Clean Products Processes* 3(2):81–91.

MANOMET CENTER FOR CONSERVATION SCIENCES. 2010. *Biomass sustainability and carbon policy study.* Available online at www.manoxmet.org/sites/manomet.org/files/Manomet_Biomass_Report_Full_LoRez.pdf; last accessed Apr. 5, 2011.

MUNSELL, J.F., AND T.R. FOX. 2010. An analysis of the feasibility for increasing woody biomass production from pine plantations in the southern United States. *Biomass Bioenergy* 34(12): 1631–1642.

NEWMAN, D.H. 1987. An econometric analysis of the southern softwood stumpage market 1950–1980. *For. Sci.* 33:932–945.

NEWMAN, D.H., AND D.N. WEAR. 1993. Production economics of private forestry: A comparison of industrial and nonindustrial forest owners. *Am. J. Agric. Econ.* 75:674–684.

PATTANAYAK, S., B. MURRAY, AND R. ABT. 2002. How joint is joint forest production? An econometric analysis of timber supply conditional on endogenous amenity values. *For. Sci.* 48(3x):479–491.

PEREZ-VERDIN, G., D.L. GREBNER, C. SUN, I.A. MUNN, E.B. SCHULTZ, AND T.G. MATNEY. 2009. Woody biomass availability for bioethanol conversion in Mississippi. *Biomass Bioenergy* 33:492–503.

PERLACK, R.D., L.L. WRIGHT, A.F. TURHOLLOW, R.L. GRAHAM, B. STOKES, AND D.C. ERBACH. 2005. *Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply.* Oak Ridge National Laboratory, Oak Ridge, TN. 78 p.

POLYAKOV, M., D.N. WEAR, AND R.N. HUGGETT JR. 2010. Harvest choice and timber supply models for forest forecasting. *For. Sci.* 56(4):344–355.

PRESTEMON, J.P., AND R.C. ABT. 2002. The Southern Timber Market to 2040. *J. For.* 100(7):16–22.

PRESTEMON, J.P., AND D.N. WEAR. 2000. Linking harvest choices to timber supply. *For. Sci.* 46(3):377–389.

REPO, A., M. TUOMI, AND J. LISKI. 2011. Indirect carbon dioxide emissions from producing bioenergy from forest harvest residues. *GCB Bioenergy* 3:107–115.

ROSSI, F.J., D.R. CARTER, AND R.C. ABT. 2010. *Final report: Woody biomass for electricity generation in Florida: Bioeconomic impacts under a proposed renewable portfolio standard (RPS) mandate, prepared for Florida Department of Agriculture and Consumer Services Division of Forestry.* Available online at www.floridaforestservice.com/forest_management/fm_pdfs/Final%20Report%20on%20Woody%20Biomass%20Demand%20and%20Supply.pdf; last accessed on Mar. 12, 2011.

SMITH, J.E., AND L.S. HEATH. 2002. *A model of forest floor carbon*

ED_000419-0008005

mass for United States forest types. US For. Serv. Res. Paper RP-NE-722. Northeastern Research Station, Newtown Square, PA.

SMITH, J.E., L.S. HEATH, K.E. SKOG, AND R.A. BIRDSEY. 2006. *Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the united states*. US. Gen. Tech. Rep. GTR-NE-343. Northeastern Research Station, Newton Square, PA.

TIMBER MART SOUTH. 2012. *South-wide average prices*. Available online at www.timbermart-south.com/prices.html; last accessed Mar. 5, 2012.

US DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS. 2011. *Industry statistics sampler: NAICS 321: Wood product manufacturing*. Available online at www.census.gov/econ/industry/current/c321.htm. *Industry statistics sampler: NAICS 322: Paper manufacturing*. Available online at http://www.census.gov/econ/industry/current/c322.htm; last accessed Mar. 11, 2009.

US DEPARTMENT OF ENERGY. 2011. *U.S. billion-ton update: Biomass supply for a bioenergy and bioproducts industry*, Perlack, R.D., and B.J. Stokes (leads). ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227 p.

US ENERGY INFORMATION ADMINISTRATION. 2007. *Energy and economic impacts of implementing both a 25-percent RPS and a 25-percent RFS by 2025*. Rep. No. SR/OIAF/2007-05. US Department of Energy. Washington, DC. 86 p.

USDA FOREST SERVICE. 2009. *Forest Inventory and Analysis National Program: TPO database*. Available online at www.fia.fs.fed.us/program-features/tpo/; last accessed Mar. 19, 2009.

USDA FOREST SERVICE. 2011. *Forest Inventory and Analysis National Program: FIA database*. Available online at fia.fs.fed.us/tools-data/default.asp; last accessed Jan. 8, 2011.

WOODS, R.A. 2009. Industrial output and employment projections to 2018. *Monthly Labor Rev*. 132(11):52–81.

WU, J., J. WANG, AND J. MCNEEL. 2011. Economic modeling of woody biomass utilization for bioenergy and its application in central Appalachia, USA. *Can. J. For. Res*. 41:165–179.

ED_000419-0008006

ncasi

NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT

GREENHOUSE GAS AND FOSSIL FUEL REDUCTION BENEFITS OF USING BIOMASS MANUFACTURING RESIDUALS FOR ENERGY PRODUCTION IN FOREST PRODUCTS FACILITIES

TECHNICAL BULLETIN NO. 1016

OCTOBER 2013

REVISED AUGUST 2014

by
Caroline Gaudreault
NCASI
Montreal, Quebec

Reid Miner
NCASI Corporate Headquarters
Research Triangle Park, North Carolina

Acknowledgments

The authors want to acknowledge Kirsten Vice (NCASI Vice President - Canadian Operations), Al Lucier (NCASI Senior Vice President), John Pinkerton (NCASI Fellow), Arun Someshwar (NCASI Fellow), Brad Upton (NCASI Principal Research Engineer), Chantal Lavigne (NCASI Senior Research Scientist), Barry Malmberg (NCASI Project Leader), Ilich Lama (NCASI Senior Research Scientist) and Laurel Eppstein (NCASI Associate Scientist) for reviewing this study and/or providing valuable feedback.

For more information about this research, contact:

Caroline Gaudreault, Ph.D.
NCASI
Senior Research Scientist
P.O. Box 1036, Station B
Montreal, QC H3B 3K5
(514) 286-1182
cgaudreault@ncasi.org

Reid Miner
NCASI
Vice President, Sustainable Manufacturing
P.O. Box 13318
Research Triangle Park, NC 27709
(919) 941-6401
rminer@ncasi.org

To request printed copies of this report, contact NCASI at publications@ncasi.org **or (352) 244-0900.**

This report was last revised on August 21, 2014. Text and data were modified in several places. See Appendix B for details.

Cite this report as:

National Council for Air and Stream Improvement, Inc. (NCASI). 2013. *Greenhouse gas and fossil fuel reduction benefits of using biomass manufacturing residuals for energy production in forest products facilities.* Technical Bulletin No. 1016 (Revised). Research Triangle Park, N.C.: National Council for Air and Stream Improvement, Inc.

© 2013 by the National Council for Air and Stream Improvement, Inc.

ncasi

serving the environmental research needs of the forest products industry since 1943

PRESIDENT'S NOTE

NCASI continues its work to address the United States Environmental Protection Agency's expressed interest in the life cycle greenhouse gas (GHG) benefits associated with using biomass. The regulatory decisions EPA makes on this topic have the potential to greatly affect the costs of doing business and the perception of the forest industry's products in the marketplace. The forest products industry, therefore, has a great deal at stake in ensuring that the agency's deliberations on this topic are well informed.

In an earlier report, NCASI examined the life cycle greenhouse gas and non-renewable energy benefits of using black liquor in the kraft recovery system. In the study described herein, NCASI extends this work to other types of biomass-based manufacturing residuals used for energy generation within the industry (woody mill residuals, waste water treatment plant residuals, and paper recycling residuals). While there are numerous studies examining the life cycle impacts of biomass energy, none has applied the comprehensive approach used here by NCASI to characterize the impacts of the industry's use of energy produced from biomass residuals.

In this study, NCASI has compared systems involving the use of biomass-based manufacturing residuals for energy to comparable systems relying on fossil fuels. The results indicate that the use of residuals examined in this study produces significant reductions in atmospheric GHGs. Combining the results of this study with the results of the previous NCASI study on black liquor reveals that each year's use of manufacturing residuals, including black liquor, in the US forest products industry avoids the emission of approximately 181 million metric tons of CO_2E, an amount approximately three times that of the annual direct emissions of CO_2 from fossil fuel combustion in the industry.

This study is one of a series of ongoing NCASI projects having the objective of helping the forest products industry and its stakeholders better understand the greenhouse gas and energy impacts of using forest biomass as a raw material and fuel.

Ronald A. Yeske

October 2013

NOTE DU PRÉSIDENT

NCASI poursuit son travail dans le contexte de l'intérêt exprimé par la United States Environmental Protection Agency (EPA) pour les bénéfices en terme de gaz à effet de serre (GES) de l'utilisation de la biomasse, et ce en adoptant une perspective cycle de vie. Les décisions réglementaires de l'EPA à ce sujet ont le potentiel d'affecter considérablement le coût de faire des affaires et la perception des produits forestiers dans le marché. L'industrie des produits forestiers a, par conséquent, beaucoup en jeu pour assurer que les délibérations de l'EPA sur ce sujet soient bien informées.

Dans un rapport antérieur, NCASI a examiné les bénéfices du cycle de vie pour les GES et la consommation d'énergie non-renouvelable lié à la récupération de la liqueur noire. Dans l'étude décrite ici, NCASI étend ce travail à d'autres types de résidus de fabrication de produits forestiers utilisés pour la production d'énergie dans cette même industrie (résidus d'usine ligneux, résidus de traitement des eaux usées et résidus de recyclage du papier). Bien qu'il existe de nombreuses études sur les impacts du cycle de vie associés à la production d'énergie à partir de biomasse, aucune n'a appliqué l'approche globale utilisée ici par NCASI pour caractériser les impacts de la production d'énergie produite à partir de résidus de biomasse de l'industrie.

Dans cette étude, NCASI a comparé des systèmes impliquant l'utilisation des résidus de fabrication à base de biomasse pour l'énergie à des systèmes comparables utilisant plutôt des combustibles fossiles. Les résultats indiquent que l'utilisation des résidus examinés dans cette étude génère des réductions significatives des GES. La combinaison des résultats de cette étude avec les résultats de l'étude précédente de NCASI sur la liqueur noire révèle que l'utilisation annuelle de résidus de fabrication, y compris la liqueur noire, dans l'industrie des produits forestiers des États-Unis permet d'éviter l'émission d'environ 181 millions de tonnes d'équivalents CO_2, une quantité environ trois fois supérieure à celle des émissions annuelles directes de CO_2 provenant de la combustion de combustibles fossiles par cette industrie.

Cette étude fait partie d'une série de projets en cours de NCASI ayant pour objectif d'aider l'industrie des produits forestiers et ses parties prenantes à mieux comprendre les impacts pour les GES et la consommation énergétique de l'utilisation de la biomasse forestière comme matière première et combustible.

Ronald A. Yeske

Octobre 2013

GREENHOUSE GAS AND FOSSIL FUEL REDUCTION BENEFITS OF USING BIOMASS MANUFACTURING RESIDUALS FOR ENERGY PRODUCTION IN FOREST PRODUCTS FACILITIES

TECHNICAL BULLETIN NO. 1016
OCTOBER 2013
REVISED AUGUST 2014

ABSTRACT

This study examined the life cycle greenhouse gas (GHG) and fossil fuel-related implications of using various manufacturing biomass residuals for energy production at pulp and paper mills and wood products manufacturing facilities. Woody mill residuals (e.g., bark, sawdust, etc.), wastewater treatment plant (WWTP) residuals, and paper recycling residuals were studied. Results from an earlier study of black liquor were also included and extended. Two product systems were compared: a product system in which the biomass residuals are burned for energy in a forest products industry facility (biomass energy system), and a product system in which the biomass residuals are disposed of and fossil fuels are used instead (non-use system). The systems were compared on the basis of a functional unit of 1 GJ energy output in same form for each system. For each residual type, various scenarios were evaluated, including one (the typical scenario) that best represents the industry average. A variety of residual characteristics were subjected to sensitivity analyses. The impacts of the systems were characterized dynamically, using cumulative radiative forcing attributable to the GHG emissions from each system over time. Impacts were calculated in terms of the differences between the biomass and non-use systems over 100 years, expressed as CO_2E, as well as the time required for the net difference in cumulative radiative forcing to reach zero (i.e., the break-even time). Reductions in consumption of fossil fuels were also computed.

In the case of woody mill and WWTP residuals, the systems using residuals for energy produced GHG emissions, not including biogenic CO_2, that were more than 98% lower than those from the systems disposing of the residuals. Paper recycling residuals and black liquor resulted in significant, but lower, benefits (86.4% and 90.5% reductions in GHG emissions, respectively, in the typical scenario). Even when biogenic CO_2 was included in the analysis, over 100 years, the GHG impacts for typical scenarios involving a) woody mill residuals, b) WWTP residuals, c) paper recycling residuals, and d) black liquor solids were lower than the comparable non-use systems by 116 kg CO_2E/GJ, 295 kg CO_2E/GJ, 112 kg CO_2E/GJ, and 184 CO_2E/GJ, respectively. Relative to the comparable fossil fuel-based systems, fossil fuel consumption was found to be lower by more than 99% for all residuals examined in this study, except black liquor, for which the reduction was 89.8%. Break-even times ranged from 0 to 1.2 years under typical scenarios.

A gate-to-gate analysis addressing only biogenic GHGs, not considering fossil fuel substitution benefits, was also performed. In this case, the net GHG impacts over 100 years for typical scenarios involving a) woody mill residuals, b) wastewater treatment plant residuals, c) paper recycling residuals, and d) black liquor were lower than the comparable non-use systems by 8.5 kg CO_2E/GJ, 190 kg CO_2E/GJ, 132 kg CO_2E/GJ, and 0 kg CO_2E/GJ, respectively. The break-even times ranged from 0 years for black liquor, which comprises 57% of the biomass used by the industry for energy, to 19.5 years for woody mill residuals, which comprise 37%. For several residuals, the results were shown to be very sensitive to the parameter value describing the extent to which residuals decompose in mill landfills, a parameter with significant uncertainty.

KEYWORDS

biomass residuals, energy, greenhouse gases, life cycle assessment

RELATED NCASI PUBLICATIONS

Technical Bulletin No. 984 (April 2011). *Greenhouse gas and non-renewable energy benefits of black liquor recovery*.

RÉDUCTION DES ÉMISSIONS DE GAZ À EFFET DE SERRE ET DE LA CONSOMMATION D'ÉNERGIE FOSSILE DUE À L'UTILISATION DE RÉSIDUS MANUFACTURIERS DE BIOMASSE POUR LA PRODUCTION D'ÉNERGIE PAR LES USINES DE PRODUITS FORESTIERS

BULLETIN TECHNIQUE N^{O} 1016
OCTOBRE 2013
RÉVISÉ EN AOÛT 2014

RÉSUMÉ

Cette étude a examiné les implications pour les gaz à effet de serre (GES) et l'utilisation de combustibles fossiles de l'utilisation de divers résidus de biomasse provenant de la fabrication de produits forestiers pour la production d'énergie à ces usines de fabrication. Les résidus d'usine ligneux (par exemple, l'écorce, la sciure de bois, etc.), les résidus de traitement des eaux usées et les résidus de recyclage du papier ont été étudiés. Les résultats d'une étude antérieure portant sur la liqueur noire ont également été inclus et étendus. Deux systèmes de produit ont été comparés: un système de produit dans lequel les résidus de biomasse sont brûlés à une usine de fabrication de produits forestiers pour produire de l'énergie (système "énergie de biomasse") et un système de produit dans lequel les résidus de biomasse sont éliminés et des combustibles fossiles sont utilisés à la place (système "non utilisation"). Les systèmes ont été comparés sur la base d'une unité fonctionnelle de production de 1 GJ d'énergie utilisable et ce, sous la même forme pour chacun des systèmes comparés. Pour chaque type de résidus, divers scénarios ont été évalués dont un, le scénario typique, qui représente le mieux la moyenne de l'industrie. Une variété de caractéristiques des résidus a été soumise à des analyses de sensibilité. Les impacts des systèmes ont été caractérisés de façon dynamique, en utilisant le forçage radiatif cumulatif attribuable aux émissions de GES de chaque système dans le temps. Les impacts ont été calculés sous forme de différences observées sur 100 ans entre les systèmes "énergie de biomasse" et "non utilisation", exprimés en CO_2E. Le temps nécessaire pour observer les bénéfices pour les GES liés à l'utilisation de la biomasse et la réduction de la consommation de combustibles fossiles ont également été calculés.

Dans le cas des résidus d'usine ligneux et des résidus de traitement des eaux usées, les systèmes utilisant les résidus pour la production d'énergie produisent des émissions de GES plus de 98% inférieures à celles des systèmes disposant des résidus lorsque le CO_2 biogénique est exclus. Les résidus de recyclage du papier et la liqueur noire présentent aussi des réductions significatives, mais moins élevées (86.4% et 90.5% de réduction des émissions de GES, respectivement, dans le scénario typique). Lorsque le CO_2 biogénique est inclus dans l'analyse, les réductions de GES observées sur 100 ans, dans le cas du scénario typique sont de 116 kg de CO_2E/GJ, 295 kg CO_2E/GJ, 112 kg CO_2E/GJ et 184 CO_2E/GJ pour les résidus d'usine ligneux, les résidus du traitement des eaux usées, les résidus de recyclage du papier et la liqueur noire, respectivement. La consommation de combustibles fossiles est plus de 99% inférieure dans les systèmes "énergie de biomasse" que dans les systèmes "non utilisation" à l'exception du cas de la liqueur noire pour lequel la réduction observée est de 89,8%. Dans les scénarios typiques, le temps nécessaire pour observer les bénéfices liés aux GES varie entre 0 et 1.2 années.

Une analyse plus restreinte, ne portant que sur les émissions de GES biogénique et ne considérant pas la substitution des combustibles fossiles, a également été réalisée. Dans ce cas, les réductions de GES (systèmes "énergie de biomasse" versus systèmes "non utilisation") observées sur 100 ans dans les scénarios typiques sont de 8.5 kg CO_2E/GJ, 190 kg CO_2E/GJ, 132 kg CO_2E/ GJ et 0 kg CO_2E/GJ pour les résidus d'usine ligneux, les résidus du traitement des eaux usées, les résidus de recyclage du papier

et la liqueur noire, respectivement. Le temps nécessaire pour observer ces réductions varie de 0 an pour la liqueur noire qui représente 57% de l'énergie produite à partir de biomasse par l'industrie forestière à 19.5 ans pour les résidus d'usines ligneux qui en représente 37%. Pour plusieurs résidus, les résultats se sont avérés être très sensibles à la valeur du paramètre décrivant la mesure dans laquelle les résidus se décomposent dans les sites d'enfouissement, un paramètre avec une incertitude importante.

MOTS-CLÉS

résidus de biomasse, énergie, gaz à effet de serre, analyse du cycle de vie

PUBLICATIONS DE NCASI RELIÉES

Bulletin Technique No. 984 (Avril 2011). *Avantages pours les émissions de gaz à effet de serre et la consommation d'énergie non renouvelable de la récupération de liqueur noire.*

GREENHOUSE GAS AND FOSSIL FUEL REDUCTION BENEFITS OF USING BIOMASS MANUFACTURING RESIDUALS FOR ENERGY PRODUCTION IN FOREST PRODUCTS FACILITIES

TECHNICAL BULLETIN NO. 1016
OCTOBER 2013
REVISED AUGUST 2014

EXECUTIVE SUMMARY

Wood handling and processing activities in log yards, sawmills, pulp and paper mills, and other forest products activities produce a significant amount of residuals, most of which consist of black liquor, bark, sawdust, shavings, and other woody debris. These currently available residuals have long been used as a source of renewable energy in the forest products industry. In this study, the greenhouse gas (GHG) impacts attributable to the industry's use of these materials for energy, compared to not using them, were assessed.

ES.1 Significance of Findings

Combining the results of this study with the results of the previous NCASI study on black liquor reveals that, when considering biogenic and non-biogenic life cycle GHG emissions, each year's use of manufacturing residuals in the US forest products industry avoids the eventual release of approximately 181 million tonnes of CO_2E. The break-even times (i.e., the times required for the GHG impacts of using biomass to be the same or less than the impacts of using an alternative source of energy) range from 0 to1.2 years under typical scenarios, depending on the residual.

An analysis addressing only biogenic GHGs, not considering fossil fuel substitution benefits, was also performed. Even ignoring fossil fuel avoidance benefits, the annual use of manufacturing residuals, including black liquor, avoids the eventual release of 5 million tonnes CO_2E with the break-even times ranging from 0 years for black liquor, which comprises 57% of the biomass used by the industry for energy, to 19.5 years for woody mill residuals, which comprise 37%.

These results have been developed by comparing the GHG emissions from systems using manufacturing residuals for energy in the forest products industry to the emissions from alternative systems producing the same amount of energy from fossil fuels while disposing of the residuals by landfilling or a combination of landfilling and incineration. In cases where it is assumed that the alternative to burning manufacturing residuals for energy is incineration, the break-even times for all residuals are zero, whether or not fossil fuel substitution is considered. Where landfilling is assumed to be the alternative, the results can be very sensitive to assumptions about the degree to which biomass carbon decomposes in landfills, a parameter with large uncertainty.

Because manufacturing residuals have been used for energy in the forest products industry for many years, estimates were also made of the time required to show net benefits from ongoing use of residuals for energy. The results provided strong evidence that the ongoing use of manufacturing residuals for energy in the forest products industry has been yielding net benefits for many years.

ES.2 Objective

The overall objective of this study was to evaluate the life cycle (cradle-to-final energy analysis) greenhouse gas and fossil fuel reduction benefits of using forest products manufacturing-related biomass residuals for energy in forest products manufacturing facilities in contrast to disposal of these

ED_000419-0008017

residuals coupled with production of the same quantity and form of energy using fossil fuels. This study also incorporates and expands upon the results of a previous NCASI study that analyzed the greenhouse gas reduction benefits of using spent pulping liquor, known as black liquor, for energy in the forest products industry

This study also included two secondary objectives: 1) to analyze the emissions of biogenic GHGs directly released from the units in which the residuals are managed (i.e., combustion units or landfills, also called a gate-to-gate analysis)[1] and 2) to analyze the cumulative emissions attributable to the use of the residuals for energy as an ongoing, long-standing practice (both in terms of cradle-to-final energy and gate-to-gate boundaries).

The biomass residuals specifically studied in this project were

- woody mill residuals (e.g., bark, sawdust and other similar manufacturing residuals from sawmills, panel plants, and pulp and paper mills);
- wastewater treatment plant (WWTP) residuals;
- paper recycling residuals (e.g., old corrugated container (OCC) rejects)[2]; and
- black liquor (based on the results of an earlier NCASI study).

ES.3 Methods

ES.3.1 Methods for the Cradle-to-Final Energy Analysis

For each type of residual, the study compared two different product systems:

1) one in which the biomass residuals are burned for energy (**biomass energy system**); and
2) one in which the biomass residuals are disposed of and fossil fuels are used instead to generate an identical amount and form of energy (**non-use system**).

More specifically, the methodology used in this study followed life cycle principles by calculating emissions from "cradle to final energy," including fuel conversion efficiency. The primary functional unit employed in this study was ***the production of 1 GJ of energy***. It is important to note that whether manufacturing residuals are used for energy or disposed of, the same number of trees would be harvested and the same quantity of resources would be required to produce the related forest products.

The overall analysis approach employed in this study is as follows. First, for each system component of the study (size reduction, biomass energy production, alternative fate of the residuals, and fossil fuel displaced), several scenarios were defined. These scenarios were intended to represent a broad range of conditions in the US forest products industry. Then, a typical scenario was defined for each residual type representing the best estimate of average conditions in the US in terms of the system components mentioned above. The typical scenario was analyzed to determine 1) typical benefits obtained by using a given residual type, 2) the contribution of each different system component to the overall results, 3) the sensitivity of various parameters (i.e., biomass properties such as higher heating value, water content, etc.) to the results, and 4) the timing of emissions. Where possible, each parameter was analyzed using a base case, low, and high value. Finally, a number of system configuration scenarios were also analyzed.

---

[1] In this gate-to-gate analysis, the benefits of avoided fossil fuel use are not included.
[2] Paper recycling residuals are materials removed during processing to eliminate contaminants and yield reusable fiber. They generally consist of a fiber and plastic fraction.

ED_000419-0008018

The difference in greenhouse gas impact (GHGI) between product systems was determined by calculating the differences in annual GHG emissions from the systems and determining the cumulative radiative forcing impacts associated with these differences over time, out to 100 years. The difference in GHGI between the two systems was calculated twice, once with biogenic CO_2 included in the analysis and once with biogenic CO_2 excluded. In addition to characterizing the total difference in GHGI over 100 years, this study examined the implications of using biomass residuals for energy as a function of time. When residuals are burned for energy, the biogenic carbon is immediately released to the atmosphere. In contrast, residuals placed into landfills degrade and release the carbon over time.[3] In such cases, the emissions from the biomass energy system could sometimes be higher in the short term than those from the non-use system, but the emissions from the non-use system typically overtake those from the biomass energy system relatively quickly. For each residual, this study computed the number of years required for the cumulative radiative forcing associated with the emissions from the non-use system to equal the cumulative radiative forcing associated with the emissions from the biomass energy system (referred to as the "break-even time" in this report). After this point, the cumulative radiative forcing associated with the non-use system remains higher than that associated with the biomass energy system for the remainder of the 100-year period. Dynamic calculations of cumulative radiative forcing were used in the analysis rather than conventional global warming potentials because the intent was to capture the time-dependent impacts of each system, which is not possible using global warming potentials which assess cumulative radiative forcing over a single period (e.g., 100 years).

The difference in fossil fuel consumption between the two systems was also calculated.

ES.3.2 Methods for Additional Analyses

In addition to the life cycle analyses described above, two secondary analyses were undertaken.

The first involved limiting the analysis to the fate of the biomass carbon, without regard to fossil fuel substitution benefits. In this analysis, the two compared systems (i.e., the biomass energy system and the non-use system) were compared in terms of the emissions coming directly out of the units receiving the residuals (i.e., combustion units or landfills). In the case of paper recycling residuals, only the fiber fraction was considered as the focus here was on the fate of the biomass carbon. The results were computed for two indicators: difference in GHGI over 100 years and break-even time.

The second analysis consisted of changing the frame of analysis to evaluate the cumulative emissions attributable to the ongoing use of the residuals. For this analysis, a different functional unit was used, defined as ***the yearly production of 1 GJ of energy as an ongoing practice***. The differential GHGI indicator was computed on a yearly basis so as to estimate when in the past the practice would have had to begin in order for the difference in GHGI to become zero in 2014. These results were computed both for the full life cycle (i.e., including fossil fuel substitution) and for the more constrained analysis looking only at the biogenic GHG emissions from the units receiving the residuals.

---

[3] The results of an earlier study of the benefits of using black liquor are also included in this report. For black liquor, it is difficult to construct an alternative fate scenario because the material is integral to pulp production. Nonetheless, in the earlier study it was assumed that, if not used in the kraft recovery cycle, black liquor would be incinerated or treated in aerobic wastewater treatment plants. In both cases, the carbon returns to the atmosphere far too rapidly for carbon storage to be important in the calculations. It was assumed that all carbon is emitted as biogenic CO_2. If, however, some of the carbon was emitted as methane, the benefits of using the liquor in the kraft recovery cycle would be greater than estimated in the previous study.

ED_000419-0008019

ES.4 Results from the Cradle-to-Final Energy Analysis, Including the Benefits of Displacing Fossil Fuels

ES.4.1 Difference in GHGI, Including Biogenic CO_2

Table ES.1 summarizes the differences in life cycle GHG impact, over 100 years, between the systems using residuals for energy and the systems using fossil fuels when biogenic CO_2 is included in the emissions. The negative values in this table indicate that the biomass energy system produced less impact (a reduction) compared to the non-use system. The weighted average reduction observed in the biomass energy system compared to the non-use system (including all residuals and black liquor) was 158 kg CO_2E/GJ. Given current fuel consumption, this means that the annual use of manufacturing residuals (including black liquor) in the industry avoids the eventual release of approximately 181 million tonnes CO_2E . The reduction occurs across a range of system configuration scenarios (boiler type, assumptions about the displaced fossil fuel, the GHG intensity of the electricity grid, and the level of cogeneration at forest products facilities) and without affecting the amount of wood harvested or the amount of forest products produced.

Table ES.1 Difference in Total Life Cycle GHG Emissions (including Biogenic CO_2) over 100 Years: Biomass Energy System Compared to Comparable Fossil Fuel-Based System Where the Residuals are Disposed

Residual Type	Differential GHGI: Difference in Emissions Impact for Typical Scenario (kg CO_2E/GJ)
Woody mill residuals	-116*
WWTP residuals	-295
Paper recycling residuals	-112
Spent liquor (incl. black liquor)†	-184
Weighted average	-158

* The results for woody mill residuals are very sensitive to the parameter used to characterize the extent to which these residuals decompose in landfills. The results shown here are based on the most conservative (i.e., least decomposition in the landfill) of several parameter values used by EPA for various purposes. Other values used by EPA, based on IPCC guidelines, yield far larger benefits (-295 kg CO_2E/GJ). †The various analyses were performed for black liquor only, which represents approximately 92% of the total spent liquor. In computing the weighted averages, it was assumed that black liquor was representative of any spent liquor.

ES.4.2 Relative Difference in GHGI, Excluding Biogenic CO_2

Table ES.2 summarizes the differences in life cycle GHG impacts, over 100 years, between the systems using residuals for energy and the systems using fossil fuels when biogenic CO_2 is excluded from the life cycle emissions. The negative results in this table indicate that the biomass energy system produces a smaller greenhouse gas impact than the non-use system. Using woody mill residuals and WWTP residuals for energy produces a reduction in impact from non-biogenic CO_2 GHGs of more than 98% compared to the non-use systems. Paper recycling residuals also result in significant, but lower, benefits (86.4% reduction in the typical scenario) mainly because these residuals are comprised of a portion of plastic. The previous study of black liquor by NCASI showed emissions of non-biogenic CO_2 GHGs that were lower by 90.5% for a system using black liquor in the kraft recovery system compared to a comparable system based on fossil fuels. The weighted average reduction in non-biogenic CO_2 GHG impact observed in the biomass energy system compared to the non-use system (including woody mill residuals, WWTP residuals, recycling residuals and black liquor) was 93.7% when compared to the non-use systems.

ED_000419-0008020

Table ES.2 Life Cycle GHG Emissions (Not Including Biogenic CO_2), over 100 Years: Percent Difference in GHG Impact between the Biomass-Based System and the Comparable Fossil Fuel-Based System Where the Residuals are Disposed

Residual Type	Relative GHGI: Difference in Typical Scenarios (%)
Woody mill residuals	-98.7*
WWTP residuals	-98.7
Paper recycling residuals	-86.4
Spent liquor (incl. black liquor)	-90.5
Weighted average	-93.7

* The results for woody mill residuals are sensitive to the parameter used to characterize the extent to which these residuals decompose in landfills. The results shown here are based on the most conservative (i.e., least decomposition in the landfill) of several parameter values used by EPA for various purposes. Other values used by EPA, based on IPCC guidelines, yield a difference of -99.2%.

ES.4.3 Emissions Timing

While not traditionally considered in LCA studies, the timing of emissions can be an important consideration for certain policy discussion/design contexts. When residuals are burned for energy, the biogenic carbon is immediately released to the atmosphere. In contrast, residuals placed into landfills release carbon over time. This delay is one of the reasons why forest biomass energy systems could initially emit more GHGs than the corresponding fossil fuel systems which dispose of the residuals. In a relatively short period, however, the cumulative radiative forcing associated with emissions from the fossil fuel systems becomes greater than that from the corresponding biomass systems due to the GHGs (including methane) produced by the decaying residuals and the GHG emissions from fossil fuel combustion. An assessment performed to address the timing of benefits produced the results summarized in Table ES.3. The results indicate that, when fossil fuel substitution is considered, it takes from 0 to 1.2 years for the cumulative radiative forcing associated with the biomass energy system to be less than that associated with the non-use system.

Table ES.3 Time for Biomass Energy Systems to Have Lower Cumulative Radiative Forcing from GHG Emissions (Including Biogenic CO_2) Than the Corresponding Non-Use Systems

Residual Type	Break-Even Time: Typical Scenarios (years)
Woody mill residuals	1.2*
WWTP residuals	0
Paper recycling residuals	0
Spent liquor (incl. black liquor)	0
Weighted average	0.5

* The results for woody mill residuals are sensitive to the parameter used to characterize the extent to which these residuals decompose in landfills. The results shown here are based on the most conservative (i.e., least decomposition in the landfill) of several parameter values used by EPA for different purposes. Other values used by EPA, based on IPCC guidelines, yield a break-even time of 0.5 years.

ED_000419-0008021

ES.4.4 Fossil Fuel Consumption

Table ES.4 summarizes the results obtained for the Fossil Fuel Consumption indicator. The negative values in this table indicate that the biomass energy systems use less fossil fuel than the corresponding non-use systems. For all residual types analyzed in this report (not including black liquor), considering all system configuration scenarios and sensitivity analyses performed, it was shown that fossil fuel consumption was lower by more than 99% in the biomass energy systems compared to the non-use systems. Note that a previous study by NCASI showed 89.8% lower fossil fuel consumption for a system using black liquor when compared to a scenario based on fossil fuel. The weighted average reduction in fossil fuel consumption observed in the biomass energy system compared to the non-use system (including all residuals and black liquor) was 93.8% when compared to the non-use systems.

Table ES.4 Fossil Fuel Consumption: Percent Difference between the Biomass-Based Systems and the Comparable Fossil Fuel-Based Systems Where the Residuals are Disposed

Residual type	Relative Fossil Fuel Consumption: Difference in Typical Scenarios (%)
Woody mill residuals	-100
WWTP residuals	-99.3
Paper recycling residuals*	-99.9
Spent liquor (incl. black liquor)	-89.8
Weighted average	-93.8

*Considering that the plastic fraction of paper recycling residuals is not a new input of fossil fuel.

ES.5 Results from Additional Analyses

ES.5.1 Analysis of Biogenic GHGs, Ignoring Fossil Fuel Displacement (Gate-to-Gate Analysis)

The results presented above were computed using a life cycle approach that considered the fossil fuels being displaced by biomass residuals. The typical scenarios for the two product systems (one system using residuals for energy and the other system managing the residuals by some other means) have also been compared in terms of the emissions coming directly out of the units receiving the residuals (i.e., combustion units or landfills). In this analysis, the benefits of fossil fuel substitution were ignored.

As shown in Table ES.5, even in this highly constrained analysis, using the biomass residuals for energy generation resulted in lower GHG impact. A previous, similarly constrained analysis on black liquor assumed that the alternative management scenario would involve returning the biogenic carbon in the liquor to the atmosphere. To be conservative, it was assumed in that study that the carbon would return to the atmosphere as CO_2 via incineration or treatment in aerobic wastewater treatment plants. This resulted in net zero biogenic GHG releases for energy production compared to an alternative fate. The reduction in biogenic GHG emissions impact over 100 years associated with the use of all manufacturing residuals (weighted according to usage), including black liquor, was shown to be 4.6 kg CO_2E/GJ. Given current fuel consumption, this means that the annual use of manufacturing residuals (including black liquor) in the industry avoids approximately 5 million tonnes CO_2E.

ED_000419-0008022

When the benefits of fossil fuel displacement are ignored, it takes longer for the biomass energy systems to arrive at the point where cumulative radiative forcing is lower than for the corresponding non-use systems. Considering only biogenic emissions, the break-even times ranged from 0 to 19.5 years.

Table ES.5 Results of Analysis of Biogenic GHGs, Ignoring Fossil Fuel Displacement

Residual Type	Differential GHGI (kg CO_2E/GJ)	Break-Even Time (years)
Woody mill residuals	-8.5*	19.5*
WWTP residuals	-190	5.9
Fiber fraction of paper recycling residuals†	-132	7.7
Spent liquor (incl. black liquor)	0	0
Weighted average	-4.6	7.6

* The results for woody mill residuals are very sensitive to the parameter used to characterize the extent to which these residuals decompose in landfills. The results shown here are based on the most conservative (i.e., least decomposition in the landfill) of several parameter values used by EPA for various purposes. Other values used by EPA, based on IPCC guidelines, yield far larger benefits (-187 kg CO_2E/GJ) and far shorter break-even times (6.6 years). † In addition to biomass, paper recycling residuals contain plastics which are produced from fossil fuels. For the purpose of the biomass carbon fate analysis, only the biomass fraction was considered.

ES.5.2 GHG Emissions from Ongoing Use of Residuals for Energy Production

The analysis above examined the impact over time associated with producing 1 GJ of energy on a one-time basis. The practice of burning residuals for energy, however, is a long-standing one in the forest products industry. It is also of interest, therefore, to examine the net impact from using residuals for energy on an ongoing basis. To do this, one can compare two facilities that are identical, except that one burns residuals for energy year after year while the other facility disposes of the residuals and uses fossil fuels for energy instead. Table ES.6 below, based on the typical scenarios used elsewhere in this study, shows the year when ongoing practices would have to have been initiated in order for the facilities using the residuals for energy production to show net benefits, in terms of cumulative radiative forcing, in 2014. The table also contains information on the industry's past use of these materials for energy. In the worst case, the use of woody mill residuals for energy without considering avoided fossil fuel emissions, the practice would have had to have started in the late 1970s in order for the "carbon debt" to be eliminated. In fact, woody mill residuals have been used for energy in the solid wood industry since the 1800s and in the paper industry since the early decades of the 1900s. The evidence is strong, therefore, that any carbon debt that might have been incurred in using manufacturing residuals for energy was eliminated long ago.

ED_000419-0008023

Table ES.6 Ongoing Use of Residuals for Energy Production: Comparing Facilities Using Biomass Residuals for Energy with Similar Facilities Using Fossil Fuels for Energy and Disposing of the Residuals

Residual		Year in the Past When Ongoing Practice Would Have Had To Be Initiated for Cumulative Radiative Forcing from the Two Facilities To Be in 2014 (under typical scenario)	Past Industry Practice in Using the Residuals for Energy
Woody mill residuals	With benefits of the displaced fossil fuels	2012*	Wood residuals have been used in saw mills going back to the mid-1800s and in paper mills back to the early decades of the 1900s. AF&PA statistics date to 1971, at which point woody mill residuals represented 7% of the fuel (16% of the biomass) burned at pulp and paper mills.
	Without benefits of the displaced fossil fuels	1979*	
WWTP residuals	With benefits of the displaced fossil fuels	2014	NCASI statistics on WWTP residuals management go back to 1979, at which point 11% of these residuals was being burned for energy.
	Without benefits of the displaced fossil fuels	2004	
Paper recycling residuals	With benefits of the displaced fossil fuels	2014	NCASI has published information showing the use of recycling residuals for energy in 1975.
	Without benefits of the displaced fossil fuels†	2001	
Spent liquor (incl. black liquor)	With benefits of the displaced fossil fuels	2014	The burning of kraft black liquor for energy and chemicals dates to before the 1950s. Based on AF&PA statistics, in 1971, 35% of the fuel (84% of the biomass) burned at pulp and paper mills was black liquor. By 1980, this had increased to 40% of the fuel (79% of the biomass).
	Without benefits of the displaced fossil fuels	2014	

* The results for woody mill residuals are very sensitive to the parameter used to characterize the extent to which these residuals decompose in landfills. The results shown here are based on the most conservative (i.e., least decomposition in the landfill) of several parameter values used by EPA for various purposes. Other values used by EPA, based on IPCC guidelines, yield dates of 2013 and 2003 when the benefits of displaced fossil fuels are included and excluded, respectively.
†Fiber fraction only.

ES.6 Conclusions

In this study, the GHG and fossil fuel-related impacts of using woody manufacturing residuals, recycling residuals, and wastewater treatment plant residuals for energy production within the forest products industry have been analyzed using life cycle principles and other methods. A previous study of the use of black liquor for producing energy and pulping chemicals has also been updated and expanded. It has been shown that using all types of residuals for energy produces benefits both in terms of reduced fossil fuel consumption and reduced greenhouse gas emissions impacts. This result is valid across a range of system configuration scenarios (boiler type, assumptions about the displaced fossil fuel, the GHG intensity of the electricity grid, and the level of cogeneration at forest products facilities), residual characteristics (e.g., heating value, moisture content), and whether or not the

ED_000419-0008024

benefits from fossil fuel substitution are considered. These findings hold true whether biogenic CO_2 is included in the analysis or excluded by giving it an emission factor of zero (equivalent to what is sometimes called "carbon neutrality"). The benefits occur without affecting the amount of wood harvested or the amount of wood products produced.

It was shown that it takes from 0 to 1.2 years for the cumulative radiative forcing associated with emissions from the biomass energy system to be lower than that of the corresponding non-use system. Even ignoring the benefits of displacing fossil fuel and limiting the analysis to biogenic emissions, the cumulative radiative forcing impacts associated with emissions from the biomass energy systems are lower than those from the non-use systems in times ranging from 0 years for black liquor, which comprises 57% of the residuals used by the energy for industry, to 19.5 years for woody mill residuals which comprise 37% of that used by the industry.

These results have been developed by comparing the GHG emissions from systems using manufacturing residuals for energy in the forest products industry to the emissions from alternative systems producing the same amount of energy from fossil fuels while disposing of the residuals by landfilling or a combination of landfilling and incineration. In cases where it is assumed that the alternative to burning manufacturing residuals for energy is incineration, the break-even times for all residuals are zero, whether or not fossil fuel substitution is considered. Where the alternative is assumed to be landfilling, results can be very sensitive to assumptions about the degree to which biomass carbon decomposes in landfills, a parameter with large uncertainty.

When considered as an ongoing practice (e.g., ongoing production of 1 GJ energy per year), and when displaced fossil fuels are considered, net benefits from using residuals for energy are observed in less than two years. In the case where the benefits of displacing fossil fuels are ignored, the break-even times are longer. Even in the worst case, however, which is the ongoing use of woody mill residuals for energy without considering fossil fuel substitution, any "carbon debt" would be eliminated if the practice began before the late 1970s. Woody mill residuals have been used for energy in solid wood manufacturing since the 1800s and in paper mills since the early decades of the 1900s, providing strong evidence that any carbon debt incurred in the past from using manufacturing residuals for energy in the forest products industry was eliminated many years ago.

The GHG emissions reduction benefits of using manufacturing residuals for energy in the forest products industry are large. Given current fuel consumption, the use of manufacturing residuals (including black liquor) in the industry for one year avoids an emissions impact of approximately 181 million tonnes CO_2E, equal to approximately three times the annual direct emissions associated with the combustion of fossil fuels in the forest products industry.

CONTENTS

1.0 INTRODUCTION AND BACKGROUND 1

1.1 Background 1

1.2 Review of LCA Studies 2

2.0 STUDY OBJECTIVES 4

3.0 INTENDED APPLICATION AND TARGETED AUDIENCE 5

4.0 METHODS 5

4.1 Cradle-to-Final Energy Analysis 5

4.2 Methodology for Additional Analyses 15

4.3 Summary of Data Sources 15

4.4 Data Quality Goals 16

4.5 Energy Considerations 16

4.6 Software Package 17

4.7 Critical Review and Public Use of the Results 17

5.0 DETAILED DATA SOURCES AND STUDY ASSUMPTIONS 17

5.1 Detailed Description of Unit Processes, System Configurations and Sensitivity Analyses 17

5.2 Definition of Typical Scenarios 33

6.0 RESULTS AND DISCUSSION: CRADLE-TO-FINAL ENERGY 38

6.1 Woody Mill Residuals 38

6.2 WWTP Residuals 48

6.3 Paper Recycling Residuals 53

6.4 Black Liquor 58

6.5 Comparison of the Residuals 59

6.6 Additional Sensitivity Analysis on Air Emission Control Equipment 60

6.7 Life Cycle Results in Context 62

7.0 RESULTS AND DISCUSSION: ADDITIONAL ANALYSES 64

7.1 Gate-to-Gate Analysis of Biogenic GHGs 64

7.2 GHG Emissions from Ongoing Use of Residuals for Energy Production 65

8.0 UNCERTAINTY AND LIMITATIONS 68

8.1 Data Accuracy and Uncertainty 68

8.2 Limitations 68

9.0 CONCLUSIONS 70

APPENDICES

A Acronyms and Nomenclature A1

B Report Revisions Since Original Publication B1

TABLES

Table 1.1 Published Studies Regarding Life Cycle GHG Mitigation Benefits for Biomass Residuals Energy Systems 3

Table 4.1 Comparison of IPCC GWPs to Results Obtained Using the Dynamic Carbon Footprint Calculator by Levasseur et al. 13

Table 4.2 Data Sources 16

Table 5.1 Summary of Components Used to Derive Possible System Configurations 18

Table 5.2 Various Available Data Sets for Size Reduction and Assumptions Made in This Study . 19

Table 5.3 Base Case and Sensitivity Analyses for Manufacturing Biomass Residual Combustion . 21

Table 5.4 haracteristics of WWTP Residuals 22

Table 5.6 Emission Factors for Burning WWTP Residuals 24

Table 5.7 General Characteristics of OCC Rejects and Sensitivity Analyses 25

Table 5.8 CHP Scenarios 26

Table 5.9 US Average Electricity Grid Fuel Consumption Mix 28

Table 5.10 Parameters Affecting Emissions from Landfilling of Woody Mill Residuals 31

Table 5.11 Parameters Affecting Emissions from Landfilling of WWTP Residuals 32

Table 5.12 Parameters Affecting Emissions from Landfilling the Fiber Fraction of OCC Rejects.... 33

Table 5.13 US Forest Products Facilities Estimated Fuel Mix (Not Including Purchased Power and Steam) 34

Table 5.14 Waste Management Practices at US Forest Products Facilities 34

Table 5.15 Typical Scenario for Woody Mill Residuals 36

Table 5.16 Typical Scenario for WWTP Residuals 37

Table 5.17 Typical Scenario for Paper Recycling Residuals 38

Table 6.1 Explanation of Annual Emissions, Woody Mill Residuals, Dynamic Carbon Footprinting 41

Table 6.2 Explanation of Cumulative Emissions, Woody Mill Residuals 43

Table 6.3 Sensitivity Analyses on Indicator Results for the Typical Scenario, Woody Mill Residuals 47

Table 6.4 Indicator Results for Various System Configuration Scenarios, Woody Mill Residuals 48

Table 6.5 Sensitivity Analyses on Indicator Results for the Typical Scenario, WWTP Residuals .. 52

Table 6.6 Indicator Results for Various System Configuration Scenarios - WWTP Residuals 53

Table 6.7 Sensitivity Analyses on Indicator Results for the Typical Scenario, Paper Recycling Residuals 57

Table 6.8 Indicator Results for Various System Configuration Scenarios - Paper Recycling Residuals 58

Table 6.9 Summary of Indicator Results for Black Liquor 59

Table 6.10 Weighted Average Indicator Results, Typical Scenarios, Life Cycle Results 60

Table 6.12 Common Combustion-Related Air Emission Control Equipment 61

Table 6.13 Sensitivity Analyses on Air Emission Control Equipment 61

Table 6.14 Various Contextual Data Regarding the US Forest Products Industry 63

Table 7.1 Results of the Gate-to-Gate Analysis of Biogenic GHGs 65

Table 7.2 The Use of Residuals for Energy as an Ongoing Practice 66

Table 8.1 Comparison of Results Obtained for Woody Mill Residuals Using the EPA and IPCC Values for Fraction of Carbon Non-Degradable Under Anaerobic Conditions and Effect for Industry Average Results 70

FIGURES

Figure 4.1 Study Overall Approach for the Life Cycle Based Analyses 7

Figure 4.2 Compared Product Systems for Woody Mill Residuals 9

Figure 4.3 Compared Product Systems for WWTP Residuals 10

Figure 4.4 Compared Product Systems for Paper Recycling Residuals 11

Figure 5.1 Stoker Boiler Efficiency as a Function of Fuel Water Content (WCR) 20

Figure 5.3 Heat/CHP Configuration Considered in the Typical Scenario for Woody Mill Residuals 35

Figure 5.4 Heat/CHP Configuration Considered in the Typical Scenario for WWTP Residuals 36

Figure 5.5 Heat/CHP Configuration Considered in the Typical Scenario for Paper Recycling Residuals 37

Figure 6.1 Contribution Analysis for the Differential GHGI (at 100 Years) for Woody Mill Residuals - Typical Scenario 40

Figure 6.2 Annual GHG Impact for the Biomass Energy and Non-Use Systems: Woody Mill Residuals - Typical Scenario 41

Figure 6.3 Cumulative GHG Impact for the Biomass Energy and Non-use Systems: Woody Mill Residuals - Typical Scenario 42

Figure 6.4 Emissions Timing: Comparing Results Based on Dynamic Carbon Footprinting and IPCC 100-Year GWPs 44

Figure 6.5 Relative Consumption of Fossil Fuels for Woody Mill Residuals - Typical Scenario 45

Figure 6.6 Sensitivity Ratios for Woody Mill Residuals 46

Figure 6.7 Contribution Analysis for the Differential GHGI (at 100 Years) for WWTP Residuals - Typical Scenario 49

Figure 6.8 Cumulative Differential GHGI Indicator Results as a Function of Time for WWTP Residuals - Typical Scenario 50

Figure 6.9 Relative FF CON Indicator Results for WWTP Residuals - Typical Scenario 51

Figure 6.10 Sensitivity Ratios for WWTP Residuals 52

Figure 6.11 Contribution Analysis for the Differential GHGI (at 100 Years) for Paper Recycling Residuals - Typical Scenario 54

Figure 6.12 Cumulative Differential GHGI Indicator Results as a Function of Time for Paper Recycling Residuals - Typical Scenario 55

Figure 6.13 Relative Consumption of Fossil Fuels for Paper Recycling Residuals - Typical Scenario 56

Figure 6.14 Sensitivity Ratios for Paper Recycling Residuals: Relative Non-BioCO_2 GHGs, Differential GHGs, and Relative FF CON 57

Figure 6.15 Comparison of the Differential Releases for the Different Residual Types a) per Gigajoule, b) per dry Tonne 60

Figure 6.16 Sensitivity Analyses on Air Emission Control Equipment - Manufacturing-Related Woody Biomass Residuals - Typical Scenario 62

GREENHOUSE GAS AND FOSSIL FUEL REDUCTION BENEFITS OF USING BIOMASS MANUFACTURING RESIDUALS FOR ENERGY PRODUCTION IN FOREST PRODUCTS FACILITIES

1.0 INTRODUCTION AND BACKGROUND

1.1 Background

The use of wood for energy has attracted considerable attention as a greenhouse gas mitigation option (FAO 2008). The United States (US) and Canada are among the largest OECD[4] users of wood for industrial bioenergy, primarily from indirect sources including black liquor and other manufacturing residuals (FAO 2008, Steierer 2007). Wood harvesting and handling, as well as processing activities in log yards, pulp and paper mills, sawmills, and other forest products activities produce a significant amount of residuals, most of which consist of bark, sawdust, shavings, and harvest residuals and other woody debris. These residuals are increasingly being used as a source of renewable energy. Often, however, the residuals that are not beneficially used are either incinerated or placed in a municipal or on-site industrial landfill.

Recent years have seen a rise in both the interest in substituting biomass for fossil fuels and in the skepticism about the greenhouse gas (GHG) benefits of this substitution. While programs that promote the use of biomass as a substitute for fossil fuel have important connections to the issues of energy security and economic sustainability, it is the questions about greenhouse gas mitigation benefits that have been at the center of the debate on whether and how to increase the reliance on the use of biomass for energy.

An important distinction between biomass carbon (also known as biogenic carbon) and the carbon in fossil fuels is that biogenic carbon was only recently removed from the atmosphere. When biomass is burned, decays, or is otherwise oxidized, the resulting CO_2 is returned to the atmosphere. The net transfers of biogenic carbon to the atmosphere can be zero if the uptake of carbon (in CO_2) by growing trees is equivalent to the biogenic carbon released in the combustion and decay of biomass (sometimes referred to as representing "carbon neutrality"). Where the amounts of biogenic CO_2 that return to the atmosphere are less than the amounts removed, the difference represents increases in stocks of stored carbon (net removals from the atmosphere). Where net returns are greater than the amounts removed, the difference represents depleted stocks of stored carbon.

The net transfers of biogenic CO_2 to the atmosphere associated with the production and use of biomass can be used to characterize the GHG emissions associated with a biomass energy system, often called the "carbon footprint" of the system. Understanding the impacts of using biomass for energy, however, requires a different analytical framework than used for a carbon footprint. In studying the impacts of using biomass for energy, one must consider how that energy might be produced if biomass was not used and the fate of the biomass if not used for energy. In this study, the objective was to understand the impacts of using biomass for energy so the life cycle emissions from a system using biomass for energy are compared to the life cycle emissions from alternative systems where the biomass undergoes an alternative fate and fossil fuels are used to produce an equivalent amount of energy.

---

[4] Organisation for Economic Co-operation and Development.

ED_000419-0008033

1.2 Review of LCA Studies

In recent years, there has been a rapidly increasing number of life cycle assessment (LCA) studies of woody biomass residual energy systems. Table 1.1 provides an overview of the main studies recently published that compared woody biomass residual energy systems with fossil fuel-based energy systems and focused on direct energy production from the residuals, not including studies looking at liquid biofuels. Only studies published in the peer-reviewed literature are presented in this table. The overview does not purport to be exhaustive.

It can be seen from Table 1.1 that these studies have mainly focused on electricity generation and direct heating and that, in cases where the authors looked at the use of woody biomass residuals by forest products facilities (e.g., sawmills), they typically did not consider alternative fates for the residuals. It is also interesting to note that there are very few studies covering other manufacturing residuals from the forest products industry, such as wastewater treatment residuals and paper recycling residuals, and their use for energy production.

In addition, while not traditionally considered in typical LCA studies, the timing of emissions may be an important consideration for certain policy discussion/design contexts. When residuals are burned for energy, the biogenic carbon is immediately released to the atmosphere. In contrast, residuals placed into landfills or left on forest sites degrade slowly, releasing carbon over time. In these cases, the emissions from burning biomass for energy could be higher in the short term than those associated with disposing of the biomass, but this is generally compensated for relatively quickly by the benefits from fossil fuel substitution or benefits from avoiding the disposal emissions of the biomass residuals.

ED_000419-0008034

Table 1.1 Published Studies Regarding Life Cycle GHG Mitigation Benefits for Biomass Residuals Energy Systems

Study	Biomass Type	Fossil Fuel Offset	Type of Facility in Which the Biofuel Is Used	Alternative Fate Considered	GHG Mitigation*	Break-Even Time
Boman and Turnbull (1997)	Agricultural residuals, energy crops, forest harvest residuals and sawmill residuals	Coal (power)	US power plants/pulp mill	Not considered	> 90%	Not applicable
Mann and Spath (2001)	Various woody residuals	Coal (power, cofiring)	US power plants	46% landfilling, 54% mulch or conversion to short-lived products	123%†	Not available
Robinson et al. (2003)	Forest harvest and agriculture residuals	Coal (power, cofiring)	US power plants	Not considered	≈ 95%	Not applicable
Wihersaari (2005)	Forest harvest residuals	Coal, peat	Finnish power plant	Decomposition in forest	> 75%	Not available
Pehnt (2006)	Forest harvest residuals, woody biomass energy crops, waste wood	German energy mix (power, home heating)	German power plants and homes	Not considered	85-95%	Not applicable
Petersen Raymer (2006)	Fuel wood, sawdust, wood pellets, demolition wood, briquettes, bark	Coal (power, cofiring) and oil (home heating)	Power plants (imports to Norway), Norwegian homes, sawmills, large combustion facilities	Not considered	81-98%	Not applicable
Kirkinen et al. (2008)	Forest harvest residuals (other biomasses not considered here)	Coal, natural gas	Finnish energy sector	Decomposition in forest	Not available	< 20 years‡
Cherubini et al. (2009)	Forest harvest residuals	Various fossil fuels used for heat, power and CHP	Various	Unknown	70-98%	Not applicable

(Continued on next page. See notes at end of table.)

ED_000419-0008035

Table 1.1 (Cont'd)

Study	Biomass Type	Fossil Fuel Offset	Type of Facility in Which the Biofuel Is Used	Alternative Fate Considered	GHG Mitigation*	Break-Even Time
Froese et al. (2010)	Forest harvest residuals	Coal (power, cofiring)	US Great Lakes region power plants	Not considered	100%	Not applicable
Jones et al. (2010)	Forest harvest residuals	Natural gas, distillate oil (heat)	Unspecified	Burn at landing	≈ 40-50%‡	Not applicable
Puettmann and Lippke (2012)	Sawmill biomass residuals, pellets, forest harvest residuals	Natural gas (heat, power)	US sawmills	Not considered	57-66%§	Not applicable
Repo et al. (2012)	Forest harvest residuals	Coal, heavy oil, natural gas	Unspecified Finnish facility	Decomposition in forest	29-81%**	< 100 years
Ruhul Kabir and Kumar (2012)	Agricultural residuals, forest harvest residuals	Coal (power, cofiring)	Canadian power plants	Not considered	74-88%*	Not applicable
Zanchi et al. (2012)	Forest harvest residuals	Coal, oil, natural gas	Austrian power plants	Decomposition in forest	76-85%**	0 - 16 years
Gaudreault et al. (2012)	Black liquor	Coal, natural gas (heat and power); US electricity grid	US pulp and paper mills	Biogenic carbon released into CO_2	69-92%	Not applicable

*Percent for full substitution; for cofiring situations the mitigation pertains to the cofire rate (e.g., if 10% fossil fuel is replaced by biomass and emissions decrease by 9%, mitigation of 90% is assigned); includes all GHGs excluding biogenic CO_2. † Mitigation greater than 100% due to avoided end-of-life methane emissions. ‡Estimated. §One of the reasons why Puettmann and Lippke obtained lower mitigation results than other authors for manufacturing residuals is that they allocated a fraction of the load from manufacturing to the residuals. **Values at 100 years.

2.0 STUDY OBJECTIVES

The main objective of this study was to evaluate the life cycle (cradle-to-final energy analysis) greenhouse gas impact (GHGI) and fossil fuel reduction benefits of using various forms of forest biomass residuals (manufacturing-related) for energy production in forest products manufacturing facilities in contrast to no beneficial use of these residuals coupled with production of the same quantity and form of energy using fossil fuels. The total 100-year and yearly impacts were investigated.

The study also included two secondary objectives: 1) to analyze the greenhouse gas impact from the emissions of biogenic GHGs released from the units in which the residuals are managed (i.e., combustion units or landfills, gate-to-gate analysis); and 2) to analyze the cumulative greenhouse gas

ED_000419-0008036

impact associated with the net emissions attributable to the use of the residuals for energy as an ongoing, long-standing, practice (both in terms of cradle-to-final energy and gate-to-gate boundaries).

The biomass residuals studied in this project were

- woody mill residuals (e.g., bark, sawdust, and other similar manufacturing woody residuals from sawmills, panel plants, and pulp and paper mills);
- wastewater treatment plant (WWTP) residuals; and
- paper recycling residuals (e.g., old corrugated container (OCC) rejects)[5].

For each type of residuals, the study compared a base case of no beneficial use of residuals (including their alternative fates) with 100% use for energy generation. Note that whether or not these residuals are used for energy production, the same number of trees would be harvested and the same quantity of resources would still be required to produce the related forest products. In addition to heat production, the study also included combined heat and power (CHP) as a second option for using the residuals. Other options for processing or using the wood residuals (e.g., torrefaction, gasification, hydrolysis and fermentation, other beneficial uses) were not analyzed.

3.0 INTENDED APPLICATION AND TARGETED AUDIENCE

The intended application is to inform the discussion and development of policies that require an understanding of the impacts of using biomass-based manufacturing residuals for energy at forest products manufacturing facilities. The targeted audience of this report is individuals interested in understanding these impacts.

4.0 METHODS

4.1 Cradle-to-Final Energy Analysis

4.1.1 Overview Methodology Employed

Life Cycle Assessment (LCA) is the *"compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle,"* the life cycle being *"consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal"* (ISO 2006a, p. 2).

LCA principles and methodology are framed by a set of standards (ISO 2006a, b) and technical reports and specifications (ISO 2002, 2012a, b) from the International Organization for Standardization (ISO). ISO describes LCA methodology in four phases:

1) **Goal and scope definition,** in which the aim of the study, the product system under study, its function and functional unit, the intended audience, and the methodological details on how the study will be performed are defined;
2) **Life cycle inventory analysis (LCI),** which is the *"phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle"*(ISO 2006a, p. 2);

[5] Paper recycling residuals are materials removed during processing to eliminate contaminants and yield reusable fiber.

3) **Life cycle impact assessment (LCIA),** which is the "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 2006a, p. 2); and
4) **Life cycle interpretation,** which is the *"phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations"* (ISO 2006a, p. 2).

This study

- used widely accepted LCA concepts, such as those described in LCA ISO standards 14040 and 14044 (International Organization for Standardization (ISO) 2006a, b);
- was built on the approaches by others [e.g., US Environmental Protection Agency (EPA), Consortium for Research on Renewable Materials (CORRIM)];
- was based on known and established competitive materials and alternative fates for biomass residuals; and
- did not consider any "export" of the residuals outside the forest products industry (e.g., to utilities).

More specifically, the methodology used in this study followed life cycle principles, by calculating emissions from "cradle to final energy" including fuel conversion efficiency. However, a simplified (streamlined) LCA methodology was applied. Streamlining generally can be accomplished by limiting the scope of the study or simplifying the modeling procedures, thereby limiting the amount of data or information needed for the assessment (Todd and Curran 1999). Many different streamlining approaches can be applied. In this study, two main approaches were taken: limiting the impact assessment to two indicators (global warming, fossil fuel consumption) and using generic information for the most part. Because of this, this study does not fully comply with ISO 14044 requirements for comparative assertions disclosed publicly. However, the study aligns as much as possible with this standard.

4.1.2 Functions and Functional Units

In this study, the primary functional unit was ***the production of 1 GJ of energy***. The product systems being compared also fulfilled an additional implicit function, which is the management of the quantity of residuals required to produce 1 GJ of energy. This is further discussed in Section 4.1.4.

4.1.3 Scenario and Sensitivity Analyses

The overall analysis approach employed in this study is depicted in Figure 4.1. First, for each system component of the study (size reduction, biomass energy production, alternative fates of the residuals and fossil fuel displaced), possible scenarios were defined. These scenarios were intended to represent a broad range of conditions in the US forest products industry.

Then, a typical scenario was established for each residual type as the best estimate for representing average conditions in the US in terms of the different system components mentioned above. The typical scenario was analyzed to determine typical benefits obtained by using a given residual type, the contribution of each different system component to the overall results, the sensitivity of various parameters (e.g., higher heating value, water content, etc.) to the results, and the effect of time on the results. Where possible, each parameter was analyzed using a base case, low, and high value, and the base case values were derived from EPA. Perturbation analyses were also performed. The general idea behind perturbation analyses is that perturbations of the input parameters propagate as smaller or

ED_000419-0008038

larger deviations to the resulting output (Heijungs and Kleijn 2001). The objectives of perturbation analyses are to provide 1) a list of those input parameters for which a small imprecision already leads to important changes in the results, and 2) interesting suggestions for improving the environmental performance of the system. For each parameter tested in sensitivity analysis, a perturbation analysis was also performed and a sensitivity ratio was calculated as outlined below.

Sensitivity ratio = Percent change in output variable/Percent change in input variable

The input variable is the parameter tested in sensitivity analysis while the output variable is a given environmental indicator (see more detail in Section 4.1.6). For instance, a sensitivity ratio of +1.0 means that the score of the environmental indicator increases by 1% when the parameter value is increased by 1%. The more negative an environmental indicator score, the better the performance of the biomass energy system compared to the non-use system. The more positive or the more negative a sensitivity ratio is, the more sensitive a parameter is.

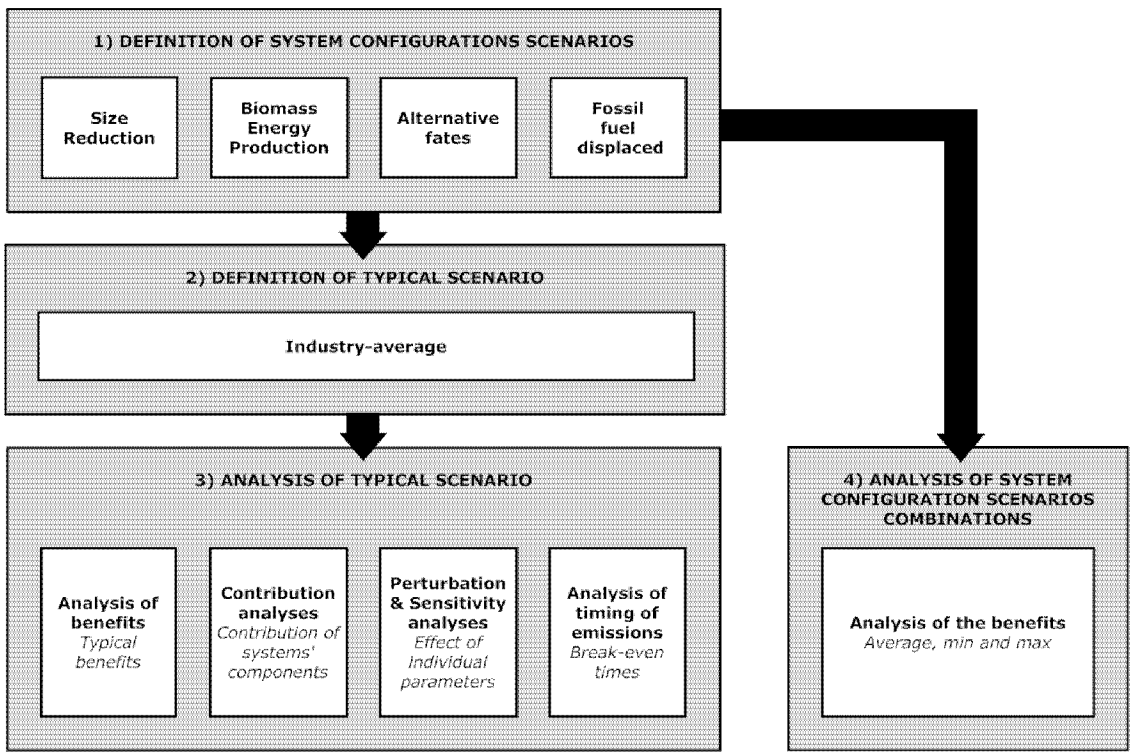


Figure 4.1 Study Overall Approach for the Life Cycle Based Analyses

ED_000419-0008039

4.1.4 Product Systems Studied, System Boundaries, and Allocation

For each type of residual, the study compared a base case of no beneficial use of residuals (while accounting for their alternative fate) with 100% use for energy generation. The different product systems studied and compared in this study are discussed next. The general approach was to include within the system boundary only the processes that were different between the biomass and non-use systems.

4.1.4.1 Woody Mill Residuals

Major sources of manufacturing residuals include sawmills, panel plants, and pulp and paper mills. These residuals consist primarily of bark and fine residuals (e.g., sawdust, planer shavings, sanderdust). In this study, all woody mill residuals were considered as a whole, in a single analysis. Sensitivity analyses were performed to encompass the variability in residual types (see Section 5.1).

Figure 4.2 illustrates the two product systems that were compared in the case of woody mill residuals.

1) **Biomass Energy System:** Production of 1 GJ of energy (heat or combined heat and power) using manufacturing residuals.
2) **Non-Use System:** Production of 1 GJ of energy (in the same form as in #1) using fossil fuels and alternative fate of the residuals.

Figure 4.2 also shows that the accounting started with the manufacturing-related biomass residuals and ended at the point at which the energy has been generated. All of these materials would be generated whether or not they would be used for energy generation, and thus there should be no effects on upstream processes attributable to the use of the materials for energy. Therefore, upstream emissions from the production of these materials were assumed to be the same for both systems and they were not included in the analysis.

In some cases, size reduction of manufacturing residuals is required. As depicted in Figure 4.2, three scenarios were considered regarding size reduction (SR0: no size reduction, SR1: size reduction in mobile chipper, and SR2: size reduction in stationary chipper). These processes, as well as any related upstream emissions, were included in the system boundary of the biomass energy system only as they were considered to be unnecessary in the non-use system. The system boundary of the biomass energy system also included the processes required to produce the energy at forest products facilities. Five system configuration scenarios were considered: heat production only in a stoker boiler (SB), heat production only in a fluidized bed boiler (FB), and three levels of combined heat and power (CHP1, CHP2, and CHP3) in which the heat is produced in a stoker boiler.

The non-use system included the upstream emissions for producing the fossil fuel and the energy production processes at forest products facilities or utilities. The energy produced was set to be in the same form as in the biomass energy system. Figure 4.2 shows the different system configurations that were analyzed regarding energy production in the non-use system. It was assumed that heat could be produced in forest products facilities using either coal (A) or natural gas (B). Electricity production at utilities (see Section 5.1) was assumed to be represented by the US average grid (C), coal (D), or natural gas combined cycle (E). When using woody mill residuals to produce 1 GJ of energy, an implicit secondary function is accomplished: the management of the quantity of residuals necessary to produce 1 GJ of energy (Q_R). For the two compared systems to be equivalent, it was necessary to expand the boundary of the non-use system to account for an alternative fate for these residuals. Figure 4.2 shows the two scenarios that were considered for the alternative fate of residuals in the non-use systems: 1) placed in landfills (MR1), and 2) incinerated without recovering the energy

ED_000419-0008040

(MR2). The typical scenario definition and rationale, and more details on the various unit processes involved in both systems, are provided in Section 5.1.

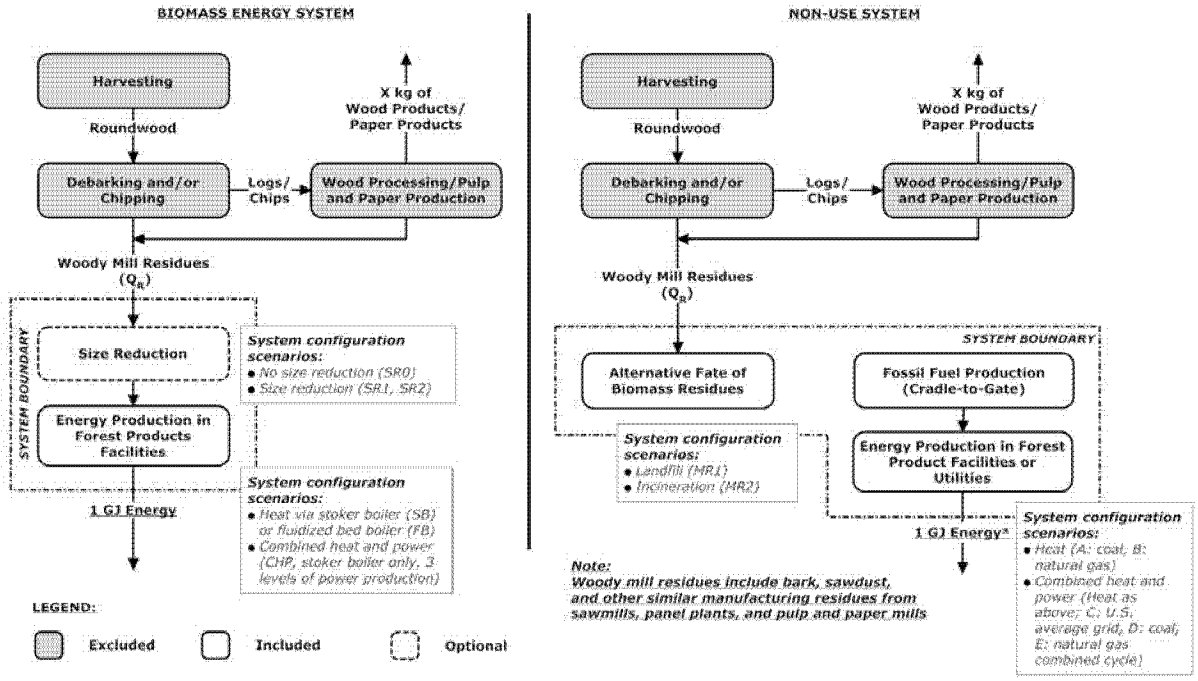


Figure 4.2 Compared Product Systems for Woody Mill Residuals

4.1.4.2 WWTP Residuals

Another manufacturing residual that was included in the study is wastewater treatment plant (WWTP) residuals. Figure 4.3 illustrates the two systems that were compared for WWTP residuals.

1) **Biomass Energy System:** Production of 1 GJ of energy (heat, power or combined heat and power) using the WWTP residuals; and
2) **Non-use System:** Production of 1 GJ of energy (in the same form as in #1) using fossil fuels and alternative fate of the WWTP residuals.

Figure 4.3 also shows that the accounting started with the WWTP residuals and ended at the point at which the energy has been generated. WWTP residuals would be generated whether or not they are used for energy generation, and thus there should be no effects on upstream processes attributable to the use of these materials for producing energy. Therefore, upstream emissions from the production of these materials were assumed to be the same for both systems and they were not included in the analysis. It was also assumed that mechanical dewatering would be required whether the residuals would be used for energy generation or disposed of, and hence was not included in the study.

The system boundary of the biomass energy system included the processes required to produce the energy at forest products facilities. Four system configuration scenarios were considered: heat production only in a stoker boiler (SB), and three levels of combined heat and power (CHP1, CHP2, and CHP3) in which the heat is produced in a stoker boiler.

The non-use system included the upstream emissions for producing the fossil fuel and the energy production processes at forest products facilities or utilities. Figure 4.3 shows the different system

configurations that were analyzed. It was assumed that heat could be produced in forest products facilities using either coal (A) or natural gas (B). Electricity production at utilities (see Section 5.1) was assumed to be represented by the US average grid (C), coal (D), or natural gas combined cycle (E). When using WWTP residuals to produce 1 GJ of energy, an implicit secondary function is accomplished: the management of the quantity of residuals necessary to produce 1 GJ of energy (Q_R). For the two compared systems to be equivalent, it was necessary to expand the boundary of the non-use system to account for an alternative fate for these residuals. Figure 4.3 shows the two scenarios that were considered for the alternative fate of residuals in the non-use systems: 1) placed in landfills (MR1), and 2) incinerated without recovering the energy (MR2). The non-use system included the upstream emissions for producing the fossil fuel and the energy production processes at forest products facilities or utilities. The typical scenario definition and rationale, and more details on the various unit processes involved in both systems, are provided in Section 5.1.

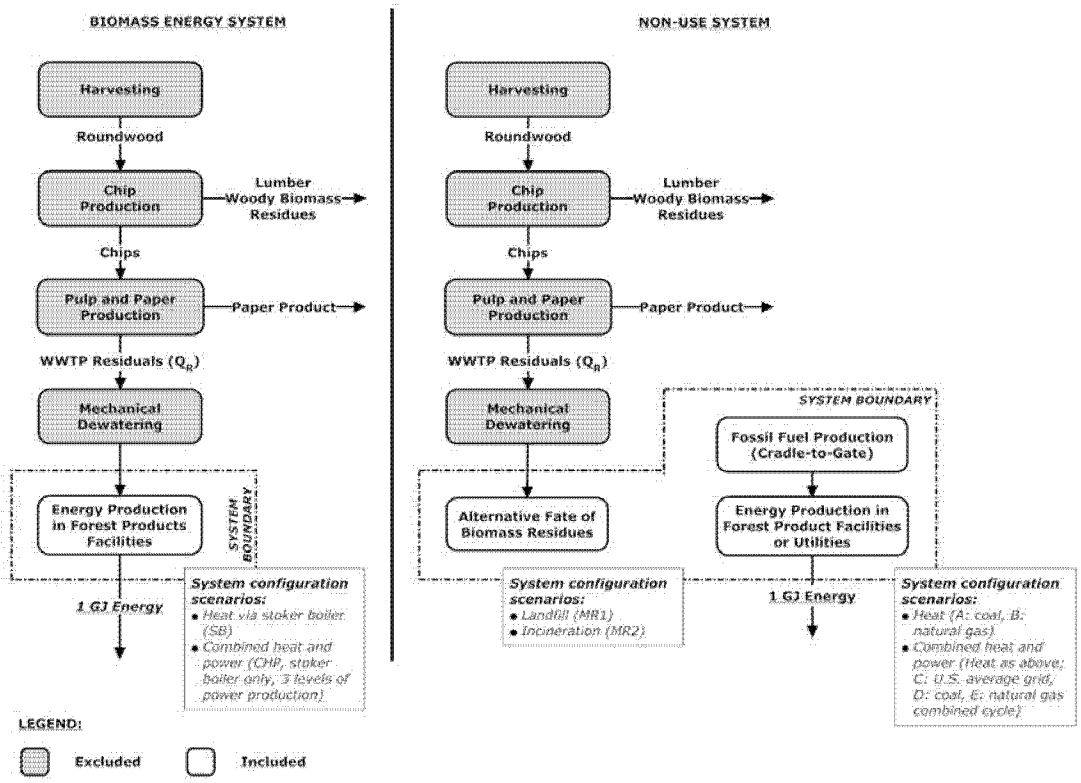


Figure 4.3 Compared Product Systems for WWTP Residuals

4.1.4.3 Paper Recycling Residuals

The last manufacturing residual that was included in the study is paper recycling residuals, and more specifically old corrugated container (OCC) rejects. Figure 4.4 illustrates the two systems that were compared for paper recycling residuals.

1) **Biomass Energy System:** Production of 1 GJ of energy (heat, power or combined heat and power) using the paper recycling residuals.
2) **Non-Use System:** Production of 1 GJ of energy (in the same form as in #1) using fossil fuels and alternative fate of the paper recycling residuals.

Figure 4.4 also shows that the accounting started with the paper recycling residuals and ended at the point at which the energy has been generated. Paper recycling residuals would be generated whether

ED_000419-0008042

or not they would be used for energy generation, and thus there should be no effects on upstream processes attributable to the use of the materials for energy. Therefore, upstream emissions from the production of these materials were assumed to be the same for both systems and they were not included in the analysis.

The system boundary of the biomass energy system included the processes required to produce the energy at forest products facilities. Four system configuration scenarios were considered: heat production only in a stoker boiler (SB), and three levels of combined heat and power (CHP1, CHP2, and CHP3) in which the heat is produced in a stoker boiler.

The non-use system included the upstream emissions for producing the fossil fuel and the energy production processes at forest products facilities or utilities. Figure 4.4 shows the different system configurations that were analyzed. It was assumed that heat could be produced in forest products facilities using either coal (A) or natural gas (B). Electricity production at utilities (see Section 5.1) was assumed to be represented by the US average grid (C), coal (D), or natural gas combined cycle (E). When using paper recycling residuals to produce 1 GJ of energy, an implicit secondary function is accomplished: the management of the quantity of residuals necessary to produce 1 GJ of energy (Q_R). For the two compared systems to be equivalent, it was necessary to expand the boundary of the non-use system to account for an alternative fate for these residuals. Figure 4.4 shows the two scenarios that were considered for the alternative fate of residuals in the non-use systems: 1) placed in landfills (MR1), and 2) incinerated without recovering the energy (MR2). The non-use system included the upstream emissions for producing the fossil fuel and the energy production processes at forest products facilities or utilities. The typical scenario definition and rationale, and more details on the various unit processes involved in both systems, are provided in Section 5.1.

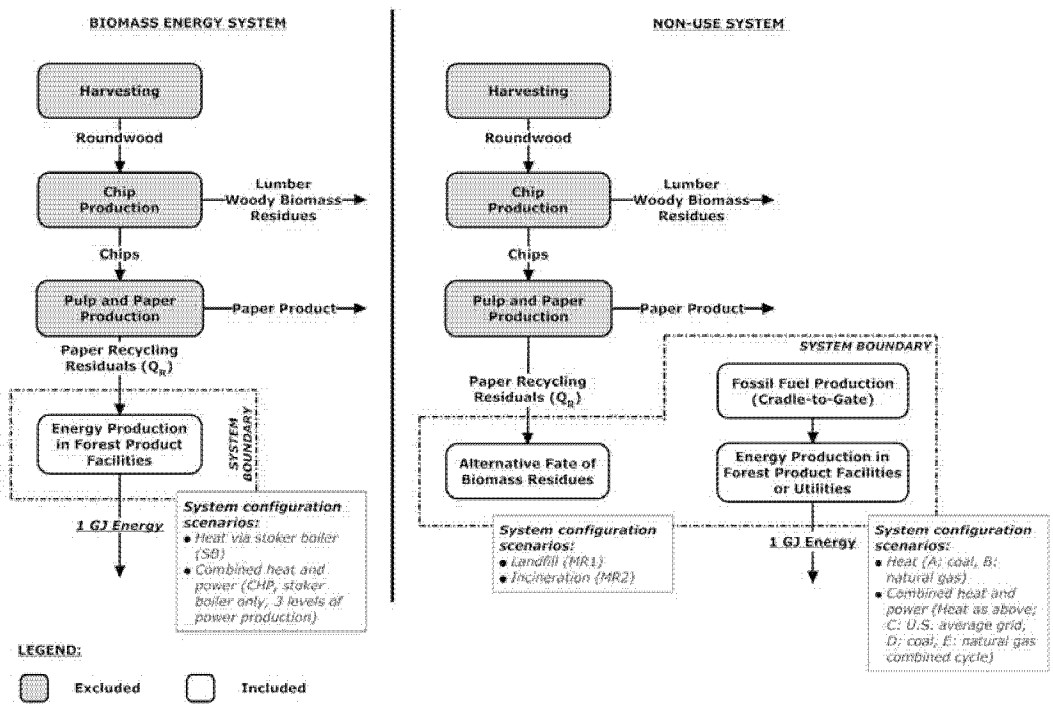


Figure 4.4 Compared Product Systems for Paper Recycling Residuals

4.1.5 Exclusions and Cut-Off Criteria

For each of the groups described above, the following components of each product system were not included in this study: manufacture of capital equipment, human activities, and unit processes common to the systems compared.

All required data were available. No cut-offs were applied.

4.1.6 Environmental Indicators Analyzed

Two main environmental aspects were studied in this study: greenhouse gases (GHGs) and fossil fuel consumption.

Note that in LCA studies, environmental indicator results are relative expressions and do not predict impacts on category endpoints, nor the exceeding of thresholds, safety margins, or risks.

4.1.6.1 Greenhouse Gas Impact (GHGI)

In this report, the term "greenhouse gas impact" is used to describe the cumulative radiative forcing over a period of time that is attributable to emissions of greenhouse gases. Various approaches can be used to calculate the greenhouse gas impact. The most common approach is to use the 100-year global warming potentials (GWPs) published by the Intergovernmental Panel on Climate Change (IPCC 2006a). The 100-year global warming potentials calculated by IPCC represent the cumulative radiative forcing over 100 years attributable to a pulse release of a GHG relative to the forcing attributable to a pulse release of the same mass of CO_2. Using this approach, the 100-year greenhouse impact is assumed to occur the same year as the pulse emission. The results are typically expressed as kilograms of CO_2 equivalents (kg CO_2E). GWPs are useful in developing GHG inventories in a way that allows the impacts associated with different types of emissions to be compared over 100 years, or some other period. IPCC has published GWPs for periods of 20, 100, and 500 years. In this study, the timing of impacts was of particular interest, which required a dynamic calculation of cumulative radiative forcing as a function of time. To accomplish this, a dynamic carbon footprinting approach developed by Levasseur (2013) and Levasseur et al. (2010) was used. This approach produces time-dependent global warming results based on the cumulative radiative forcing concept. The same scientific models are used in the dynamic carbon footprinting approach as used by IPCC to develop global warming potentials but the equations are integrated continuously over time with the exception of one element (see below). Although the results are typically expressed in units of radiative forcing (Wm^{-2}), they can also be presented in terms of kg CO_2E, especially if the objective is to compare the results to those obtained using GWPs. Approaches similar to the approach proposed by Levasseur et al. (2010) have been used elsewhere (e.g., Alvarez et al. 2012).

A difference between the dynamic approach proposed by Levasseur et al. (2010) and IPCC's scientific models was mentioned above. The approach proposed by Levasseur et al. includes the radiative forcing associated with CO_2 formed when methane decomposes in the atmosphere while IPCC's GWPs for methane do not (IPCC 2007, Chapter 2, paragraph 2.10.3). Because this study is attempting to identify the difference in total impacts between systems over time, it is appropriate to include the radiative forcing associated with CO_2 produced from the decomposition of methane in the atmosphere. Simulations performed by NCASI comparing the method of Levasseur et al. to IPCC global warming potentials indicate that the effect of this difference on results is relatively small over periods of interest in this study (i.e., 100 years and less). Table 4.1 shows the results of applying the dynamic approach compared to 100-year global warming potentials from IPCC (IPCC 2006a). The results using both approaches are also shown in several places in this report.

ED_000419-0008044

Table 4.1 Comparison of IPCC GWPs to Results Obtained Using the Dynamic Carbon Footprint Calculator by Levasseur et al.

GHG	20-Year		100-year		500-year	
	IPCC GWPs	**Dynamic Calculator**	**IPCC GWPs**	**Dynamic Calculator**	**IPCC GWPs**	**Dynamic Calculator**
Methane	72	72.9	25	27.5	7.6	10.3
Nitrous Oxide	289	289	298	298	153	153

In this study, the results for the GHGI indicator have been computed in three different ways, both for the IPCC 100-year GWPs and using the dynamic calculator.

First, the absolute difference in impact attributable to releases of GHGs over 100 years, including biogenic CO_2 emissions and removals[6] was used to calculate the results of the greenhouse gas impact indicator ("Differential GHGI") as follows:

Differential GHGI (kg CO_2E/GJ) = Total greenhouse gas impact caused by GHG releases, including biogenic CO_2 emissions and removals, for energy production using residuals – Total greenhouse gas impact of GHG releases, including biogenic CO_2 emissions and removals, for energy production using fossil fuels, including alternative fate of residuals,

or in a shorter form,

Differential GHGI (kg CO_2E/GJ) =
$[\text{Total GHGI}^7]_{\text{Biomass system}}$ - $[\text{Total GHGI}]_{\text{Non-use system}}$

Second, the greenhouse gases impact was computed using the percent difference in radiative forcing or GHGI impact calculated using IPCC GWPs attributable to GHGs released over 100 years, not including biogenic CO_2 ($BioCO_2$), of the biomass energy system compared to the non-use system ("Relative Non-$BioCO_2$ GHGI") as follows:

Relative Non-$BioCO_2$ GHGI (%) = (greenhouse gas impact caused by GHG releases, not including biogenic CO_2, for energy production using residuals – greenhouse gas impact caused by GHG releases, not including biogenic CO_2, for energy production using fossil fuels, including alternative fate of residuals)/(greenhouse gas impact caused by GHG releases, not including biogenic CO_2, for energy production using fossil fuels, including alternative fate of residuals),

or in a shorter form,

Relative Non-$BioCO_2$ GHGI (%) =
$[(\text{GHGI, excl. } BioCO_2)_{\text{Biomass energy system}}$ - $(\text{GHGI, excl. } BioCO_2)_{\text{Non-use system}}]$/ $(\text{GHGI, excl. } BioCO_2)_{\text{Non-use system}}$

---

[6] As described in Figures 4.2 to 4.4, the system boundary for the product systems did not include harvesting and forest-related activities because they are the same in the biomass and non-use systems. This means that the associated forest-related CO_2 removals, i.e., the sequestration or absorption of CO_2 from the atmosphere by the trees, were not included in this study.

[7] In this report, "Total GHG releases" is used as a short form for the sum of non-biogenic CO_2 GHGs and biogenic CO_2 GHGs.

ED_000419-0008045

Third, while not traditionally considered in typical LCA studies, the timing of emissions and of greenhouse gas impact may be an important consideration for certain policy discussion/design contexts. For instance, in the context of this study, timing may be important in cases where the alternative to using residuals is allowing them to decay in waste disposal sites. Therefore, this study examined the life cycle implications of using biomass residuals for energy as a function of time. For each residual, the study computed the number of years it would take for the cumulative greenhouse gas impact from the two systems to be equal (break-even time). After this time, the cumulative greenhouse gas impacts from the biomass systems remain lower than that from the non-use system for remainder of the 100-year period of study. While the Differential GHGI results are presented in terms of kg CO_2E to facilitate comparison with using the 100-year IPCC GWPs, the yearly differential impact is presented in terms of radiative forcing because the graphical results are much easier to interpret when presented in terms of radiative forcing units (Wm^{-2}).

Notes:

- The materials being examined are biomass residuals. Their use was assumed to have no effect on carbon in growing biomass or gross removals of carbon from the atmosphere by the forest.
- Carbon in products-in-use was not modeled in this study because the fate of carbon in products is not affected by the fate of the residuals.

4.1.6.2 Fossil Fuel Consumption

Fossil fuel used in the life cycle of each of the product systems studied was computed. The relative fossil fuel consumption ("Relative FF CON") was calculated as follows:

Relative FF CON (%) = (fossil fuel consumption score for energy production using residuals – fossil fuel consumption score for energy production using fossil fuels, including alternative fate of residuals)/(fossil fuel consumption score for energy production using fossil fuels, including alternative fate of residuals)

Fossil fuel consumption indicators are not based on an impact assessment model but rather on a quantification of the energy inputs to the studied product system. The cumulative energy demand method (Hischier and Weidema 2009) was used to quantify fossil fuel consumption because it is the most consistent with the life cycle inventory database used in this study. This method uses higher heating values in an attempt to characterize the total amount of energy consumed rather than only the energy directly used within the system being studied. The cumulative energy demand method tracks energy from the point of extraction.

Note: In this report, when a percent reduction is discussed, it is compared to the non-use system as defined in this study, unless otherwise mentioned.

4.1.7 Temporal Boundary

The temporal boundary describes the time horizon within which the results of the LCA are analyzed. The temporal boundary applies to inventory data and to the impact assessment. In this study, a temporal boundary of 100 years was selected because anything beyond that was judged to be too uncertain in relation to the goal of the study. This means that emissions were considered within 100 years after the residuals are used for energy or discarded. The greenhouse gas impact was also analyzed within this same 100-year time frame. When using IPCC GWPs, the greenhouse gas impact of an emission over 100 years is assumed to occur in the same year as the emissions. As a result, when using 100-year GWPs to study systems where emissions occur over time, some of the impacts associated with emissions occurring after year 1 actually occur after the 100-year period is ended.

ED_000419-0008046

4.2 Methodology for Additional Analyses

In addition to the life cycle analyses described above, the study also included two secondary analyses: a gate-to-gate analysis of the fate of biomass carbon, and one of the GHG emissions from the ongoing use of residuals for energy production.

4.2.1 Gate-to-Gate Analysis of Biogenic GHGs

The gate-to-gate analysis consisted of a more constrained analysis of the emissions of biogenic GHGs (mainly CO_2, CH_4, and N_2O) in isolation from any fossil fuel substitution benefits. In this analysis, the two compared systems (the biomass energy system and the non-use system) have been compared in terms of the emissions coming directly out of the units receiving the residuals (combustion units or landfills). In the case of paper recycling residuals, only their fiber fraction was considered because the focus here was on the fate of the biomass carbon. In this analysis, the system boundary for the various product systems was limited to the units receiving the residuals (i.e., "Energy Production in Forest Products Facilities" and "Alternative Fate of Biomass Residuals" in Figure 4.2 to Figure 4.4). The results were computed for two indicators described previously: differential GHGI and break-even times. A temporal boundary of 100 years was also used for that analysis.

4.2.2 GHG Emissions from Ongoing Use of Residuals for Energy Production

The analyses presented above focused on the one-time production of 1 GJ of energy (the functional unit) and looked forward in time to estimate the number of years it will take before the emissions impact attributable to the one-time use of biomass for energy is less than the emissions impact from a comparable system that disposes of the residuals. The practice of burning residuals for energy, however, is a long-standing one in the forest products industry. Therefore, it was also of interest to examine the net greenhouse gas impact over time attributable to the use of manufacturing residuals for energy on an ongoing basis. To look at the greenhouse gas impact from the ongoing use of biomass for energy production, a different functional unit is required. The functional unit used to assess emissions from ongoing practice is ***"the yearly production of 1 GJ of energy using biomass residuals as an ongoing practice."***

The definition of the temporal boundary is slightly different when analyzing the emissions attributable to ongoing practice. In fact, the time it takes for the cumulative greenhouse gas impact from a facility using residuals for energy on an ongoing basis to equal the cumulative greenhouse gas impact of a facility disposing of those residuals needs to be considered.

Data from AF&PA and NCASI were used to document the forest product industry's practices related to the use of biomass residuals for energy production.

4.3 Summary of Data Sources

North American data were used where possible and data gaps were filled using European data. The main data sources are summarized in Table 4.2.

ED_000419-0008047

Table 4.2 Data Sources

Process	Data Source
Direct combustion of wood residuals	NCASI, USEPA emission factors, literature
Direct combustion of WWTP residuals	Literature, NCASI
Combined heat and power from direct combustion	NCASI data
Landfilling	USEPA, IPCC, NCASI
Production of energy using fossil fuels	US-EI Database* (EarthShift 2009) modified to US 2010 power grid
Transportation distances	US Census 2002 (United States Department of Transportation and United States Department of Commerce 2004)
Transportation processes	US-EI Database (EarthShift 2009)

* The US-EI database (EarthShift 2009) bridges the current gap in the US LCI database (National Renewable Energy Laboratory 2008) and applies US electrical conditions to the ecoinvent database (ecoinvent Centre 2010). The database includes modified processes for the 423 processes contained in the US LCI database (version 1.6) and for the 3,974 unit processes contained in the ecoinvent database (version 2.2). Specifically, for the US LCI Database, most dummy processes (processes for which no life cycle information was available) were replaced with ecoinvent proxies using US electricity. Some of the dummy processes were not replaced if they were not available in the ecoinvent data set. For the ecoinvent data set, all processes using electricity from Switzerland or one of the European regions (RER, UCTE, CENTREL or NORDEL) were indirectly adapted to instead use US electricity. This was done by rerouting data for electricity production/distribution to data for US electricity production/distribution. NCASI also updated the data for electricity production to the most recent available data. The main data sets from the US-EI database that were used in this study are documented in this report. A data set with the "WITH US ELECTRICITY" mentioned in its title was originally developed by ecoinvent, while a data set with the "NREL" mentioned in its title was originally developed by the US LCI database.

4.4 Data Quality Goals

The ISO 14044 Standard (ISO 2006b) characterizes various aspects related to data quality and data quality analysis. It lists three critical data quality requirements: time-related coverage, geographical coverage, and technology coverage. The geographic coverage for this study is related to energy produced in US forest products facilities and utilities. When feasible, the most current available data were collected, which were most frequently for 2010. For data from secondary sources (literature, databases), the most current publicly available data for North America were used. A data quality goal of this study was to depict the GHG benefits of using biomass residuals within the forest products industry in a way that is representative of current average technology across the entire industry. Data were most frequently available from the members of the American Forest and Paper Association (AF&PA) and/or NCASI. Data obtained from these members were considered representative of the broader industry. The precision of the data is discussed where appropriate.

4.5 Energy Considerations

Energy requirement calculations were made using higher heating values (HHVs). HHVs account for the total heat content of the fuel when it is burned, some of which provides useful energy to the system in which the fuel is burned and some of which is used to evaporate the water in the combustion products. The latter is generally not available for use. For life cycle purposes, HHV is a more complete method of energy accounting compared to using the lower heating value (LHV), as LHV does not account for the energy content of the fuel that was used to evaporate the water. For this reason, HHVs were used in this study.

ED_000419-0008048

4.6 Software Package

This modeling for this study was performed using SimaPro™ version 7.3.3 and DynCO_2 (Levasseur 2013).

4.7 Critical Review and Public Use of the Results

Section 5.2 of ISO 14044 (ISO 2006b, p. 28) specifies that *"when results of the LCA are to be communicated to any third party (i.e., interested party other than the commissioner or the practitioner of the study), regardless of the form of communication, a third-party report shall be prepared".* This Technical Bulletin is intended to serve as a third-party report. The Standard also specifies that *"in order to decrease the likelihood of misunderstandings or negative effects on external interested parties, a panel of interested parties shall conduct critical reviews on LCA studies where the results are intended to be used to support a comparative assertion intended to be disclosed to the public"* (ISO 2006b, p. 31). This study constitutes a comparative assertion of biomass and non-use systems. However, no formal peer review was performed, meaning that the study is not fully compliant with the ISO 14044 Standard.

5.0 DETAILED DATA SOURCES AND STUDY ASSUMPTIONS

This section describes the life cycle inventory step of the LCA, in which the typical scenarios studied are described, as are the unit processes modeled, the related system configuration scenarios, and sensitivity analyses.

5.1 Detailed Description of Unit Processes, System Configurations and Sensitivity Analyses

Table 5.1 presents an overview of the individual components that were combined into the various system configurations scenarios that were studied in this project. All possible combinations were studied, with a few exceptions that are discussed later in this section of the report, as appropriate. From these possible configurations, a typical scenario was also constructed for each of the biomass residuals studied. These are presented in Section 5.1.2.5. The next paragraphs describe in detail each of the unit processes that were involved in the various system configurations and typical scenarios.

ED_000419-0008049

Table 5.1 Summary of Components Used to Derive Possible System Configurations

Pre-Processing		Energy Produced at Forest Products Facilities Using Biomass Residuals		Energy Produced at Forest Products Facilities Using Fossil Fuels		Alternative Fate of Residuals	
SR0	No size reduction	SB	Heat from stoker boiler	A	Heat from natural gas	MR1	Landfill
		FB	Heat from fluidized bed	B	Heat from coal		
SR1	Size reduction	CHP1	Combined heat and power: low power to steam ratio*	C	Power from average US grid	MR2	Incineration
		CHP2	Combined heat and power: medium power to steam ratio*	D	Power from coal		
		CHP3	Combined heat and power: high power to steam ratio*	E	Power from natural gas combined cycle		

*All CHP scenarios were based on the use of a stoker boiler to produce the heat from biomass residuals. CHP configurations vary from facility to facility. In some cases, the turbines used to produce the power receive steam from all boilers of the facility (biomass and fossil fuel boilers). In other cases, they receive steam only from specific boilers (biomass or fossil fuel). Analyzing a case where the same amount of CHP would be achieved using biomass or fossil fuel boilers would have led to results that are very similar to those obtained for cases where it was assumed there was only heat produced because the only difference would have been due to energy losses in the CHP system. Therefore, in this project, a more useful CHP scenario for comparison is one where there would be CHP production only in the biomass energy system; if biomass residuals would not be used for energy production at wood products facilities, then the facility would have burned fossil fuel without CHP and would have to purchase the power from local utilities.

5.1.1 Size Reduction of Biomass Residuals

In some cases, additional size reduction is necessary before using biomass residuals for energy production. In this study, it was assumed that size reduction would sometimes be required for woody mill biomass residuals fuel and other similar manufacturing biomass residuals and never required for WWTP and paper recycling residuals.

Size reduction is typically accomplished by means of chippers, hogs, and shredders. Chippers can slice logs and mill residuals and produce chips with two surfaces and clean edges of pre-specified dimensions. Hogs (e.g., hammermills) and shredders reduce wood particles through impact force, and thus produce coarse and multi-surface particles. Hybrid size reduction equipment, such as rotary knife hogs or pan-and-disc grinders, combine the durability of hogging equipment with the sharp cutting action of chippers to produce wood chunks with cleaner edges than those produced by shredders or hogs.

A few data sets, summarized in Table 5.2, were found in the literature concerning size reduction of wood. These served as the basis for this study. More specifically, size reduction-related emissions were modeled using the US-EI database, modified with the use of diesel and electricity as presented in this table. The following US-EI data sets were used:

- **Mobile chipper:** "Wood chopping, mobile chopper, in forest/RER WITH US ELECTRICITY"; and
- **Stationary chipper:** "Industrial residual wood chopping, stationary electric chopper, at plant/RER WITH US ELECTRICITY."

ED_000419-0008050

Table 5.2 Various Available Data Sets for Size Reduction and Assumptions Made in This Study

Source	Operation		Diesel (L/BDmT)	Lubricants (L/BDmT)	Electricity (kWh/BDmt)
Johnson et al. (2012)	Grinding of logging residuals		2.51 - 3.76	0.05 - 0.07	0
Johnson et al. (2012)	Chipping of thinnings		1.08 - 1.62	0.02 - 0.03	0
Werner et al. (2007)	Chopping of wood in mobile choppers		3.89*	0.06†	0
Werner et al. (2007)	Chopping in stationary chopper		0	0.002†	20
Jones et al. (2010)	Grinding of thinnings		2.42	N/Av.‡	0
System Configuration Scenarios and Sensitivity Analyses Considered in This Study					
SR0	No additional size reduction		0	0	0
SR1	Additional size reduction in mobile chipper	BC	2.49§	0.05	0
		Low	1.08	0.02	0
		High	3.89	0.07	0
SR2	Additional size reduction in stationary chipper	BC	0	0.002	20

*Werner et al. report 0.141 MJ of diesel burned per kg of residues and Kellenberger et al. (2007), 0.0234 kg of diesel per MJ. Using a density of 847.31 kg/m^3 (American Petroleum Institute 2009), this is equivalent to 3.89 L per BDmt. † Assuming a density of 900 kg/m^3.‡Not available. §Base case was taken as the middle of the range.

5.1.2 Energy Production Processes

5.1.2.1 Combustion of Woody Mill Residuals

Combustion of woody mill residuals is one of the unit processes that needed to be modeled to analyze the effects of producing energy using biomass residuals. Two types of boilers were modeled. First, a stoker boiler was assumed as it is the most commonly used firing method for burning woody biomass in the US forest products industry (NCASI 2011a). Stoker boiler efficiencies vary as a function of water content of the fuel. This is depicted in Figure 5.1. Sensitivity analyses were performed on water content and higher heating values. Second, to analyze the effect of the technology choice, a fluidized bed was also modeled using a single average residual water content and a single average higher heating value. Because smaller particles are required for a fluidized bed boiler, the analyses always incorporated size reduction. Table 5.3 summarizes the parameters that were varied for the modeling of manufacturing biomass residual combustion.

In addition, woody mill residuals are either used for energy production in the facility where they are generated or transported to another wood products facility. No transportation has been considered for the base case and transportation by truck over 130 km (United States Department of Transportation and United States Department of Commerce 2004, Table 14 available online only, value for trucking wood chips and particles) was modeled as a sensitivity analysis. The US-EI data set for single unit truck ("Transport, single unit truck, diesel powered NREL/US"), originally a US LCI Database data set, was used in this study.

ED_000419-0008051

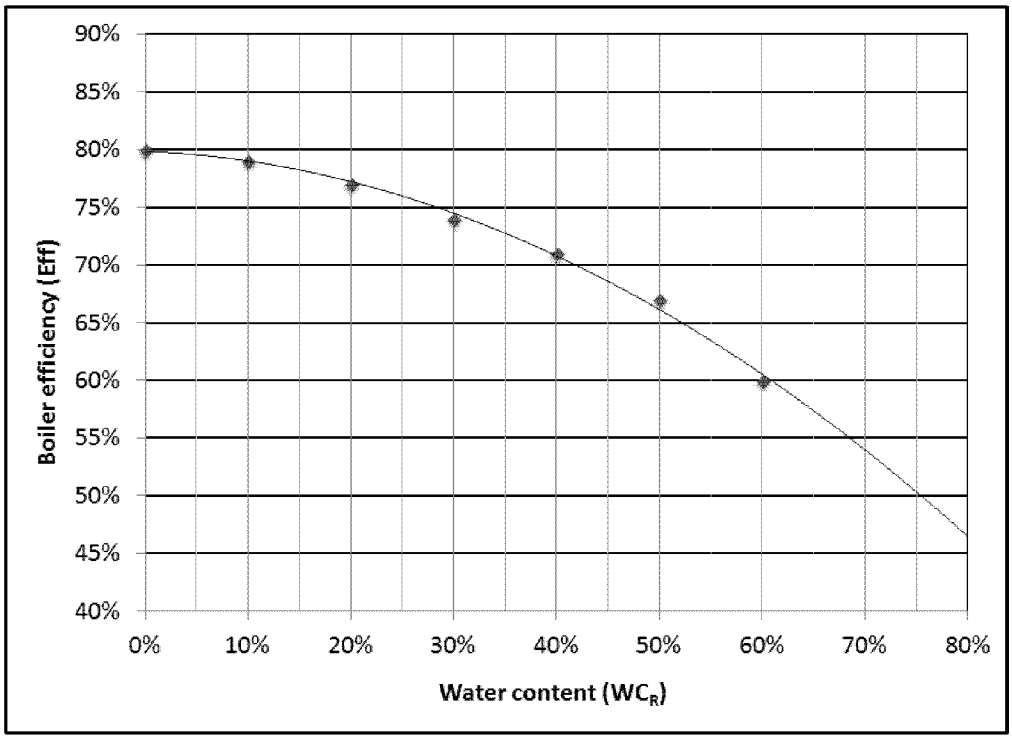


Figure 5.1 Stoker Boiler Efficiency as a Function of Fuel Water Content (WC_R)
[Based on Kostiuk and Pfaff (1997)]

The amount of residuals (Q_R) in dry tonnes required to produce a given amount of usable energy was calculated as follows:

$$Q_R = \frac{E_{DC}}{HHV \times Eff}$$

Where:

E_{DC}: Usable energy from direct combustion (GJ);
HHV: Higher heating value (GJ HHV/BDmT); and
Eff: Boiler efficiency (fraction between zero and 1).

GHG emissions due to biomass residual combustion were modeled using emission factors from USEPA (2009, Tables C-1 and C-2), converted to physical units[8]:

- 1,807 kg $BioCO_2$[9]/BDmT;
- 0.617 kg CH_4/BDmT; and
- 0.0809 kg N_2O/BDmT.

Ashes (2%) were assumed to be disposed of in facility landfills. Landfilling of wood ashes was modeled using data from the US-EI database ("Disposal, wood ash mixture, pure, 0% water, to sanitary landfill/CH WITH US ELECTRICITY U").

---

[8] Heating value and emission factors for wood and wood residuals specified by USEPA are as follows: 15.38 mmBtu HHV/short ton @12% water, 93.80 kg CO_2/mmBtu, 3.2E-2 kg CH_4/mmBtu and 4.2E-3 kg N_2O/mmBtu.
[9] $BioCO_2$: biogenic CO_2.

ED_000419-0008052

Table 5.3 Base Case and Sensitivity Analyses for Manufacturing Biomass Residual Combustion

Technology Scenario		Parameter Analyzed	Value Analyzed		Comments
SB	Stoker boiler	Water content (W_R)	BC	50% (Eff = 66%)	The range of water content for wood residuals was based on rounded values from a literature review by NCASI (2011a) and assumed to be representative of the full range of wood residuals (e.g., chips, sawdust, etc.). The base case was selected as 50% because the moisture content of as-fired wood is typically near 50% for the pulp, paper and lumber industries (USEPA 1995). Efficiencies were based on Forintek (Kostiuk and Pfaff 1997). According to NCASI's literature review, water content of residuals can be as high as 75%, but this is not very realistic.
			Low	10% (Eff = 79%)	
			High	60% (Eff = 60%)	
		Higher heating value (HHV)	BC	20 GJ/BDmT	The range of heating values is based on a literature review by NCASI (2011a) and is assumed to be representative of the full range of wood species (hardwood and softwood). USEPA (2009, Tables C-1 and C-2) proposed heating value for wood is 20.3 GJ/BDmT (see below for more details).
			Low	13 GJ/BDmT	
			High	26 GJ/BDmT	
FB	Fluidized bed	Water content	50% (Eff = 80%)		Water content was assumed the same as above. Efficiency for the fluidized bed was from a NCASI literature review (2011a).
		Higher heating value	20 GJ/BDmT		

5.1.2.2 Combustion of Wastewater Residuals

Residuals from pulp and paper mill wastewater treatment plant (WWTP) operations are often burned in mill boilers both to recover energy and for solid waste minimization.

Table 5.4 presents example characteristics of WWTP residuals that can affect their suitability for combustion. From this table, it can be seen that characteristics of residuals vary significantly. In this study, sensitivity analyses for residuals combustion were set to account for this variation.

Co-firing with bark in a stoker boiler was assumed; however, only the fraction of heat from the WWTP residuals was analyzed. Burning WWTP residuals is more difficult than burning bark mainly because of their high ash and low oxygen content. To compensate for the effects of higher ash and lower oxygen contents, the moisture of the residuals must be lower to produce the same efficiency in stoker boilers (Kraft and Orender 1993). The authors suggested that for sludge to burn like bark, the equivalent of 5 moisture points must be compensated for in some way. Switching from all bark to all residuals is worth 5 equivalent moisture points (1 moisture point being the same as 1% water content) and

- co-firing 90% bark with 10% sludge is worth 0.5 moisture points; and
- co-firing 80% bark with 20% sludge is worth 1.0 moisture point.

In this study, the latter, which is more conservative, was assumed. However, as mentioned above, only the heat fraction from the residuals was analyzed. Only stoker boilers were analyzed.

ED_000419-0008053

Table 5.4 Characteristics of WWTP Residuals

Source	WWTP Residual	Ash Content (%wt, dry basis)	Carbon Content (%wt, dry basis)	Water Content (%wt, wet basis)	Heat Content (GJ HHV/BDmT)*
Durai-Swami et al. (1991)	Recycled paper mill and kraft mill	5.5 - 18.9	47.2 - 48.2	49.5 - 62.4	20.6 - 24.1
James and Kane (1991)	Kraft mill	8.0	48.0	37.5	19.8
Nickull et al. (1991)	Clarifier and dredged from sulfite mill	1.9	48.7	66.6	20.1
Kraft (1994), Kraft and Orender (1991, 1993)	Deinking, pulp mill, unspecified	11.3 - 48.1	28.8 - 51.8	58.0 - 60.6	5.0 - 21.5
Aghamohammadi and Durai-Swamy (1993)	Recycled paper and cardboard	2.8 - 3.0	48.4 - 48.6	50 - 85	20.6 - 20.8
Douglas et al. (1994)	Deinking	31.9 - 33.2	32.7 - 38.2	42.7 - 68.6	12.3 - 15.3
Frederik et al. (1996)	Recycled paper mill	43.8	16.1	42.0	8.38
La Fond et al. (1997)	Secondary	N/Av	49.3	N/Av	23.1
Hischier (2007)	Mechanical, primary and secondary Deinking	36.4 - 67.3 (deink only, wet)	19.0 - 35.8	25 - 70.6	2.6 - 8.6 GJ (LHV)
NCASI (2005a) and USEPA (ERG 2002)	Bleached kraft, unbleached kraft, unbleached kraft colored, deinked, mechanical, groundwood, chemi-mechanical – mixed and secondary	9.9 - 56.8	37.4 - 45.5	36.2 - 80.6†	7.6 - 18.1†
USEPA GHG Reporting Rule (2009, Tables C-1 and C-2)	Wastewater from paper mills	N/Av	N/Av	N/Av	20.3§
Woodruff et al. (2012)	Pulping, deinking	10 - 50	N/Av	50 - 60	9.3 - 23.3
NCASI unpublished lab experiments	Bleached kraft combined, deinking combined, non-integrated combined, non-integrated primary, deinking primary	26.1 - 74.4	23.1 - 37.3	N/Av	N/Av
IPCC (2006b, Chapter 2, Section 2.3.2)	"Industrial sludge" including WWTP residuals from pulp and paper industry	N/Av	27**	N/Av	N/Av

*When unknown, assumed to be HHV. †Includes dewatered and not dewatered residuals. ‡Assuming USEPA values are expressed in Btu HHV/lb. §According to USEPA (2010b, p. 79138), wood residuals means materials recovered from three principal sources: municipal solid waste (MSW); construction and demolition debris; and primary timber processing. Wood residuals recovered from MSW include wooden furniture, cabinets, pallets and containers, scrap lumber (from sources other than construction and demolition activities), and urban tree and landscape residuals. Wood residuals from construction and demolition debris originate from the construction, repair, remodeling and demolition of houses and non-residential structures. Wood residuals from primary timber processing include bark, sawmill slabs and edgings, sawdust, and peeler log cores. Other sources of wood residuals include, but are not limited to, railroad ties, telephone and utility poles, pier and dock timbers, wastewater process sludge from paper mills, trim, sander dust, and sawdust from wood products manufacturing (including resinated wood products residuals), and logging residuals. **Example from Japan.

ED_000419-0008054

Water content of WWTP residuals (WC_R, primary and secondary treatment, deinking residuals) can vary widely; see Table 5.4. Residuals are typically mechanically dewatered. The general objective of dewatering is to remove water to the extent that the solids volume is reduced and the resulting residuals behave as a solid and not as a liquid. Residuals dewatering is accomplished at pulp and paper facilities by incorporating equipment and practices that result in increased WWTP residuals solids content. Employing residuals dewatering a) reduces the costs associated with residuals hauling, b) maximizes the use of remaining landfill capacity, c) makes residuals a more attractive fuel for combination fuel-fired boilers, and d) makes residuals more attractive for beneficial use opportunities (NCASI 2008). WWTP residuals can be dewatered using several technologies, of which belt filter presses and screw presses are the most frequently used in the US industry (NCASI 2008). Solids contents achievable using belt filter and screw presses are over 30% (WC_R < 70%[10]) and 40% (WC_R < 60%), respectively. A lower value of 50% water was also analyzed.

In this study, it was assumed that WWTP residuals were dewatered to 40% solids content, whether they were to be burned or landfilled, i.e., dewatering is assumed to happen both in the biomass and non-use systems. For this reason, dewatering was not included in the study. Ashes from residuals combustion were assumed to be landfilled on site. Landfilling of sludge ashes was modeled using the US-EI database (Disposal, wood ash mixture, pure, 0% water, to sanitary landfill/CH WITH US ELECTRICITY), assuming landfilling of wood ash could be taken as a proxy. Sensitivity analyses were performed on water content, heating value, and ash content. These are summarized in Table 5.5. Efficiencies have been derived from Figure 5.1 (assuming WC_R + 1%).

Table 5.5 Scenarios/Sensitivity Analyses for WWTP Residual Combustion

Parameter Analyzed	Value Analyzed		Rationale/Sources
Water content (WC_R)	BC	60% (Eff =60%)	BC and high values are based on achievable dry contents for screw presses. NCASI analysis of data in Table 5.4 was used to determine the low value by eliminating less probable drier residuals.
	Low	50% (Eff =66%)	
	High	70% (Eff =53%)	
Higher heating value (HHV)	BC	15 GJ/BDmT	BC, low, and high values are based on NCASI analysis of data in Table 5.4.
	Low	10 GJ/BDmT	
	High	20 GJ/BDmT	
Ash content	BC	30%	BC, low, and high values are based on NCASI analysis of data in Table 5.4.
	Low	10%	
	High	50%	

According to USEPA (2009), emission factors for wood and wood residuals should be used for WWTP sludge. However, the carbon content of WWTP residuals can vary significantly depending on the type of residuals. In this study, USEPA emission factors are used as a base case and sensitivity analyses are performed to accommodate the variability in the carbon content of WWTP residuals. This is summarized in Table 5.6. It is also assumed that the higher carbon contents are associated with the higher HHVs.

[10] WC_R: water content of residuals.

ED_000419-0008055

Table 5.6 Emission Factors for Burning WWTP Residuals

Parameter Analyzed		Value Analyzed		Rationale/Sources
Biogenic CO_2	kg CO_2/BDmT	BC	1,807 (CC = 49%)	According to USEPA (2010b, p. 79138), wood residuals include WWTP residuals. Hence, the same emission factor as for woody mill residuals was used (USEPA 2009, Tables C-1 and C-2).
		Low	733 (CC = 20%)	Low and high values are based on NCASI analysis of data in Table 5.4.
		High	2017 (CC = 55%)	
CH_4	kg CH_4/BDmT	BC	0.617	According to USEPA (2010b, p. 79138), wood residuals include WWTP residuals. Hence, the same emission factor as for woody mill residuals was used (USEPA 2009, Tables C-1 and C-2).
N_2O	kg N_2O/BDmT	BC	0.0809	

5.1.2.3 Combustion of Paper Recycling Residuals (OCC Rejects)

Paper recycling residuals, and more specifically OCC rejects, are often burned in boilers at pulp and paper mills that process recovered paper. This is done both for volume reduction and for energy recovery. Table 5.7 presents some general characteristics of OCC rejects, as well as the assumptions that were made in this study. OCC rejects were considered representative of the broader paper recycling residuals category. Ranges provided in the table are based on typical characteristics at a number of mills. They are intended to capture the breadth of anticipated variation for these materials.

Paper recycling residuals are a mix of fiber and plastic. In a stoker boiler, the fiber fraction is likely to behave as WWTP residuals (lower efficiency than that for wood biomass residuals). The plastic fraction is likely to behave like a fossil fuel (higher efficiency than that for woody biomass residuals). In this study, it was assumed that the boiler efficiency would be the same as that for woody biomass residuals at similar water content. Only stoker boilers were analyzed.

Ashes from residuals combustion were assumed to be landfilled on site. Landfilling of paper recycling residuals ashes was modeled using the US-EI database (Disposal, wood ash mixture, pure, 0% water, to sanitary landfill/CH WITH US ELECTRICITY), under the assumption that landfilling of wood ash could be taken as a proxy.

ED_000419-0008056

Table 5.7 General Characteristics of OCC Rejects and Sensitivity Analyses

Parameter		Range	Source	Range Analyzed in This Study		
				BC	Low	High
Fiber	% dry wt.	30 - 95	NCASI (2000)	60	30	90
Plastics	% dry wt.	5 - 70	NCASI (2000)	40	10	70
Ashes	% dry wt.	1 - 10	NCASI (2000)	5		
Biogenic CO_2 emissions when burning fiber fraction of OCC	kg CO_2/kg fiber	1.807*-1.833†	USEPA (2009, Tables C-1 and C-2)	1.807	N/A	N/A
CH_4 emissions when burning fiber fraction of OCC	kg CH_4/kg fiber		Estimated*	6.17E-5*		
N_2O emissions when burning fiber fraction of OCC	kg N_2O/kg fiber		Estimated*	8.09-6*		
Fossil CO_2 emissions when burning plastic fraction	kg CO_2/kg plastic	2.30	US-EI (EarthShift 2009)‡	2.30		
CH_4 emissions when burning plastic fraction of OCC	kg CH_4/kg plastic	6.38E-6	US-EI (EarthShift 2009)‡	6.38E-6		
N_2O emissions when burning plastic fraction of OCC	kg N_2O/kg plastic	2.58E-5	US-EI (EarthShift 2009)‡	2.58E-5		
Higher heating value	GJ HHV/BDmT	18.8-27.7	NCASI (2000)	Fiber fraction: 19.1 Plastic fraction: 40.9		
Water content (boiler efficiency)	% wet wt. (%)	35-70	NCASI (2000)	55(63)	40 (71)	70 (54)

NOTE: Ranges are based on NCASI analysis of the literature. Base case is selected as the middle of the range unless otherwise selected.
* USEPA (2009) emission factors for wood and wood residuals, expressed based in physical units, are used for the fiber fraction of OCC rejects. † Assuming all carbon emitted as CO_2. ‡Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH WITH US ELECTRICITY.

The carbon dioxide produced when plastics are burned is commonly accounted for using the same methods as for carbon dioxide produced in burning fossil fuels (USEPA 2010c, Table C-1 and Section 98.33(e)). For the gate-to-gate analyses of the biogenic GHG releases, it is only the accounting methods for biogenic carbon that are in question. For this reason, for these analyses, only the fiber fraction of paper recycling residuals was considered.

The heating values of the individual plastic and fiber fractions were presented in Table 5.7. There is no available information for the individual water contents of each of the fractions. However, it was shown in Table 5.7 that water content of paper recycling residuals varies significantly and it can be assumed that, while the plastic fraction of the residuals may contain some water, most of it would be found in the in the fiber fraction. In this analysis, the same water content as paper recycling residuals was applied to its fiber fraction. This resulted in 66% water for base case condition, which is very similar to WWTP residuals.

ED_000419-0008057

5.1.2.4 Combined Heat and Power (CHP)

In this study, a hypothetical combined heat and power configuration (CHP) representative of those commonly used in the forest products industry was modeled. This system, depicted in Figure 5.2, consisted of a biomass-fired boiler with high pressure steam routed to a back pressure turbine.

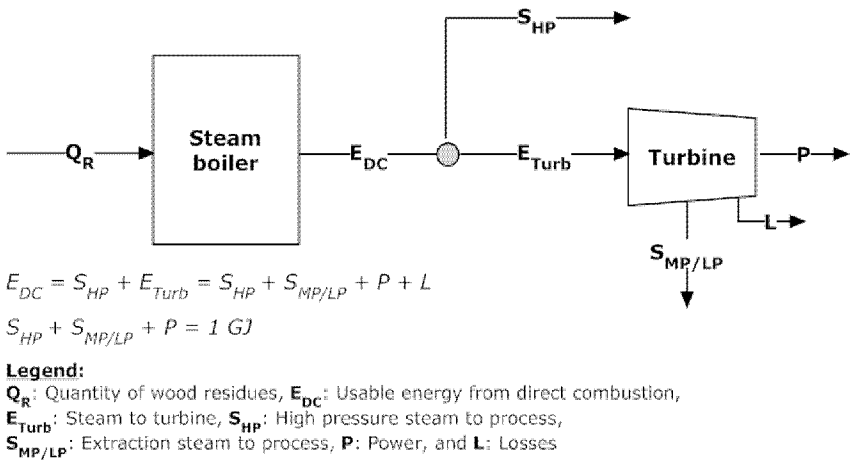


Figure 5.2 Hypothetical CHP Configuration Considered in This Study

The relationship between Q_R and E_{DC} is described above in Section 5.1.2.1. Three scenarios were considered: 1) one representing an older pulp and paper mill (CHP1), 2) one representing a newer pulp and paper mill (CHP2), and 3) one considering the maximum power production through use of a condensing turbine. This last scenario could be considered representative of cases where very little steam is required. All three scenarios are presented in Table 5.8.

All the CHP scenarios were performed with base case stoker boiler conditions.

Table 5.8 CHP Scenarios

Scenario #	E_{DC}	E_{Turb}	S_{HP}	P	$S_{MP/LP}$	$S_{HP}+S_{MP/LP}$	L
	(GJ)						
CHP1	1.0499	0.9974	0.05 E_{DC} = 0.0525	0.18 E_{Turb} = 0.1795	0.77 E_{Turb} = 0.7680	0.8205	0.05 E_{Turb} = 0.0499*
CHP2	1.0499	0.9974	0.05 E_{DC} = 0.0525	0.29 E_{Turb} = 0.2892	0.66 E_{Turb} = 0.6583	0.7108	0.05 E_{Turb} = 0.0499*
CHP3	1.0499	0.9974	0.05 E_{DC} = 0.0525	0.95 E_{Turb} = 0.9475	0	0.0525	0.05 E_{Turb} = 0.0499*

* Used for sootblowing.

5.1.2.5 Energy Production Using Fossil Fuels

Two possible options for producing energy from biomass residuals were considered: heat and combined heat and power. This means that an equivalent system needed to be studied regarding fossil fuels. For cases where the biomass energy system included heat production at the forest products facility, it was assumed that in the fossil fuel-based system an equivalent quantity of heat would be produced at the facility using either coal (A) or natural gas (B).

ED_000419-0008058

A somewhat different approach was taken for cases where combined heat and power would be applied to the biomass energy system. CHP configurations vary from facility to facility. In some cases, the turbines used to produce power receive steam from all boilers at the facility (i.e., both biomass and fossil fuel boilers). In other cases, they receive steam only from specific boilers (biomass or fossil fuel). Analyzing a case where the same amount of CHP would be achieved using biomass or fossil fuel boilers would have led to results that are very similar to those that were obtained for the case where it was assumed there was only heat produced, because the only difference would have been due to energy losses in the CHP system, which are typically very small. Therefore, in this project, a more useful CHP scenario for comparison is one where there would be CHP production only in the biomass energy system; if biomass residuals were not used for energy production at forest products facilities, then the facility would have burned fossil fuel without CHP and would have to purchase the power from local utilities. Three scenarios were analyzed: C) US average electrical grid mix, D) power generated using coal, and E) power generated using natural gas combined cycle. These scenarios were selected in order to cover a large spectrum of possible mill situations.

All energy production processes from fossil fuel-related processes were modeled using the US-EI database. In specific, the following data sets were used for heat production:

- **Heat from coal:** "Bituminous coal, combusted in industrial boiler NREL/US" (this data set includes transportation of the coal to the boiler); and
- **Heat from natural gas:** "Natural gas, combusted in industrial boiler NREL/US" (this data set includes transportation of the natural gas to the boiler).

Both these data sets are expressed based on the quantity of fuel burned and not on the quantity of energy produced. To calculate the energy produced, the following was assumed:

- **Coal:** boiler efficiency of 85% and higher heating value of 24.93 MMBtu per short ton (29.0 GJ/tonne); and
- **Natural gas:** boiler efficiency of 80% and HHV of 1.028E-3 MMBtu per cubic feet (0.0383 GJ/m^3).

Heating values were obtained from USEPA (2009, Table C-1). GHG emission factors were also derived from EPA. The emission factors for natural gas are 93.4 kg CO_2, 1.1E-2 kg CH_4 and 1.6E-3 kg N_2O per MMBtu. The emission factors for coal are 53.02 kg CO_2, 1.0E-3 kg CH_4 and 1.0E-4 kg N_2O per MMBtu.

The following data sets were used for electricity production at utilities:

- Electricity, bituminous coal, at power plant NREL/US; and
- Electricity, natural gas, at turbine, 10MW/GLO WITH US ELECTRICITY.

The US average consumption grid mix was also modeled using processes from the US-EI Database. It was calculated by considering the quantity of power produced in the US by type of fuel, the quantity of power exported, and the quantity imported from Canada and Mexico. The production mix for the United States was calculated using 2010 data from the US Department of Energy, Energy Information Administration (EIA 2012, Forms EIA-906, EIA-920 and EIA-923). Data for 2009 from the International Energy Agency were used for Mexico (IEA 2013), as these were the most recent data available. Since electricity imports from Mexico represent less than 3% of the total energy consumed in the US, these data are not expected to have a significant effect on the results. Canadian data were taken from Statistics Canada (2013a, b, c). Table 5.9 presents the fuel mix for US average electricity consumption as well as the US-EI data sets that were used to model it.

ED_000419-0008059

Table 5.9 US Average Electricity Grid Fuel Consumption Mix

Fuel Type	%	US-EI Data Set Used
Coal (including CHP)	45	Electricity, bituminous coal, at power plant NREL/US
Petroleum	1	Electricity, residual fuel oil, at power plant NREL/US
Natural gas (including CHP)	24	Electricity, natural gas, at power plant NREL/US
Nuclear	20	Electricity, nuclear, at power plant NREL/US
Hydroelectric	7	Electricity, hydropower, at power plant/SE WITH US ELECTRICITY U (89%), and Electricity, hydropower, at pumped storage power plant/US WITH US ELECTRICITY U (11%)
Wind	2	Electricity, at wind power plant/RER WITH US ELECTRICITY
Wood and wood derived fuels (CHP)	1	Electricity, biomass, at power plant NREL/US

Note that this US average grid mix was also used for the background electricity consumption of all processes modeled with the US-EI database.

Different fuels may be associated with different energy requirements for air emissions control of combustion units. In this study, it was assumed that the differences in energy requirements for emissions control were insignificant compared to the energy produced by the combustion units. This assumption was tested using sensitivity analyses.

5.1.3 Alternative Fates

5.1.3.1 Landfilling of Manufacturing Residuals

In landfills, a fraction of the biogenic carbon in wood-based material decays, primarily into gas. The remaining fraction is non-degradable under anaerobic conditions. The non-degradable fraction varies by type of product, being generally higher in materials with more lignin. In this study, the degradable fraction of the biogenic carbon in landfills was assumed to decay according to a first order decay equation, with a variable rate constant. This approach is recommended by IPCC (IPCC 2006b) and used by EPA (2010a, 2014a) for a number of purposes.

Reported decay rates are highly variable from one material to another and from one study or program to another. The factors that affect the rate of decomposition in landfills include waste management and processing variables (such as the size of the waste particles), the waste properties, factors that influence bacterial growth (such as moisture, available nutrients, pH, and temperature), and the design of the landfill (Micales and Skog 1997). EPA tested 52 municipal solid waste landfills and found decay rates that varied on average from 0.020 to 0.057, depending on precipitation conditions (USEPA 2014a, Annex 3.14, Table A-262). Published values for wood product and pulp and paper waste, branches, and solid wood products vary from 0.01 to 0.1 (De la Cruz and Barlaz 2010, IPCC 2006b, Chapter 3, Table 3.3, Micales and Skog 1997, NCASI 2005b, Section 14.2, Skog 2008, U.S. EPA 2012a, U.S. EPA 2013, Table TT-1, U.S. EPA 2014a, Annex 3.14). These values were mostly derived from laboratory experiments. NCASI knows of no published data, however, on decay rates specific to forest products industry manufacturing residuals in industry landfills based on actual measurements. Therefore, in this study, the EPA decay rates for municipal solid waste (MSW) were used (US EPA 2014a, Annex 3.14, Table A-262). These were used because 1) 50 to 60% of the biodegradable material in discarded MSW in the US (after recovery for recycling) is paper, paperboard, wood, and yard trimmings (USEPA 2014b, Table 3), 2) unlike most of the decay rates

ED_000419-0008060

found in the literature, these decay rates are derived from field data instead of laboratory experiments, and 3) they are based on a robust data set, having been derived from 52 representative landfills from across the United States with varying amounts of precipitation. These EPA MSW decay rates are somewhat higher than those used in the EPA GHG emissions reporting program for pulp, paper, and wood products mill landfills, somewhat lower than those used for pulp and paper mills in the EPA national GHG inventory, and are within the range of those reported elsewhere for forest-derived materials.

The fraction of material degradable under anaerobic conditions must also be known in order to estimate GHG emissions from landfills receiving manufacturing residuals. Data are available for some of the specific residuals in this study; the parameter values used to characterize the extent of decomposition are discussed below in the sections dealing with individual types of residuals.

Under anaerobic conditions, about one-half of the degradable carbon is converted to biogenic CO_2 while the other half is converted to CH_4. Under aerobic conditions (e.g., in shallow unmanaged landfills), a much smaller fraction of the gas consists of CH_4. The methane correction factor (MCF, fraction between zero and 1) is used to reflect the fraction of material that is degraded under anaerobic conditions.

Another factor influencing the releases of landfill CO_2 and CH_4 methane to the atmosphere is the extent to which CH_4 is oxidized to biogenic CO_2 before exiting the landfill. Even in the absence of systems designed to capture and destroy methane, it is commonly assumed that about 10% of the methane is oxidized as it moves through the surface layers of the landfill (IPCC 2006b, Chapter 3, Table 3.2, U.S. EPA 2014a, Section 8.1). Finally, some landfills are equipped with cover systems to collect and destroy methane by burning, and assumptions need to be made regarding the fraction of the methane that is collected and burned. In this study, it was assumed that manufacturing residuals are landfilled in a landfill receiving primarily forest product industry waste and that for these landfills there is no methane capture, assumptions consistent with current practice in the industry and with the approach used by EPA to calculate landfill emissions from pulp and paper mills landfills for the national inventory (USEPA 2014a, Annex 3.14).

Cumulative quantities of carbon dioxide and methane from mill landfills emitted at a given time are calculated as follows.

Quantity of Carbon Converted to Gas at a Given Time Under Anaerobic Conditions:

$$Q_{C\rightarrow Gas,ana} = MCF \times Q_R\left(1 - e^{-kt}\right) \times CC \times (1 - F_{CCND})$$

where Q_R is the quantity of residuals required to produce a given amount of usable energy in the biomass product system, t the time in years, CC the carbon content of residuals, F_{CCND} the fraction of carbon that is non-degradable under anaerobic condition, and k the decay rate.

Quantity of Carbon in Gas Converted to Methane ($Q_{C\rightarrow CH4}$):

$$Q_{C\rightarrow CH4} = Q_{C\rightarrow Gas,an} \times F$$

where F is the fraction of gas converted to methane under anaerobic conditions.

Quantity of Methane Not Collected and Burned (Q_{CH4NCB})

$$Q_{CH4NCB} = Q_{C\rightarrow CH4} \times \frac{16}{12}(1 - F_{CH4CB})$$

where F_{CH4CB} is the fraction of methane collected and burned or oxidized.

Quantity of Methane Released to the Environment ($Q_{CH4,Landfill}$):

$$Q_{CH4,Landfill} = Q_{CH4NCB} \times (1 - F_{CH4OX})$$

where F_{CH4OX} is the fraction of methane oxidized in landfill covers.

Quantity of Carbon Converted to Gas at a Given Time Under Aerobic Conditions:

$$Q_{C\rightarrow Gas,ae} = (1 - MCF) \times Q_R\left(1 - e^{-kt}\right) \times CC$$

Total Quantity of Gas at a Given time:

$$Q_{C\rightarrow Gas} = Q_R\left(1 - e^{-kt}\right) \times CC \times [1 - MCF * F_{CCND}]$$

Quantity of Carbon Dioxide Released to the Environment ($Q_{CO2,Landfill}$):

$$Q_{CO2,Landfill} = \left(Q_{C\rightarrow Gas} - Q_{CH4,landfill} \times \frac{12}{16}\right) \times \frac{44}{12}$$

Other environmental loads related to landfilling activities were modeled using the US-EI database (Disposal, wood untreated, 20% water, to sanitary landfill/CH WITH US ELECTRICITY).

5.1.3.1.1 Woody Mill Residuals

As mentioned above, an important factor in calculating emissions from landfills is the fraction of the original biogenic carbon that is non-degradable under anaerobic conditions. There is a wide variation of values for this parameter in the case of wood and wood-derived materials. Values published in the literature for woody materials vary from 50% (IPCC 2006b) to over 90% (Wang et al. 2011). Values for paper-based materials can be significantly lower than those for woody materials (USEPA 2012a). In this study, the value used in the EPA GHG Inventory for wood products disposed in MSW landfills was used in the typical scenario. This was done because 1) in the context of this study, it is more conservative than lower values sometimes used by EPA (i.e., it results in lower methane emissions from landfilling, reducing the relative benefits of burning for energy); and 2) given recent studies (e.g., Wang et al. 2011), it is likely more realistic than lower values sometimes used by EPA. There is large uncertainty in this parameter however. Materials like bark and sawdust that comprise woody mill residuals have not been studied to NCASI's knowledge. Landfill parameter values selected in this study for woody mill residuals are summarized in Table 5.10.

ED_000419-0008062

Table 5.10 Parameters Affecting Emissions from Landfilling of Woody Mill Residuals

Parameter Analyzed	Value Analyzed		Rationale/Source(s)
Biogenic carbon content (CC)	BC	50%	IPCC (2006c, Table 12.4, default value for carbon fraction of wood residues)
Non-degradable carbon under anaerobic conditions (F_{CCND})	BC	77%	USEPA (2014a, Annex 3.13); see rationale above
	Low	50%	IPCC (2006b, Chapter 3, p. 3.13) and USEPA (2010a, p. 39773, 2013, Table TT-1) recommend using a default value of 50% for the fraction of carbon that decomposes under anaerobic conditions for all waste
	High	90.0%	Mid-point of the range for wood and wood products (Wang 2011, Table 2)
Decay rate (k)	BC	0.038 yr^{-1}	USEPA (2012b), value representative of 52 US municipal solid waste landfills and various precipitation conditions; see rationale above
	Low	0.020 yr^{-1}	
	High	0.057 yr^{-1}	
Methane correction factor (MCF) i.e., fraction of landfill under anaerobic conditions	BC	1	IPCC (2006b), methane correction factors set up to be representative of managed anaerobic
Fraction of gas converted to methane under anaerobic conditions (F)	BC	0.5	IPCC (2006b)
Fraction of methane oxidized in landfill covers (F_{CH4OX})	BC	10%	IPCC (2006b)
Fraction of methane burned or oxidized (F_{CH4CB})	BC	0%	Assuming no mill landfill is equipped with methane collection systems (USEPA 2014a)

5.1.3.1.2 WWTP Residuals

Assumptions made to model GHG emissions from landfilling WWTP residuals are summarized in Table 5.11. Detailed calculations were presented in Section 5.1.3.1. Other environmental loads from landfilling of WWTP residuals were modeled using the US-EI database (Disposal, sludge from pulp and paper production, 25% water, to sanitary landfill/CH WITH US ELECTRICITY).

ED_000419-0008063

Table 5.11 Parameters Affecting Emissions from Landfilling of WWTP Residuals

Parameter Analyzed	Value Analyzed		Source(s)
Biogenic carbon content (CC)	BC	49%	See Table 5.6.
	Low	19%	
	High	55%	
Non-degradable carbon under anaerobic conditions (F_{CCND})	BC	50%	From NCASI unpublished experiments
	Low	40%	
	High	60%	
Decay rate (k)	BC	0.038	USEPA (2012b), value representative of 52 US municipal solid waste landfills and various precipitation conditions, see rationale above
	Low	0.020	
	High	0.057	
Methane correction factor (MCF)	BC	1	IPCC (2006b), methane correction factors set up to be representative of managed anaerobic landfills
Fraction of gas converted to methane under anaerobic conditions (F)	BC	0.5	IPCC (2006b)
Fraction of methane oxidized in landfill covers (F_{CH4OX})	BC	10%	IPCC (2006b)
Fraction of methane burned or oxidized (F_{CH4CB})	BC	0%	Assuming no mill landfill is equipped with methane collection systems

5.1.3.1.3 Paper Recycling Residuals

Assumptions made to model GHG emissions from landfilling the fiber fraction of OCC rejects are summarized in Table 5.12. Detailed equations were provided in Section 5.1.3.1. Other environmental emissions related to the use of resources for landfilling the fiber fraction, as well as for landfilling the plastic fraction of OCC rejects, were modeled using the US-EI database.

- **Fiber fraction of residuals:** Disposal, sludge from pulp and paper production, 25% water, to sanitary landfill/CH WITH US ELECTRICITY, assuming WWTP residuals are representative of the fiber fraction of the paper recycling residuals
- **Plastic fraction of residuals:** Disposal, paper, 11.2% water, to sanitary landfill/CH WITH US ELECTRICITY

ED_000419-0008064

Table 5.12 Parameters Affecting Emissions from Landfilling the Fiber Fraction of OCC Rejects

Parameter Analyzed	Value Analyzed		Source(s)
Biogenic carbon content (CC)	BC	50%	IPCC (2006b)
Non-degradable carbon under anaerobic conditions (F_{CCND})	BC	61%	Based on NCASI (2004)
	Low	40%	Based on lower value for WWTP residuals (see Table 5.11)
Decay rate (k)	BC	0.038	USEPA (2012b), value representative of 52 US municipal solid waste landfills and various precipitation conditions, see rationale above
	Low	0.020	
	High	0.057	
Methane correction factor (MCF)	BC	1	IPCC (2006b), methane correction factors set up to be representative of managed anaerobic
Fraction of gas converted to methane under anaerobic conditions (F)	BC	0.5	IPCC (2006b)
Fraction of methane oxidized in landfill covers (F_{CH4OX})	BC	10%	IPCC (2006b), assuming no mill landfill is equipped with methane collection systems
Fraction of methane burned or oxidized (F_{CH4CB})	BC	0%	Assuming no mill landfill is equipped with a methane collection system

5.1.3.2 Incineration of Woody Mill Residuals

Incinerating the woody mill residuals without recovering the energy is modeled in this study as a way to illustrate the simplest way by which biogenic carbon can return to the atmosphere. Emissions from incineration are assumed the same as those for combustion for energy generation (see Section 5.1.2.1).

5.1.3.3 Incineration of WWTP Residuals

Emissions from incineration are assumed to be the same as those related to combustion for energy generation (see Section 5.1.2.2).

5.1.3.4 Incineration of Paper Recycling Residuals

Emissions from the incineration of paper recycling residuals are assumed to be the same as those related to combustion for energy generation (see Section 5.1.2.3).

5.2 Definition of Typical Scenarios

5.2.1 Current Energy Use and Waste Management Practices at Forest Products Facilities

Energy production and waste management data were compiled for the US forest products facilities (both pulp and paper and wood products) using data collected by AF&PA, NCASI, and the American Wood Council (AWC) and are summarized in Table 5.13 and

ED_000419-0008065

Table 5.14. Most data are from 2010. Waste management data for the wood products facilities were compiled through 2008 only. For this reason, to produce a representative number for the entire forest products industry in 2010, the ratio of management options in 2008 was applied to 2010 production data. There are no "waste management" data available for bark, sawdust, and similar woody mill residuals produced at pulp and paper facilities, as they are not a waste but rather almost always being burned for energy.

Table 5.13 US Forest Products Facilities Estimated Fuel Mix
(Not Including Purchased Power and Steam)

Fuel Type	Paper Products Facilities	Wood Products Facilities	Forest Products Industry (AF&PA, NCASI and AWC members used as a proxy for the entire US industry)
	%		
Biomass fuels	**70.9**	**90.1**	**72.1**
Fossil fuels	**29.1**	**9.9**	**27.9**
Natural gas	13.9%	8.6%	13.5%
Coal	10.9%	0.3%	10.2%
Other fossil	4.4%	0.9%	4.1%
Power produced through combined heat and power	**GJ/GJ fuel input**	0.06	

Table 5.14 Waste Management Practices at US Forest Products Facilities

Waste Type	% Beneficial Use	Disposal		
		Total	% Landfill (% of disposal)	% Burning* (% of disposal)
Paper Products Facilities				
WWTP residuals	32.5%	67.5%	44.4% (65.8%)	23.1% (34.2%)
All others (causticizing wastes, general mill trash, construction debris, OCC rejects, landfilled broke, bark, wood residual, sawdust, knots, metal and other recyclable)	26.9%	73.1%	68.4% (93.6%)	4.7% (6.4%)
Wood Products Facilities				
All waste types (incl.: unusable sawdust, shavings, bark, garbage, recyclables, used oil, pallets, etc.)	96.2%	3.8%	3.8% (100%)	Negligible
Forest Products Industry (AF&PA and NCASI members used as a proxy for the whole US industry)				
Other waste from pulp and paper facilities and all waste from wood products facilities	57.8%	42.2%	39.6% (93.8%)	2.6% (6.2%)

*This does not include burning for energy.

ED_000419-0008066

Typical scenarios were modeled to be as representative as possible of current practices within US forest products manufacturing facilities using the information in the tables above. In addition, all parameters were set to their base case values for typical scenarios.

5.2.2 Woody Mill Residuals

The typical scenario considered for woody mill residuals is summarized in Table 5.15. A stoker boiler was assumed in the typical scenario as it is the most commonly used firing method for burning woody biomass (NCASI 2011a). Size reduction is sometimes required to process oversized particles prior to burning. Stoker boilers can be used to burn biomass residuals for a broad spectrum of sizes (NCASI 2011a). Woody mill residuals are generally found in sizes suitable for stoker boilers (NCASI 2011a). For this reason, as a typical scenario, no size reduction was considered. The ratio of steam to power produced was set based on industry data for CHP (from AF&PA, NCASI, and AWC). This study analyzed only cases where steam and electricity would be produced via CHP using biomass boilers and not fossil fuel boilers. Therefore, it was assumed that, at the industry level, the total power produced from CHP would be generated from biomass and fossil fuels in forest products facilities in the same ratio as overall fuel usage, and only the fraction from biomass was considered. Power to heat ratio ($P/S_{MP/LP}$) assumed for the CHP1 scenario above was assumed for the typical scenario as a conservative assumption. The actual heat/CHP configuration assumed for this system is depicted in Figure 5.3.

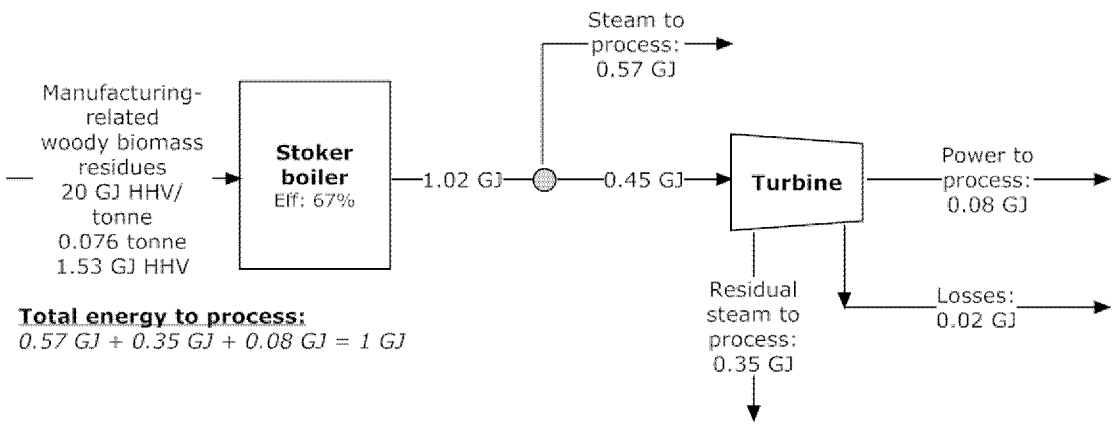


Figure 5.3 Heat/CHP Configuration Considered in the Typical Scenario for Woody Mill Residuals

The typical scenario considered was based on the data presented earlier in Table 5.13 for the entire forest products industry. It can be seen from this table that natural gas and coal are the main fossil fuels used by the US forest products industry. Therefore, in the typical scenario, only those two were considered in the ratio used by the industry. It was hence assumed that 57% of the steam produced from biomass would displace heat from natural gas and 43% would displace heat from coal. All (100%) of the displaced power was assumed to be from the US power consumption grid mix average. As shown previously in

Table 5.14, when woody mill residuals are disposed of, they are either landfilled (94%) or burned (6%). However, as the burning reported by NCASI/AF&PA members most likely involves recovery of energy, this was not considered to be an alternative fate for the typical scenario. Instead, 100% landfilling was considered. It should be noted however, that there are very few data on what would be a reasonable "typical" alternative fate for woody mill residuals as it is not a common practice of the industry to dispose of these.

ED_000419-0008067

Table 5.15 Typical Scenario for Woody Mill Residuals

Pre-Processing			Energy Produced at Forest Products Facilities/Utilities				Alternative Fate of Residuals		
			Biomass Residuals		Corresponding Fossil Fuels				
SR0	No size reduction	100%	Heat from stoker boiler and residual steam from CHP	92%	Heat from natural gas	57%	MR1	Landfill	100%
					Heat from coal	43%			
SR1	Size reduction - Mobile chipper	0%	Power from CHP	8%	US average power consumption mix	100%	MR2	Incineration	0%
SR2	Size reduction - Stationary chipper	0%							

5.2.3 WWTP Residuals

The typical scenario considered for WWTP residuals is summarized in Table 5.16. A stoker boiler was also assumed in the typical scenario as a conservative assumption. The ratio of steam to power produced was set based on industry data (from AF&PA, NCASI, and AWC) regarding CHP. This study analyzed only cases where CHP would be produced using biomass boilers and not fossil fuel boilers. Therefore, it was assumed that, at the industry level, the total power produced from CHP would be generated from biomass and fossil fuels in forest products facilities in the same ratio as overall fuel usage and only the fraction from biomass was considered. Power to heat ratio ($P/S_{LP/MP}$) assumed for the CHP1 scenario above was used for the typical scenario as a conservative assumption. The actual heat/CHP configuration assumed for this system is depicted below in Figure 5.4.

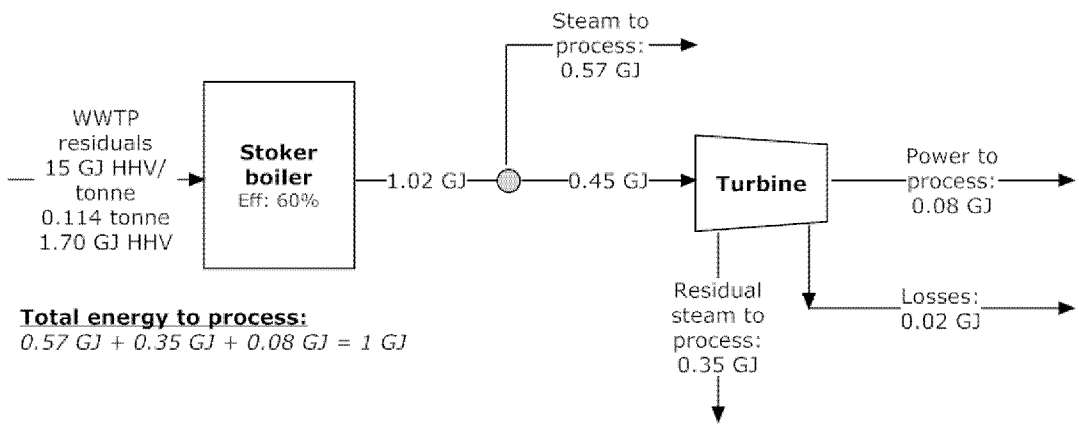


Figure 5.4 Heat/CHP Configuration Considered in the Typical Scenario for WWTP Residuals

The typical scenario considered was based on the data presented in Table 5.13 for the whole industry. It can be seen from this table that natural gas and coal are the main fossil fuels used by the US forest products industry. In the typical scenario, therefore, only these two fuels were considered in the ratio used by the industry. It was hence assumed that 57% of the steam produced from biomass would

ED_000419-0008068

displace heat from natural gas and 43% would displace heat from coal. All (100%) of the displaced power was assumed to be from the US power consumption grid mix average. Finally, as shown previously in Table 5.14, WWTP residuals that are not beneficially used are typically landfilled (66%) or burned (34%). As it is not necessary that burning residuals would involve recovery of energy (for instance, in cases where the heating value would be too low), this ratio was assumed in the typical scenario.

Table 5.16 Typical Scenario for WWTP Residuals

Energy Produced at Forest Products Facilities/Utilities				Alternative Fate of Residuals		
Biomass Residuals		Corresponding Fossil Fuels				
Heat from stoker boiler and residual steam from CHP	92%	Heat from natural gas	57%	MR1	Landfill	66%
		Heat from coal	43%			
Power from CHP	8%	US average power consumption mix	100%	MR2	Incineration	34%

5.2.4 Paper Recycling Residuals

The typical scenario considered for paper recycling residuals is summarized in Table 5.17. A stoker boiler was assumed in the typical scenario as a conservative assumption. The ratio of steam to power produced was set based on industry data (from AF&PA, NCASI, and AWC) for CHP. This study analyzed only cases where CHP would be produced using biomass boilers and not fossil fuel boilers. Therefore, it was assumed that, at the industry level, the total power produced from CHP would be generated from biomass and fossil fuels in forest products facilities in the same ratio as overall fuel usage and only the fraction from biomass was considered. Turbine efficiency assumed for the CHP1 scenario above was used for the typical scenario as a conservative assumption. The actual heat/CHP configuration assumed for this system is depicted below in Figure 5.5.

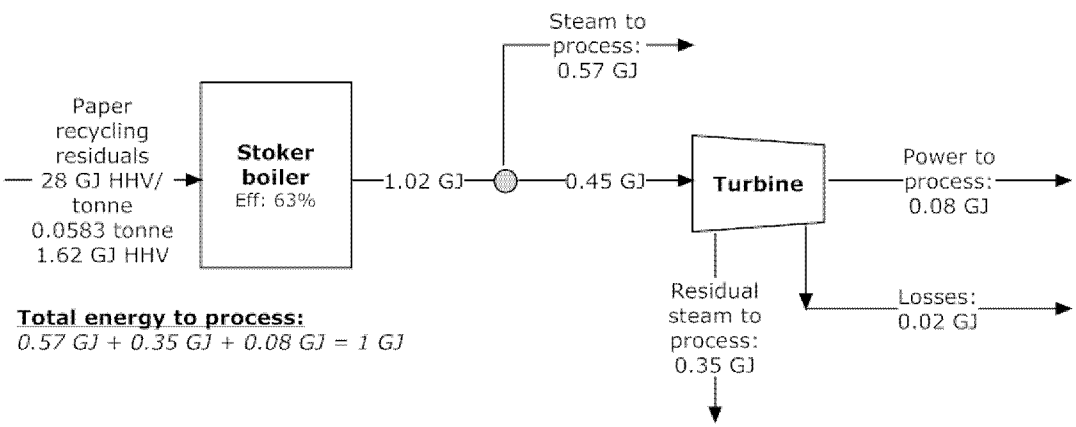


Figure 5.5 Heat/CHP Configuration Considered in the Typical Scenario for Paper Recycling Residuals

The typical scenario considered was based on the data presented above in Table 5.13 for the whole industry. It can be seen from this table that natural gas and coal are the main fossil fuels used by the US forest products industry. In the typical scenario, only those two were considered in the ratio used by the industry. It was hence assumed that 57% of the steam produced from biomass would displace heat from natural gas and 43% would displace heat from coal. All (100%) of the displaced power was assumed to be from the US power consumption mix average. Finally, as shown in Table 5.14, paper

ED_000419-0008069

recycling residuals that are not beneficially used are typically landfilled (93.6%) or burned (6.4%). As it is not necessary that burning residuals would involve recovery of energy (for instance if they were disposed of in municipal facilities), this ratio was assumed in the typical scenario.

Table 5.17 Typical Scenario for Paper Recycling Residuals

Energy Produced at Forest Products Facilities/Utilities				Alternative Fate of Residuals		
Biomass Residuals		Corresponding Fossil Fuels				
Heat from stoker boiler and residual steam from CHP	92%	Heat from natural gas	57%	MR1	Landfill	93.6%
		Heat from coal	43%			
Power from CHP	8%	US average power consumption mix	100%	MR2	Incineration	6.4%

6.0 RESULTS AND DISCUSSION: CRADLE-TO-FINAL ENERGY

This section discusses the results of the cradle-to-final energy analysis, including fossil fuel substitution.

Note: For the GHGIs indicators, the results at 100 years developed by applying the dynamic carbon footprinting approach are compared with those obtained using the IPCC 100-year GWPs. Because the comparisons reveal that the differences at 100 years are small, for simplicity, the contribution, scenarios, and sensitivity analyses results are presented using only 100-year GWPs.

6.1 Woody Mill Residuals

This section presents the results for the woody mill residuals.

6.1.1 Typical Scenario: Base Case Results

The typical scenario was first analyzed with all parameters at their base case values.

6.1.1.1 Greenhouse Gas Impact: Differential GHGI

When using the dynamic carbon footprinting approach, the biomass energy system produces, after 100 years, a greenhouse gas impact that is **116 kg CO_2E lower**[11] per gigajoule of energy produced compared to the defined non-use system. This reduction is **111 kg CO_2E** when applying IPCC 100-year GWPs.

Figure 6.1 presents the 100-year differential GHGI for the biomass energy system compared to the non-use system as well as the contribution of each system component to the results using IPCC 100-year GWPs. In this figure,

- the GHGI indicator results from the non-biogenic CO_2 releases [which include fossil fuel-related CO_2, CH_4 and N_2O as well as biomass-related CH_4 and N_2O and other GHGs (fossil

[11] Results in this report are always presented as differences (i.e., biomass energy system minus non-use system). The "Relative GHGI" indicator does not include biogenic CO_2. The "Differential GHGI" indicator includes emissions and removals of biogenic CO_2.

ED_000419-0008070

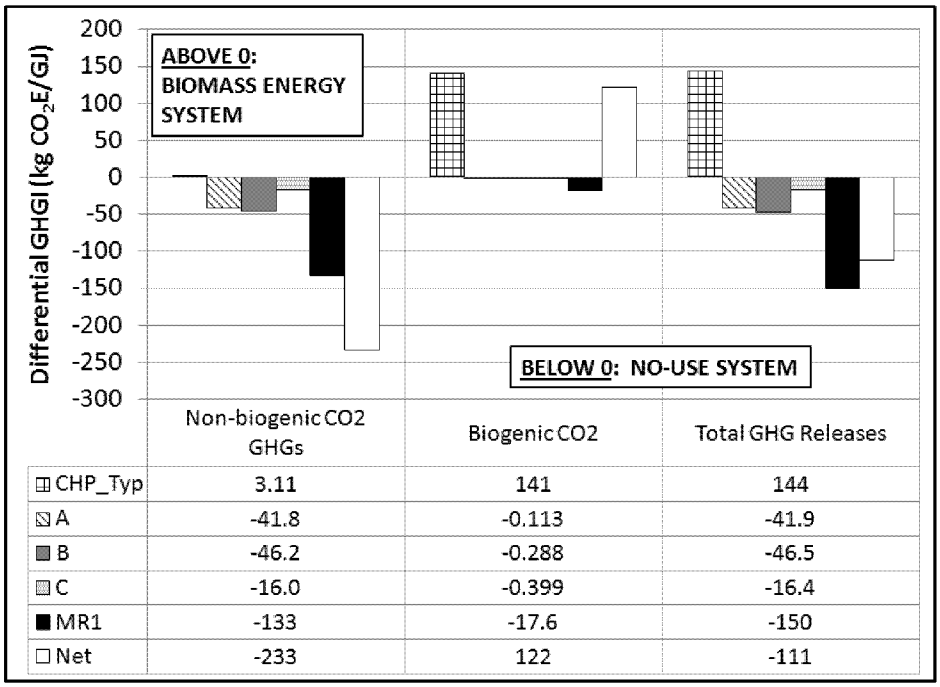
fuel- and biomass-related)], the GHGI indicator results from biogenic CO_2 releases and the total GHG releases[12] are depicted separately;

- the results from the biomass energy system are shown as positive numbers;
- the results from the non-use system are shown as negative numbers (because they are avoided);
- the "net" bars represent the sum of the different system components; and
- a net positive indicates that the biomass energy system impacts are greater than the non-use system and a net negative indicates that the biomass energy system impacts are lower than the non-use system (in other words, the more net negative the indicator result, the more beneficial is the biomass energy system).

As shown in this figure, a significant fraction of the difference between the biomass energy and non-use systems is attributable to non-biogenic CO_2 GHGs, i.e., GHGs other than biogenic CO_2. More specifically, the methane emissions from landfills (most of MR1) avoided when burning residuals to produce energy is responsible for a large portion of the benefits from the biomass energy system. Reducing energy production from fossil fuels [i.e., heat from coal (A), heat from natural gas (B), and US average power grid (C)] also contributes to the difference, but to a lesser extent. The greenhouse gas impact caused by the emissions of biogenic CO_2 is different in the two systems (i.e., the net is not zero) for two reasons. First, much of the biogenic carbon is released as methane in the non-use system (included within non-biogenic CO_2 GHGs) and mostly as carbon dioxide in the biomass energy system. Second, some of the carbon is stored in landfills in the non-use system.

[12] In this report, "Total GHG releases" is used as a short form for the sum of non-biogenic CO_2 GHGs and biogenic CO_2 GHGs.

ED_000419-0008071



	Non-biogenic CO2 GHGs	Biogenic CO2	Total GHG Releases
CHP_Typ	3.11	141	144
A	-41.8	-0.113	-41.9
B	-46.2	-0.288	-46.5
C	-16.0	-0.399	-16.4
MR1	-133	-17.6	-150
Net	-233	122	-111

Figure 6.1 Contribution Analysis for the Differential GHGI (at 100 Years) for Woody Mill Residuals - Typical Scenario
[In the figure, the different components of the biomass energy system are depicted as follows: CHP system as described in Figure 5.3 (CHP_Typ). The components of the non-use system are depicted as follows: heat from coal (A), heat from natural gas (B), US average power grid (C), residuals in landfills (MR1). Results reflect the use of 100-year GWPs.]

6.1.1.2 Greenhouse Gas Impact: Relative Non-BioCO_2 GHGI

The result for the "Relative Non-BioCO_2 GHGs" indicator is -98.7%[13] for both the dynamic carbon footprinting approach and IPCC 100-year GWPs, meaning that the biomass product system generates almost no GHGs when ignoring biogenic CO_2.

6.1.1.3 Greenhouse Gases: Timing of Impacts

When residuals are burned for energy, the biogenic carbon is immediately released to the atmosphere. In contrast, residuals placed into landfills degrade relatively slowly, releasing the carbon (both CO_2 and CH_4) over time.

Figure 6.2 shows the annual radiative forcing attributable to greenhouse gas emissions from producing 1 GJ of energy in the biomass energy and non-use systems. These values have been calculated based on the dynamic radiative forcing approach, described in Section 4.1.6.1 of this report.[14] An explanation of the factors contributing to the radiative forcing is shown in Table 6.1.

---

[13] Non-biogenic CO_2 GHGs only. Calculated as follows: (CHP_Typ - A - B - C - MR1)/(A+B+C+MR1).
[14] In Figure 6.2 and Figure 6.3, radiative forcing due to the GHG emissions is plotted in units of Wm^{-2} instead of units of CO_2E because, when using dynamic radiative forcing calculations, the relationship between annual and cumulative results is much easier to illustrate visually using units of Wm^{-2}. For other residuals addressed later in this report, only the differential cumulative results are shown.

ED_000419-0008072

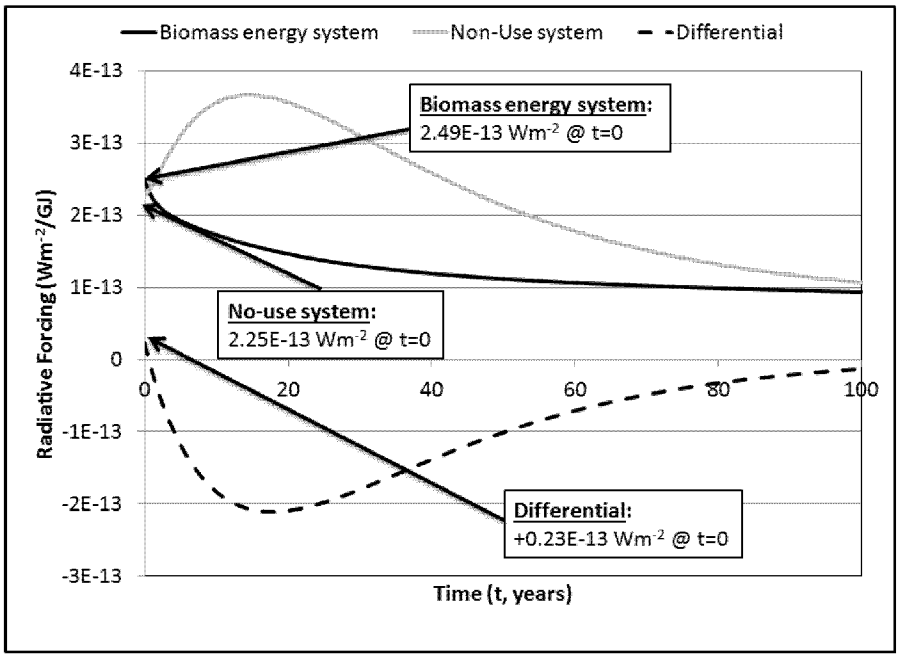


Figure 6.2 Annual GHG Impact for the Biomass Energy and Non-Use Systems: Woody Mill Residuals - Typical Scenario

Table 6.1 Explanation of Annual Emissions, Woody Mill Residuals, Dynamic Carbon Footprinting

Time (years)	Biomass Energy System	Non-Use System	Differential (i.e., biomass energy system minus non-use system)
t = 0	The woody residuals are burned, releasing GHGs, which result in radiative forcing at the time of combustion of 2.49E-13 Wm^{-2}.	The fossil fuels are burned, releasing GHGs, which result in radiative forcing at the time of combustion of 2.25E-13 Wm^{-2}. Biomass residuals are placed in landfills. There are no releases from the landfills at time 0.	The differential radiative forcing is positive (0.23E-13 Wm^{-2}) because at time 0 there is more forcing from the emissions released by the biomass energy system than from the non-use system.
$0 < t < \infty$	There are no additional emissions from the biomass energy system. The radiative forcing caused each year by GHGs released in year 0 slowly declines as these GHGs degrade (e.g., CH_4) or are removed from the atmosphere (e.g., CO_2).	Although there are no additional emissions from combustion, residuals start degrading in landfills releasing GHGs. In each year, there is radiative forcing from landfill GHGs released in the current year plus forcing due to GHGs released in previous years that are still in the atmosphere. During the period that landfill emissions are high, annual radiative forcing increases because the forcing from new emissions increases faster than previously emitted GHGs are removed from the atmosphere. Over time, however, the GHG releases from landfills decline and approach zero and the GHGs in the atmosphere degrade (e.g., CH_4) or are removed from the atmosphere (e.g., CO_2). As a result, the annual radiative forcing approaches zero.	The differential radiative forcing goes through a minimum and then increases, approaching zero, because the emissions from both systems eventually degrade or are removed from the atmosphere.

ED_000419-0008073

While Figure 6.2 shows the annual radiative forcing, Figure 6.3 shows the same data but plotted as cumulative radiative forcing, in units of Wm^{-2}, associated with emissions of GHGs in the biomass energy and non-use systems for woody mill residuals as a function of time. An explanation of the sources of this radiative forcing is provided in Table 6.2. Figure 6.3 shows that the differential radiative forcing is initially positive because the forcing due to the emissions from the biomass energy system is higher than that for the non-use system. The differential cumulative greenhouse gas impact quickly becomes negative, however, as landfill emissions increase in the non-use scenario. The figure shows that, under the typical scenario assumptions (e.g., alternative fate is 100% landfill), it takes 1.2 years before the cumulative radiative forcing due to GHG releases in the biomass energy system is less than the radiative forcing due to releases in the non-use system.

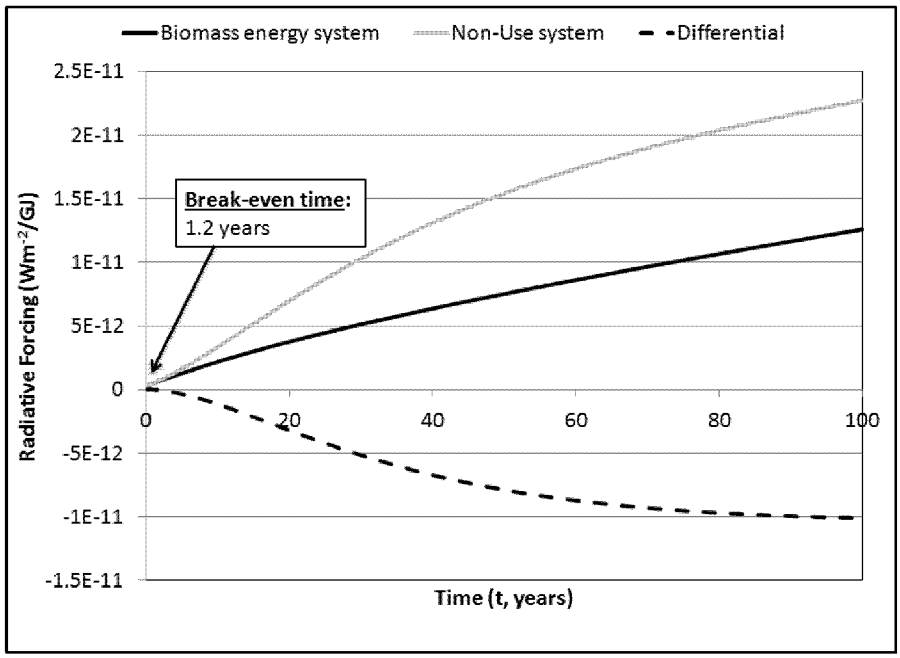


Figure 6.3 Cumulative GHG Impact for the Biomass Energy and Non-use Systems: Woody Mill Residuals - Typical Scenario

ED_000419-0008074

Table 6.2 Explanation of Cumulative Emissions, Woody Mill Residuals

Time (years)	Biomass Energy System	Non-Use System	Differential (i.e., biomass energy system minus non-use system)
t = 0	The woody residuals are burned, releasing GHGs, which result in radiative forcing at the time of combustion of 2.49E-13 Wm^{-2}.	The fossil fuels are burned, releasing GHGs, which result in radiative forcing at the time of combustion of 2.25E-13 Wm^{-2}. Biomass residuals are placed in landfills. There are no releases from the landfills at time 0.	The differential radiative forcing is positive (0.23E-13 Wm^{-2}) because at time 0, there is more forcing from the emissions released by the biomass energy system than from the non-use system.
$0 < t < 1.2$	There are no new emissions from the biomass energy system. The initially released GHGs remain in the atmosphere for a period of time, so each year, the cumulative radiative forcing increases.	Biomass residuals placed in landfills start to degrade, releasing GHGs. The cumulative GHG emissions, and their cumulative radiative forcing, increase rapidly.	The difference in cumulative radiative forcing decreases as the forcing associated with the non-use system increases more rapidly that that associated with the biomass energy system.
t = 1.2	Cumulative radiative forcing reaches 5.2E-13 Wm^{-2}.	Cumulative radiative forcing reaches 5.2E-13 Wm^{-2}.	The cumulative differential radiative forcing is 0 (break-even time).
$1.2 < t < \infty$	There are no new emissions from the biomass energy system but cumulative forcing continues to increase until all GHGs are removed from the atmosphere.	The emissions from the landfill continue for a considerable period. Cumulative radiative forcing continues to increase until all GHGs released from fossil fuel combustion and from disposal operations are removed from the atmosphere.	At 100 years, the difference in cumulative radiative forcing is -1.01E-11 Wm^{-2}. The difference changes only slowly after this point.

Figure 6.4 compares the timing of differential cumulative GHGI results obtained using the dynamic carbon footprinting approach with those obtained using IPCC 100-year GWPs, both in units of kg CO_2E. In both approaches, the difference in emissions between the two systems is computed for each year. The dynamic approach calculates the environmental impact in terms of the radiative forcing that is associated with GHGs remaining in the atmosphere attributable to all current and past emissions. Each year's forcing is added to past years to obtain cumulative radiative forcing. The IPCC approach calculates impact by assigning each year's emissions an impact equal to the cumulative radiative forcing occurring over 100 years, using 100-year GWPs. Both approaches consider the timing of emissions but only the dynamic approach accurately characterizes the timing of the warming associated with those emissions.

The first observation that can be made from Figure 6.4 is that the differential cumulative GHGI results decline faster when using the dynamic carbon footprinting approach than with IPCC GWPs. In other words, more short-term benefits from using biomass residuals for energy production are observed when applying dynamic carbon footprinting. The break-even time is 1.2 years using dynamic carbon footprinting and 7.5 years when using IPCC global warming potentials. The difference is due to the methane released from the landfills under the non-use scenario. Methane is a potent greenhouse gas but it has a short lifetime in the atmosphere so its greenhouse gas impact is

ED_000419-0008075

concentrated in the years immediately following its release, as opposed to carbon dioxide, which is much more persistent. This short-term warming effect of methane is captured by the dynamic approach but not by the use of 100-year GWPs.

Because both approaches are affected by the timing of emissions, and because methane emissions are higher in the earlier years of the simulation, both approaches show the benefits (i.e., negative differential impacts) increasing more rapidly in the early years. Because the 100-year GWPs approach is affected only by emissions timing, the curve flattens out as methane generation slows. In the case of the dynamic approach, the benefits accrue more rapidly in the early years but diminish later in the simulation as methane in the atmosphere decomposes to CO_2, exerting a lower radiative forcing effect and reducing the differences between the biomass energy and non-use systems. As methane generation ceases and all of the methane in the atmosphere decomposes to CO_2, the results for the two approaches converge.

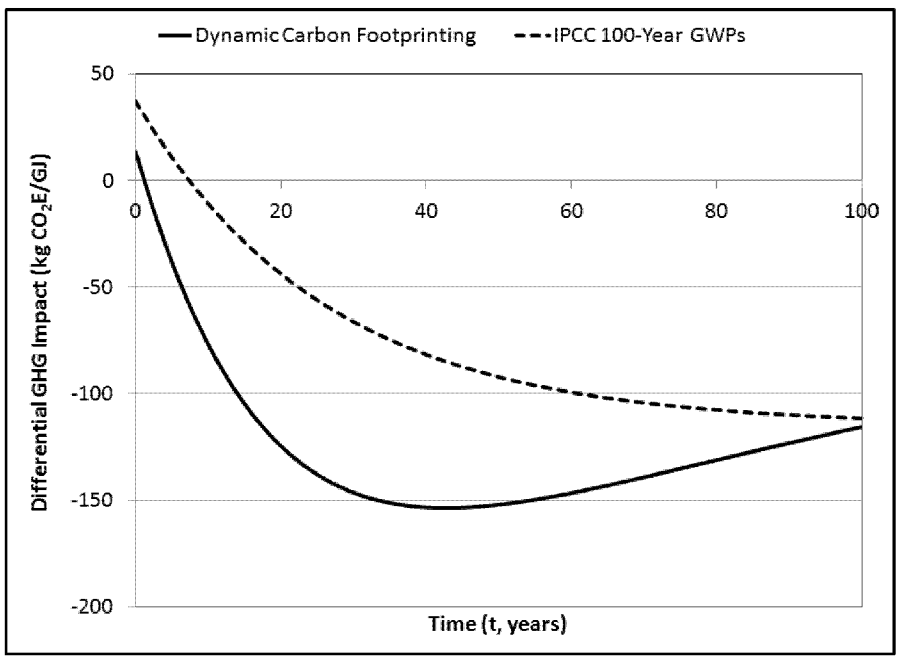


Figure 6.4 Emissions Timing: Comparing Results Based on Dynamic Carbon Footprinting and IPCC 100-Year GWPs

6.1.1.4 ***Consumption of Fossil Fuels***

Figure 6.5 shows the relative consumption of fossil fuels ("Relative FF CON," biomass energy system compared to non-use system). It can be seen from the figure that fossil fuel use in the biomass energy system is 100% lower; virtually no fossil fuels are used in the biomass energy system. It can also be seen from the figure that the main contributor to the difference between the systems is the heat from natural gas in the non-use system.

ED_000419-0008076

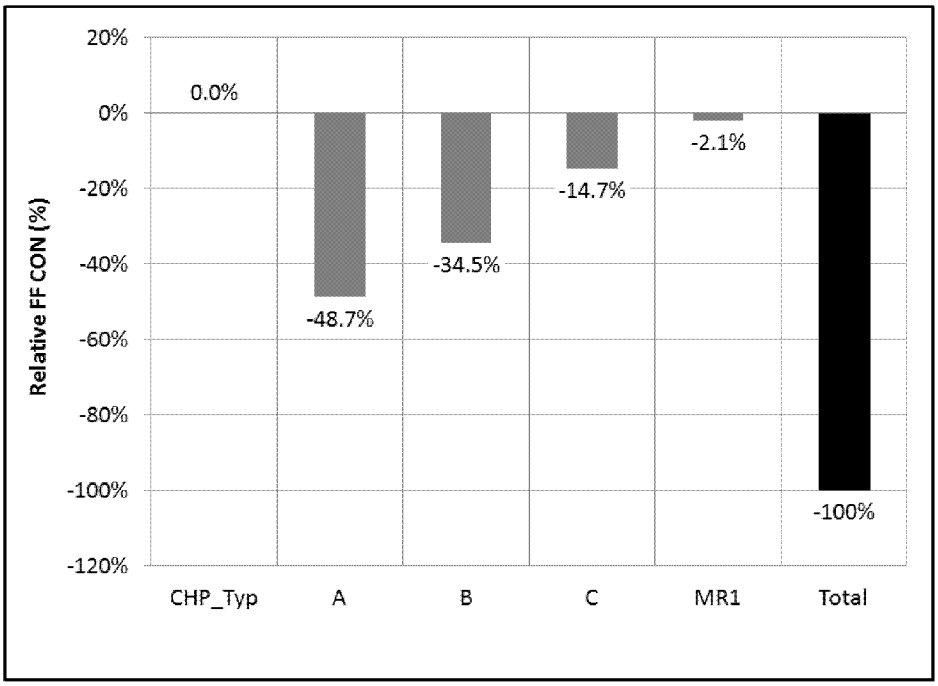


Figure 6.5 Relative Consumption of Fossil Fuels for Woody Mill Residuals - Typical Scenario [In the figure, the different components of the biomass energy system are depicted as follows: CHP system as described in Figure 5.3 (CHP_Typ). The components of the non-use system are depicted as follows: heat from coal (A), heat from natural gas (B), US average power grid (C), residual in landfills (MR1).]

6.1.2 Typical Scenario: Perturbation and Sensitivity Analyses

6.1.2.1 Perturbation Analyses

As mentioned in Section 4.1.3, sensitivity ratios represent the percent change in an output variable caused by a 1% change in one given input variable. For simplicity and given that the GHGI results do not vary significantly over a 100-year period depending on the approach used, perturbation analyses were performed using IPCC 100-year GWPs. Figure 6.6 shows the sensitivity ratios for the four indicators analyzed in this study, for woody mill residuals. The following input variables were tested in sensitivity analyses: transportation distance of the residuals (Distance), their water content (WC_R), their heating value (HHV), and the fraction of their carbon content that is non-degradable carbon (F_{CCND}).

The results depicted in Figure 6.6 should be interpreted as follows. A sensitivity ratio of +1.0 means that value of the output variable increases by 1% when the input variable value is increased by 1%. The greater the absolute value of the sensitivity ratio, the more intrinsically sensitive a parameter was.

It can be seen from Figure 6.6 that transportation distance of residuals to the boiler had very little effect on the "Differential GHGI" indicator results when compared to the other studied parameters. The fraction of non-degradable carbon (F_{CCND}) had the most significant effect on the results, with sensitivity ratios of 4.5. The positive ratio means that when increasing the value of the parameter, the indicator result is also increased, indicating a declining performance of the biomass energy system compared to the non-use system. Increasing the water content of the residuals, and thus reducing the boiler efficiency, produced a negative sensitivity ratio, i.e., a positive effect on the results. This is because on a per gigajoule basis, more residuals are required to produce the energy and thus more

ED_000419-0008077

landfilling, and associated methane emissions from landfills, are avoided. The opposite can be seen when increasing the higher heating value.

The time for the biomass energy system to have lower cumulative emissions than the non-use system ("break-even time" in Figure 6.6) was significantly affected, relatively speaking, by the various parameters analyzed, except for the transportation distance of residuals.

Finally, overall, the relative GHGI and relative fossil fuel consumption (FF CON) indicator results were not significantly affected by the parameters analyzed.

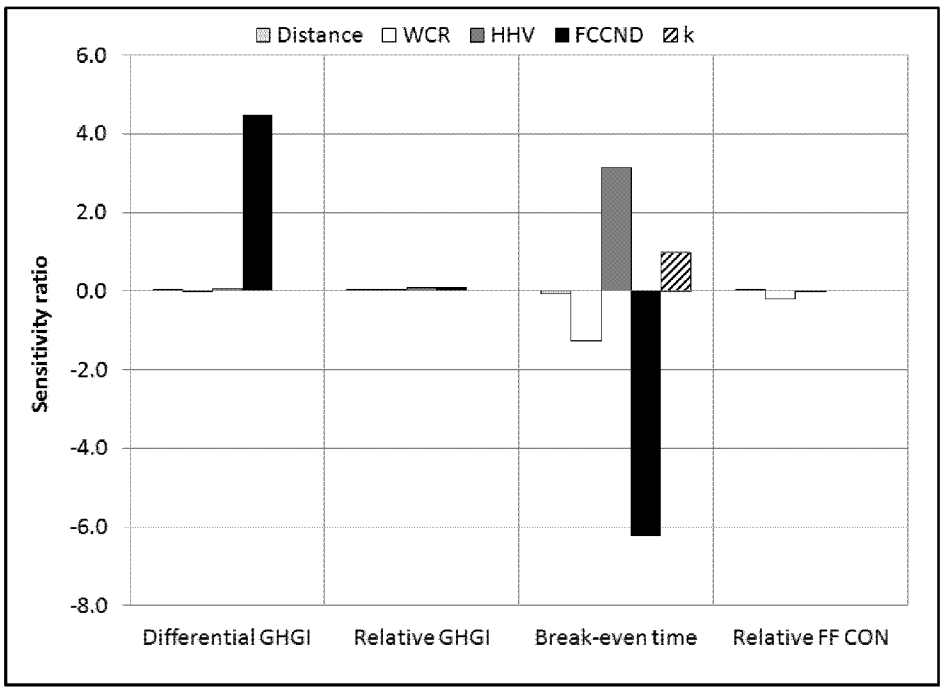


Figure 6.6 Sensitivity Ratios for Woody Mill Residuals

6.1.2.2 ***Sensitivity Analyses***

Table 6.3 shows the results of sensitivity analyses considering the actual possible ranges of variation for each parameter. It is shown that the range of the fraction of carbon in woody mill residuals that is non-degradable under anaerobic conditions (F_{CCND}) had the most effect on the results. With the higher fraction considered, smaller benefits are observed from the combustion of woody mill residuals, whereas with the lower value of F_{CCND}, benefits are far higher and break-even times far shorter than those calculated in the typical scenario.

ED_000419-0008078

Table 6.3 Sensitivity Analyses on Indicator Results for the Typical Scenario, Woody Mill Residuals

Para-meter	Differential GHGI* ($kg\ CO_2E/GJ$)			Relative Non-BioCO_2 GHGI* (%)			Break-Even Time* (years)			Relative FF CON (%)		
	Typ	Min	Max	Typ	Min	Max	Typ	Min	Max	Typ	Min	Max
WC_R	-111†	-110	-112	-98.7‡	-98.6	-98.8	7.5§	3.2	9.6	-100	-100	-100
HHV		-110	-115		-98.4	-98.8		1.1	17.6		-100	-100
F_{CCND}		-27.2	-286		-97.5	-99.2		3.2	22.0		-100	-100
Transp. of residuals		-109	-111		-97.8	-98.7		7.5	7.9		-98.2	-100
k		-94.1	-114		-98.6	-98.7		1.3	3.5		-100	-100

*Computed using IPCC 100-Year GWPs. †-116 kg CO_2E/GJ using dynamic modeling of cumulative radiative forcing. ‡ -98.7% using dynamic modeling of cumulative radiative forcing. §1.2 years using dynamic modeling of cumulative radiative forcing.

6.1.3 System Configuration Scenarios

In Section 5.0, various system configuration scenarios were presented. For instance, it was noted that the alternative fate of woody mill residuals was difficult to determine. System configuration scenarios were used to analyze those system configuration assumptions that were uncertain.

All possible scenario combinations presented in Section 5.1 were analyzed (132 combinations). The calculations were performed using IPCC 100-year GWPs. Results are presented in Table 6.4 for cases where parameters would be at their base case value. GHG releases and fossil fuel consumption are significantly lower for all scenarios. Maximum differences were obtained in scenarios in which

- there is no size reduction;
- combined heat and power with maximum power production is produced;
- coal is being displaced (for both heat and power production);
- there is no transportation; and
- alternative fate is landfilling.

Minimum differences were obtained in scenarios in which

- there is size reduction;
- only heat is produced;
- natural gas is being displaced (for both heat and power production);
- there is transportation; and
- alternative fate is incineration.

Results in Table 6.4 also show that the time for the biomass energy system to have lower cumulative emissions than the non-use system varies between 0 and 9.7 years, the lowest being observed when incineration is the alternative fate.

ED_000419-0008079

Table 6.4 Indicator Results for Various System Configuration Scenarios, Woody Mill Residuals

Indicator	Unit	Typical	Min	Max
Differential GHGI*	kg CO_2E/GJ	-111†	-78.4	-312
Relative non-BioCO_2 GHGI*	%	-98.7‡	-94.9	-99.3
Break-even time*	years	7.5§	0	9.7
Relative FF CON	%	-100%	-98.5	-100

*Computed using IPCC 100-Year GWPs. † -116kgCO_2E/GJ using dynamic modeling of cumulative radiative forcing. ‡ -98.7% using dynamic modeling of cumulative radiative forcing. §1.2 years using dynamic modeling of cumulative radiative forcing.

6.2 WWTP Residuals

This section presents results for the WWTP residuals.

6.2.1 Typical Scenario: Base Case Results

The typical scenario was first analyzed with all parameters at their base case values.

6.2.1.1 Greenhouse Gases: Differential GHGs

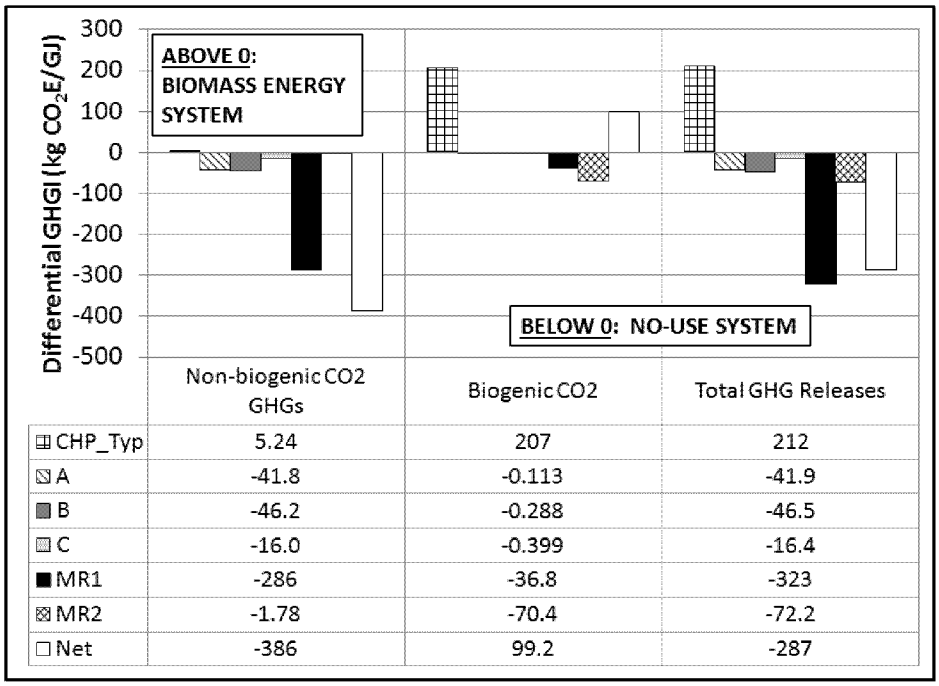
When using the dynamic carbon footprinting approach, the biomass energy system produces, after 100 years, a greenhouse gas impact that is **295 kg CO_2E lower**[15] per gigajoule of energy produced compared to the defined non-use system. This reduction is **287 kg CO_2E** when applying IPCC 100-year GWPs.

Figure 6.7 presents the 100-year differential GHGI for the biomass energy system compared to the non-use system as well as the contribution of each system component to the results using IPCC 100-year GWPs. In this figure, emissions from the non-use system are shown as a negative number because to obtain the Differential GHGs indicator overall result, the emissions of the non-use scenario were subtracted from those of the biomass energy system.

The figure shows that non-biogenic CO_2 GHGI is mostly lower because when burning residuals to produce energy, there are no methane emissions from landfills. The fact that there is less heat generated from fossil fuels also contributes to the lower impact, but to a lesser extent. Emissions of biogenic CO_2 are different in the two systems for two reasons. First, much of the biogenic carbon is released as methane in the non-use system (included within non-biogenic CO_2 GHGs) and mostly as CO_2 in the biomass energy system. Second, some of the carbon is stored in landfills in the non-use system.

[15] Results in this report are always presented as differences (i.e., biomass energy system minus non-use system). The "Relative GHGI" indicator does not include biogenic CO_2. The "Differential GHGI" indicator includes emissions and removals of biogenic CO_2.

ED_000419-0008080



	Non-biogenic CO2 GHGs	Biogenic CO2	Total GHG Releases
CHP_Typ	5.24	207	212
A	-41.8	-0.113	-41.9
B	-46.2	-0.288	-46.5
C	-16.0	-0.399	-16.4
MR1	-286	-36.8	-323
MR2	-1.78	-70.4	-72.2
Net	-386	99.2	-287

Figure 6.7 Contribution Analysis for the Differential GHGI (at 100 Years) for WWTP Residuals - Typical Scenario
[In the figure, the different components of the biomass energy system are depicted as follows: CHP system as described in Figure 5.4 (CHP_Typ). The components of the non-use system are depicted as follows: heat from coal (A), heat from natural gas (B), US average power grid (C), residual in landfills (MR1), incineration of residuals (MR2). Results reflect the use of 100-year GWPs.]

6.2.1.2 Greenhouse Gases: Relative Non-BioCO$_2$ GHGs

The result for the "Relative Non-BioCO$_2$ GHGs" indicator is -98.7%[16] (-99.1% using IPCC GWPs), meaning that the biomass energy system generates almost no GHGs when ignoring biogenic CO_2 and hence, produces a significant reduction when compared to the non-use system.

6.2.1.3 Greenhouse Gases: Timing of Impacts

When WWTP residuals are burned for energy, the related biogenic carbon is released to the atmosphere immediately. In contrast, WWTP residuals placed into landfills degrade slowly, releasing the related biogenic carbon (both CO_2 and CH_4) over time. Figure 6.8 presents the results of the "Differential GHGI" indicator over time using U.S. EPA's decay rates for materials placed in municipal landfills, for the typical scenario. These results were developed using the dynamic carbon footprinting approach described in Section 4.1.6.1 of this report and are expressed in units of radiative forcing (Wm^{-2}). The net difference is initially negative (i.e., the impact from the biomass energy system is lower than that from the no-use system from time equals zero, meaning that the break-even time is zero) and then declines over time as the material degrades in landfills. When using IPCC 100-year GWPS, the difference in impact is initially positive and the break-even time is observed at 1.8 years.

---

[16] Non-biogenic CO_2 GHGs only. Calculated as follows: (CHP_Typ - A - B - C - MR1- MR2)/ (A+B+C+MR1+MR2).

ED_000419-0008081

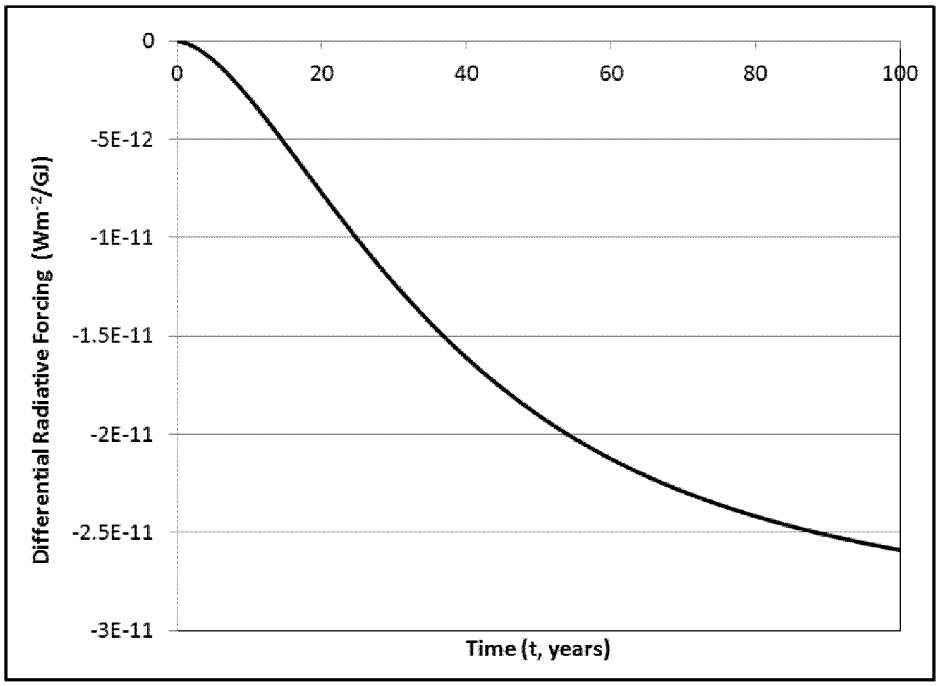


Figure 6.8 Cumulative Differential GHGI Indicator Results as a Function of Time for WWTP Residuals - Typical Scenario

6.2.1.4 ***Consumption of Fossil Fuels***

Figure 6.9 shows the results for the relative consumption of fossil fuels indicator ("Relative FF CON," biomass energy system compared to non-use system).

It can be seen from Figure 6.9 that the biomass energy system used 99.3% less fossil fuel when compared to the non-use system defined in this study. This is due to the fact that virtually no fossil fuels are used in the biomass energy system. It can also be seen from the figure that the main contributor to the lower emissions is avoided heat from natural gas.

ED_000419-0008082

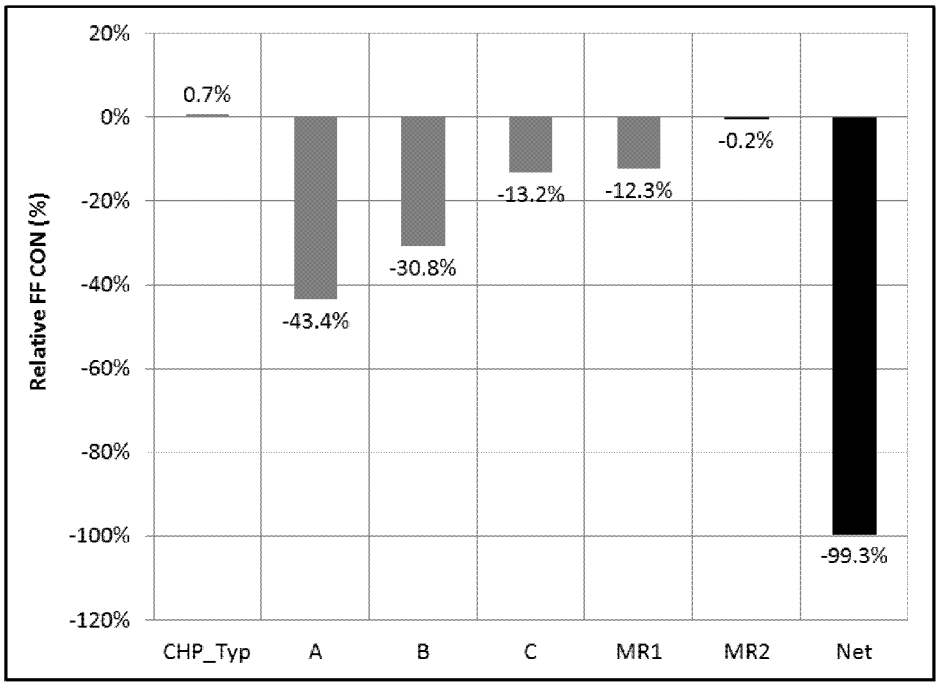


Figure 6.9 Relative FF CON Indicator Results for WWTP Residuals - Typical Scenario [In the figure, the different components of the biomass energy system are depicted as follows: CHP system as described in Figure 5.4 (CHP_Typ). The components of the non-use system are depicted as follows: heat from coal (A), heat from natural gas (B), US average power grid (C), residual in landfills (MR1), incineration of residuals (MR2).]

6.2.2 Typical Scenario: Perturbation and Sensitivity Analyses

6.2.2.1 Perturbation Analyses

Various parameters were analyzed in perturbation analyses. For each of these parameters, a sensitivity ratio was calculated (see Section 4.1.3). For simplicity and given that the GHGI results do not vary significantly over a 100-year period depending on the approach used, perturbation analyses were performed using IPCC 100-year GWPs.

Sensitivity ratios for the parameters tested in this study are presented in Figure 6.10. It can be seen from that figure that the carbon content of the residuals has the most significant effect on the GHGI results, with a sensitivity ratio of -1.3. The negative ratio means that when increasing the value of the parameter, the score is decreased, indicating an improving performance of the biomass energy system compared to the non-use system. The fraction of non-degradable carbon (F_{CCND}) also has a significant effect on the Differential GHGs results, with a sensitivity ratio of 1.1. The positive ratio means that when increasing the value of the parameter, the score is also increased, indicating a declining performance of the biomass energy system compared to the non-use system. Increasing the water content of the residuals, and thus reducing the boiler efficiency, produced a negative sensitivity ratio, i.e., a positive effect on the results. This is because on a per gigajoule basis, more residuals are required to produce the energy; thus, more landfilling and associated methane emissions from landfills are avoided. The opposite can be seen when increasing the higher heating value. Overall, Relative GHGs and fossil fuel consumption results were not significantly affected by the parameters analyzed. Break-even time was shown, relatively speaking, to be highly sensitive to all parameters tested, with the exception of the ash content.

ED_000419-0008083

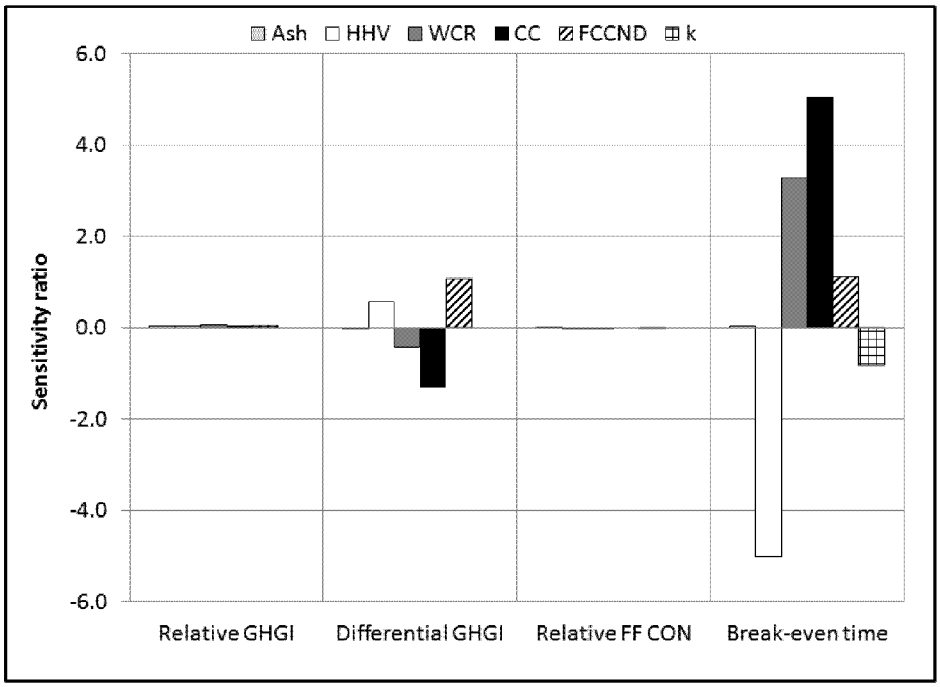


Figure 6.10 Sensitivity Ratios for WWTP Residuals

*6.2.2.2 **Sensitivity Analyses***

Above, perturbation analyses were applied to determine which parameters were intrinsically the most sensitive to the results without considering the actual ranges of possible values for these parameters. In Table 6.8, the results of sensitivity analyses considering the actual possible ranges of variation for each parameter are presented. It is shown that the range of possible heating values and carbon content for WWTP residuals had the most effect on the results. Also, even in the worst conditions, the GHG benefits of the biomass energy system compared to the non-use system are still considerable.

Table 6.5 Sensitivity Analyses on Indicator Results for the Typical Scenario, WWTP Residuals

Para-meter	Differential GHGI* (kg CO_2E/GJ)			Relative Non-BioCO_2 GHGI* (%)			Break-Even Time* (years)			Relative FF CON (%)		
	Typ	Min	Max	Typ	Min	Max	Typ	Min	Max	Typ	Min	Max
WC_R	-287†	-271	-310	-99.1 ‡	-98.6	-98.7	1.8§	1.0	3.0	-99.3	-99.2	-99.4
HHV		-242	-378		-98.5	-98.8		0	5.6		-99.0	-99.5
Ash		-287	-288		-98.5	-98.8		1.9	3.0		-98.8	-99.8
CC		-178	-309		-97.7	-98.8		0	3.0		-99.3	-99.3
F_{CCND}		-226	-349		-98.4	-98.8		1.6	2.4		-99.3	-99.3
k		-287	-287		-98.7	-98.7		1.3	3.5		-99.3	-99.3

*Computed using 100-year GWPs.†-295 kg CO_2E/GJ using dynamic modeling of cumulative radiative forcing. ‡-98.7% using dynamic modeling of cumulative radiative forcing. §0.0 years using dynamic modeling of cumulative radiative forcing.

ED_000419-0008084

6.2.3 System Configuration Scenarios

In Section 5.0, various system configuration scenarios were presented. All relevant scenario combinations were analyzed (40 combinations). Results are presented in Table 6.6 for scenarios where parameters would be at their base case values. Results obtained for the typical scenarios are also reproduced in this table for comparison purposes. GHG releases and fossil fuel consumption are significantly lower for all scenarios. Maximum differences were obtained in scenarios in which

- combined heat and power with maximum power production is produced;
- coal is being displaced (for both heat and power production); and
- alternative fate is landfilling.

Minimum differences were obtained in scenarios in which

- only heat is produced;
- natural gas is being displaced (for both heat and power production); and
- alternative fate is incineration.

Table 6.6 Indicator Results for Various System Configuration Scenarios - WWTP Residuals

Indicator	Unit	Typical	Min	Max
Differential GHGI*	kg CO_2E/GJ	-287†	-79.5	-589
Relative Non-BioCO_2 GHGs *	%	-99.1‡	-93.9	-99.3
Break-even time*	years	1.8§	0	6.4
Relative FF CON	%	-99.3	-99.1	-99.7

*Computed using 100-year GWPs.†-295 kg CO_2E/GJ using dynamic modeling of cumulative radiative forcing. ‡-98.7% using dynamic modeling of cumulative radiative forcing. §0.0 years using dynamic modeling of cumulative radiative forcing

6.3 Paper Recycling Residuals

6.3.1 Typical Scenario: Base Case Results

The typical scenario was first analyzed with all parameters at their base case values.

6.3.1.1 Greenhouse Gases: Differential GHGs

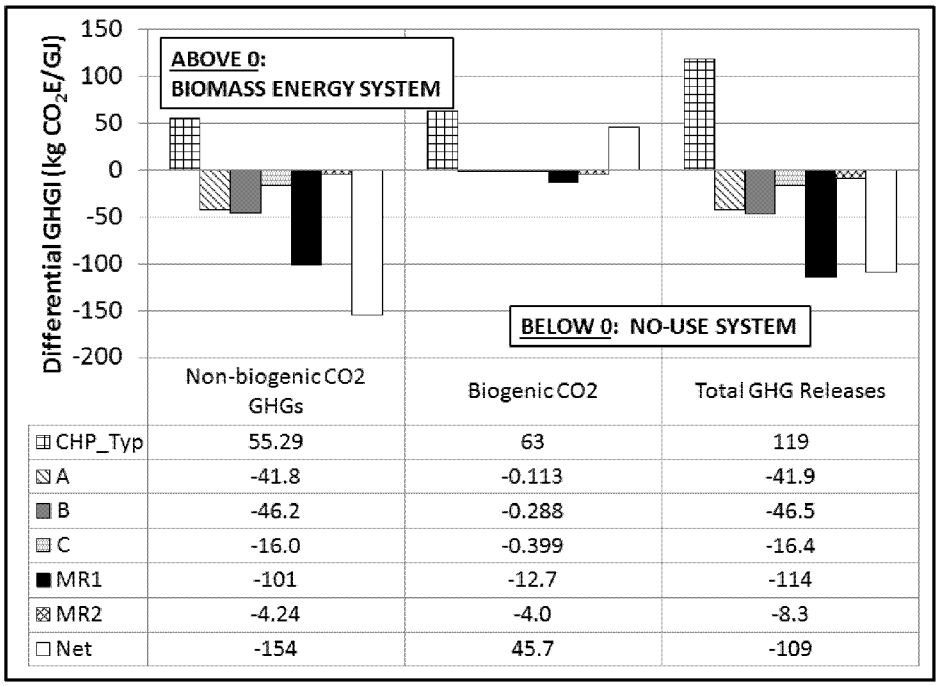
When using the dynamic carbon footprinting approach, the biomass energy system produces, after 100 years, a greenhouse gas impact that is **112 kg CO_2E lower**[17] per gigajoule of energy produced compared to the defined non-use system. This reduction is **109 kg CO_2E** when applying IPCC 100-year GWPs.

Figure 6.11 shows that the non-biogenic CO_2 GHGI is mostly lower because when burning residuals to produce energy, there are no methane emissions from landfills. Alone, the avoided methane emissions from landfills lower the impact by 154 kg CO_2E/GJ. The fact that there is less heat from fossil fuels also contributes to the lower impact, but to a lesser extent. Emissions of biogenic CO_2 are

[17] Results in this report are always presented as differences (i.e., biomass energy system minus non-use system). The "Relative GHGI" indicator does not include biogenic CO_2. The "Differential GHGI" indicator includes emissions and removals of biogenic CO_2.

ED_000419-0008085

different in the two systems for two reasons. First, much of the biogenic carbon is released as methane in the non-use system (included within non-biogenic CO_2 GHGs) and mostly as CO_2 in the biomass energy system. Second, some of the carbon is stored in landfills in the non-use system.



	Non-biogenic CO2 GHGs	Biogenic CO2	Total GHG Releases
CHP_Typ	55.29	63	119
A	-41.8	-0.113	-41.9
B	-46.2	-0.288	-46.5
C	-16.0	-0.399	-16.4
MR1	-101	-12.7	-114
MR2	-4.24	-4.0	-8.3
Net	-154	45.7	-109

Figure 6.11 Contribution Analysis for the Differential GHGI (at 100 Years) for Paper Recycling Residuals - Typical Scenario

[In the figure, the different components of the biomass energy system are depicted as follows: CHP system as described in Figure 5.5 (CHP_Typ). The components of the non-use system are depicted as follows: heat from coal (A), heat from natural gas (B), US average power grid (C), residual in landfills (MR1), incineration of residuals (MR2). Results reflect the use of 100-year GWPs.]

6.3.1.2 Greenhouse Gases: Relative Non-BioCO$_2$ GHGs

The result for the "Relative Non-BioCO$_2$ GHGI" indicator is -86.4%[18] (-75.2% when using IPCC GWPs), meaning that the biomass product system generates almost no GHGs when ignoring biogenic CO_2. When compared to other types of residuals presented above (woody mill residuals and WWTP residuals), the use of paper recycling residuals presents significantly lower overall benefits. This is because paper recycling residuals are composed of an important fraction of plastic which, when combusted, releases fossil fuel GHGs.

6.3.1.3 Greenhouse Gases: Emissions Timing

When paper recycling residuals are burned for energy, the biogenic carbon (both CO_2 and CH_4) is immediately released to the atmosphere. In contrast, residuals placed into landfills degrade slowly, releasing the carbon over time. Figure 6.12 analyzes the "Differential GHGI" indicator results over time using U.S. EPA's decay rate for materials placed in municipal landfills for the typical scenario.

[18] Non-biogenic CO_2 GHGs only. Calculated as follows: (CHP_Typ - A - B - C - MR1 - MR2)/ (A+B+C+MR1+MR2).

ED_000419-0008086

It shows that the differential impact is initially slightly negative (i.e., the impact from the biomass-based system is lower than that from the fossil fuel-based system, meaning that the break-even time is zero) and declines over time as the material degrades in landfills. When using the IPCC GWPs, the break-even time is also zero years.

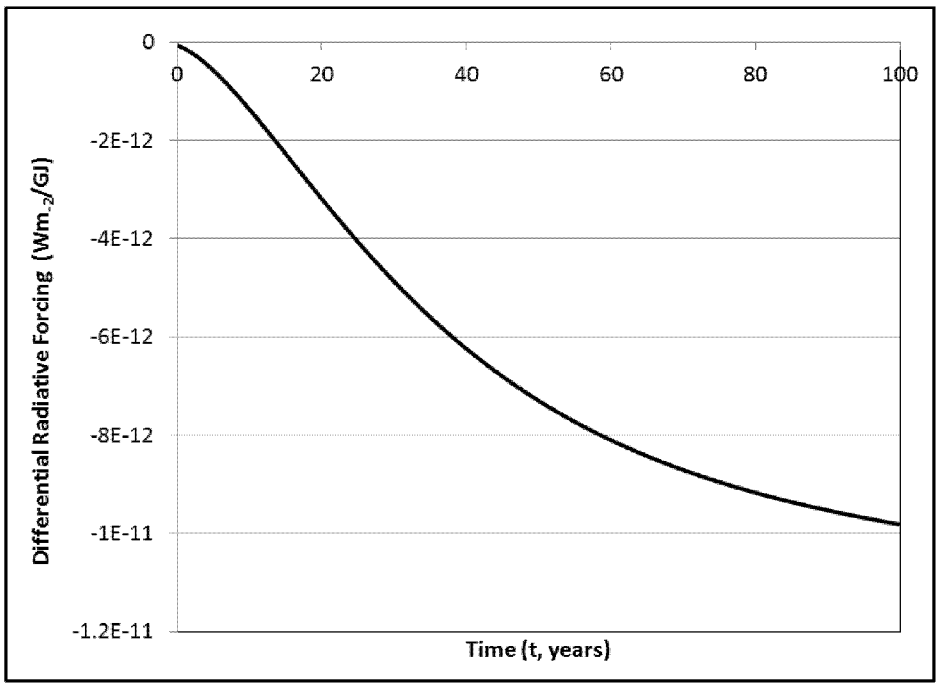


Figure 6.12 Cumulative Differential GHGI Indicator Results as a Function of Time for Paper Recycling Residuals - Typical Scenario

6.3.1.4 ***Consumption of Fossil Fuels***

Figure 6.13 shows the relative consumption of fossil fuels ("Relative FF CON," biomass energy system compared to non-use system) for paper recycling residuals.

It can be seen from that figure that the biomass energy system uses 99.9% less fossil fuel than the non-use system. This is due to the fact that virtually no fossil fuels are used in the biomass energy system. It can also be seen from the figure that the main contributor to the lower emissions is avoided heat from natural gas. Note that the plastic fraction of paper recycling residuals was not considered to be fossil fuel.

ED_000419-0008087

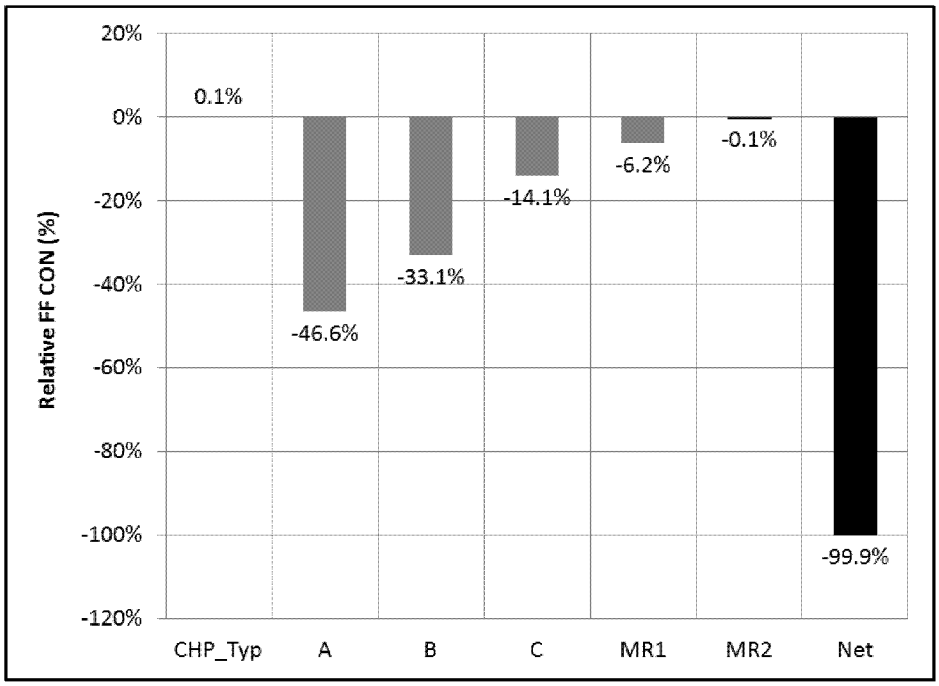


Figure 6.13 Relative Consumption of Fossil Fuels for Paper Recycling Residuals - Typical Scenario [In the figure, the different components of the biomass energy system are depicted as follows: CHP system as described in Figure 5.5 (CHP_Typ). The components of the non-use system are depicted as follows: heat from coal (A), heat from natural gas (B), US average power grid (C), residual in landfills (MR1), incineration of residuals (MR2).]

6.3.2 Typical Scenario: Perturbation and Sensitivity Analyses

6.3.2.1 Perturbation Analyses

Various parameters were analyzed in perturbation analyses. For each of these parameters, a sensitivity ratio was calculated (see Section 4.1.3). Sensitivity ratios for the parameters tested in this study are presented in Figure 6.14. Sensitivity ratios are not shown for break-even times as they were initially zero. It can be seen from Figure 6.14 that the fraction of non-degradable carbon (F_{CCND}) and the fiber fraction of paper recycling residuals have the most significant effect on the results, with sensitivity ratios up to 1.5. The positive ratio obtained for F_{CCND} means that when increasing the value of the parameter, the score is also increased, indicating a declining performance of the biomass energy system compared to that of the non-use system. Increasing the fiber fraction resulted in a negative sensitivity ratio. This means the biomass energy system generated lower emissions or consumed less fossil fuel than the non-use system. The water content of the residuals had little effect on the results compared to the other parameters. Finally, overall, fossil fuel consumption scores were not significantly affected by the parameters analyzed.

ED_000419-0008088

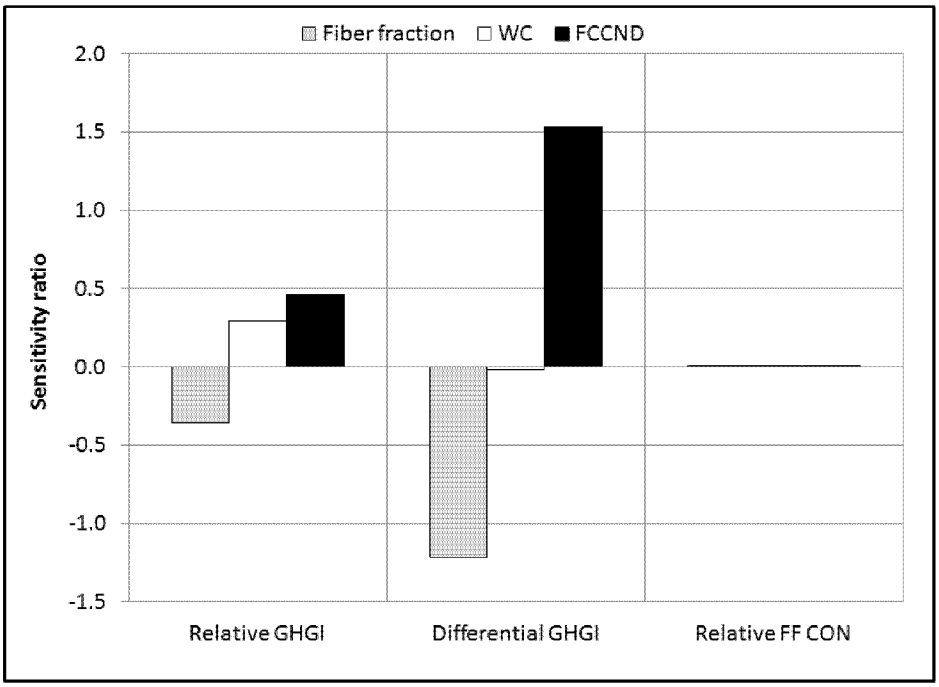


Figure 6.14 Sensitivity Ratios for Paper Recycling Residuals: Relative Non-BioCO_2 GHGs, Differential GHGs, and Relative FF CON

6.3.2.2 Sensitivity Analyses

Above, perturbation analyses were applied to determine which parameters were intrinsically the most sensitive to the results without considering the actual ranges of possible values for these parameters. In Table 6.7, the results of sensitivity analyses considering the actual possible ranges of variation for each parameter are presented. It is shown that the range of possible heating values for paper recycling residuals had the most effect on the results. Also, even with the highest heating value for residuals, the GHG benefits of the biomass energy system compared to the non-use system are still considerable.

Table 6.7 Sensitivity Analyses on Indicator Results for the Typical Scenario, Paper Recycling Residuals

Para-meter	Differential GHGI* (kg CO_2E/GJ)			Relative Non-BioCO_2 GHGI* (%)			Break-Even Time* (years)			Relative FF CON (%)		
	Typ	Min	Max	Typ	Min	Max	Typ	Min	Max	Typ	Min	Max
Fiber fraction	-109 †	-57.8	-191	-75.2 ‡	-49.6	-93.2	0§	0	2.3	-99.9	-99.9	-99.9
WC_R		-108	-109		-71.5	-75.1		0	3.4		-99.9	-99.9
FCCND		-109	-166		-75.2	-78.7		0	0		-99.9	-99.9
K		-109	-109		-75.2	-75.2		0	-0.7		-99.9	-99.9

*Computed using 100-year GWPs. †-112 kg CO_2E/GJ using dynamic modeling of cumulative radiative forcing. ‡-86.4% using dynamic modeling of cumulative radiative forcing. §0 years using dynamic modeling of cumulative radiative forcing.

ED_000419-0008089

6.3.3 System Configuration Scenarios

In Section 5.0, various system configuration scenarios were presented. All relevant scenario combinations were analyzed (40 combinations). Results are presented in Table 6.8 for scenarios where parameters would be at their base case values. Results obtained for the typical scenarios are also reproduced in that table for comparison purposes. The biomass energy system resulted in lower GHG releases and fossil fuel consumption in all scenarios. Maximum differences were obtained in scenarios in which

- the fiber fraction of paper recycling residuals is higher;
- combined heat and power with maximum power production is employed;
- coal is being displaced (for both heat and power production); and
- alternative fate is landfilling.

Minimum differences were obtained in cases in which

- the plastic fraction of paper recycling residuals is higher;
- only heat is produced;
- natural gas is being displaced (for both heat and power production); and
- alternative fate is incineration.

Table 6.8 Indicator Results for Various System Configuration Scenarios - Paper Recycling Residuals

Indicator	Unit	Typical	Min	Max
Differential GHGs*	kg CO_2E/GJ	-109†	-82.9	-316
Relative GHGs *	%	-75.2‡	-62.5%	-86.3%
Break-even time*	years	0§	0	7.6
Relative FF CON	%	-99.9	-99.9	-100

*Computed using 100-year GWPs. †- 112 kg CO_2E/GJ using dynamic modeling of cumulative radiative forcing. ‡-86.4% using dynamic modeling of cumulative radiative forcing. §0 years using dynamic modeling of cumulative radiative forcing.

6.4 Black Liquor

In a previous study by NCASI (Gaudreault et al. 2012, NCASI 2011b), the benefits of recovering black liquor for production of energy and pulping chemicals that would otherwise need to be produced from other resources were analyzed. In that study, it was determined that developing a detailed model of the alternative fate of black liquor would have required too much speculation because black liquor is not disposed of. Its use in the kraft recovery cycle is integral to pulp production. Nonetheless, it was reasonable to assume that alternative management would involve returning the biogenic carbon in the liquor to the atmosphere, perhaps via incineration (in which case the carbon is emitted immediately), or aerobic wastewater treatment (in which case the carbon would be emitted over a period of hours to months depending on the type of treatment system in use). In either case, the carbon is returned to the atmosphere far too quickly to make carbon storage a significant factor in the calculations. To be conservative, it was also assumed that all of the carbon in the black liquor would be emitted as CO_2. If, in the alternative management scenario, some of the carbon was emitted as methane, the benefits of using black liquor in the kraft recovery cycle would be larger than estimated in the study.

The detailed results obtained for black liquor can be found in NCASI (2011b) and Gaudreault et al. (2012). These are summarized in Table 6.9. At the time of this earlier study, no dynamic carbon footprint approach was applied and the results were not limited to 100 years. The break-even time

ED_000419-0008090

would remain zero using dynamic carbon footprinting but limiting the analysis to 100 years would slightly reduce the GHG benefits.

Table 6.9 Summary of Indicator Results for Black Liquor

Indicator	Unit	Typical	Min	Max
Differential GHGI*	kg CO_2E/GJ	-182 (184‡)	-97.9	-192
Relative Non-BioCO_2 GHGI*	%	-90.5	-69.0	-92.4
Break-even time*,†	years	0	Not available	
Relative FF CON	%	-89.8	-71.1	-90.7

* Based on 100-year GWPs. † Break-even time was not analyzed in NCASI (2011b) and Gaudreault et al. (2012). However, assuming that the most likely alternative fate for black liquor is incineration, consistent with the conservative assumption made regarding carbon emission from this alternative fate, the break-even time would be zero years. ‡Computed using dynamic cumulative radiative forcing.

6.5 Comparison of the Residuals

Figure 6.15 compares the GHG benefits for the different types of biomass residuals on 1) a functional unit basis (i.e., 1 GJ of energy), and 2) a tonne of residual basis. "Differential GHGs" indicator results are depicted for the biomass energy system compared to the non-use system.

The figure shows that producing 1 GJ of energy using WWTP residuals produces greater benefits than does using woody mill residuals. This may seem counterintuitive, as WWTP residuals are a fuel of lesser quality than woody biomass residuals. This result was obtained because to produce 1 GJ of energy, more WWTP residuals are needed than when using woody biomass residuals, which also means diverting more WWTP residuals from landfills and hence avoiding more methane emissions. Paper recycling residuals generated relatively lower benefits than woody mill residuals and WWTP residuals on a per GJ basis. This was due to the plastic fraction of the residuals, which produce fossil fuel GHGs when burned.

On a per tonne of residual basis, fuels with higher HHV, lower water content, and greater degradable fraction in landfills led to greater benefits. The plastic fraction of paper recycling residuals was also an important factor explaining the lower benefits observed for this material.

ED_000419-0008091

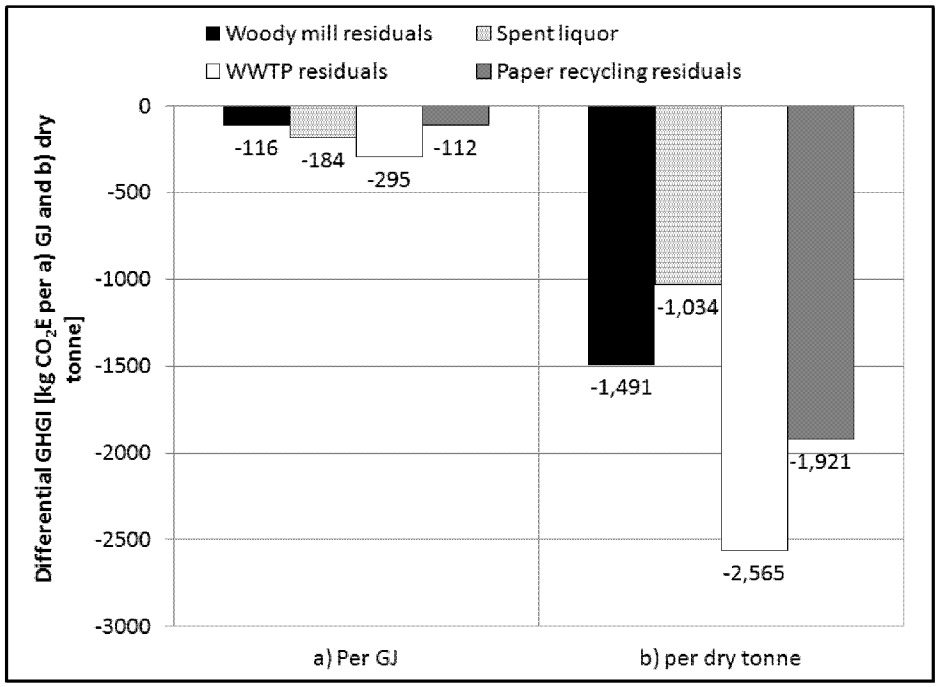


Figure 6.15 Comparison of the Differential Releases for the Different Residual Types a) per Gigajoule, b) per dry Tonne

It is also possible to use the numbers presented in Table 6.14 below to calculate typical scenario weighted average indicator results for all residuals included in this study. In calculating these averages, it was assumed that the results were the same for other spent liquor as for black liquor. Residuals other than black liquor and those analyzed in this study were not included. The weighted average results are presented in Table 6.10.

Table 6.10 Weighted Average Indicator Results, Typical Scenarios, Life Cycle Results

Indicator	Unit	Weighted Average Result (all manufacturing residuals)	
		Dynamic Carbon Footprint	IPCC GWPs
Differential GHGI	kg CO_2E/GJ	-158	-155
Relative non-bioCO_2 GHGI	%	-93.7%	-94.3%
Break-even time	Years	0.5	2.9
Relative FF CON	%	-93.8%	-93.8%

6.6 Additional Sensitivity Analysis on Air Emission Control Equipment

As mentioned in Section 5.1.2.1, it was assumed in this study that the difference in energy requirements for air emission control was negligible for boilers combusting biomass residuals, coal, and/or natural gas. There is very little information available regarding air emission control device energy requirements and what information is available is rarely in a format that is usable for this study. Some of the available information is summarized in Table 6.11. Table 6.12 presents common air emission control equipment used for various boiler types within the forest products industry.

ED_000419-0008092

Based on the information in Table 6.11 and Table 6.12, two sensitivity analyses were performed to test the significance of the differences in control equipment and are summarized in Table 6.13. The results of the sensitivity analyses, presented in Figure 6.16, indicate that neglecting the differences in energy requirements for air emission control has likely led to a slight overestimation (of less than 3%) of the benefits related to the biomass energy system, especially in the context of fossil fuel consumption benefits.

Table 6.11 Power Consumption for Various Air Emission Control Devices

Air Emission Control Equipment	Power Consumption (% of energy output)	Applicability	Reference
Electrostatic precipitator	0.1 - 1.8%	Power utilities	European Commission (2006)
	0.2%*	Heat from coal	NCASI (1998)
	0.3%†	Heat from biomass	NCASI (1998)
	≈ 0.6%	Heat from coal‡	USEPA (2002)
Wet scrubber	≤ 3.0%	Power utilities	European Commission (2006)
Dry scrubber	0.3% - 1.0%	Power utilities	European Commission (2006)
	0.5% - 1.0%	Heat production	Kitto (1996)
Unspecified scrubber	1.0%*	Heat from coal	NCASI (1998)
	1.0%†	Heat from biomass	NCASI (1998)
Selective catalytic reduction (SCR)	0.5%	Power utilities	European Commission (2006)
Selective non-catalytic reduction (SNCR)	0.1 - 0.3%	Power utilities	European Commission (2006)

*Assuming 0.04 - 1.3 W/acfm, 0.5 acfm/(lb steam/hr) and 1.52E-03 GJ/lb steam. †Assuming 0.04 - 1.3 W/acfm, 0.92 acfm/(lb steam/hr) and 1.27E-03 GJ/lb steam. ‡Assuming 8640 hr/yr, 0.06$/kWh, 9780dscf/MMBtu, 3% O_2 at T=325°F.

Table 6.12 Common Combustion-Related Air Emission Control Equipment

Fuel Burned	Most Common Control Equipment
Coal	ESP, low NO_x burner
Biomass	ESP, wet scrubber (newer boilers have SNCR for NO_x control)
Natural gas	Low NO_x burner, flue gas recirculation

Table 6.13 Sensitivity Analyses on Air Emission Control Equipment

#	Electricity Consumption for Air Emission Control (% of heat output)		
	Biomass	Natural Gas	Coal
S1	0.3%	0.0%	0.2%
S2	2.1%	0.0%	1.8%

ED_000419-0008093

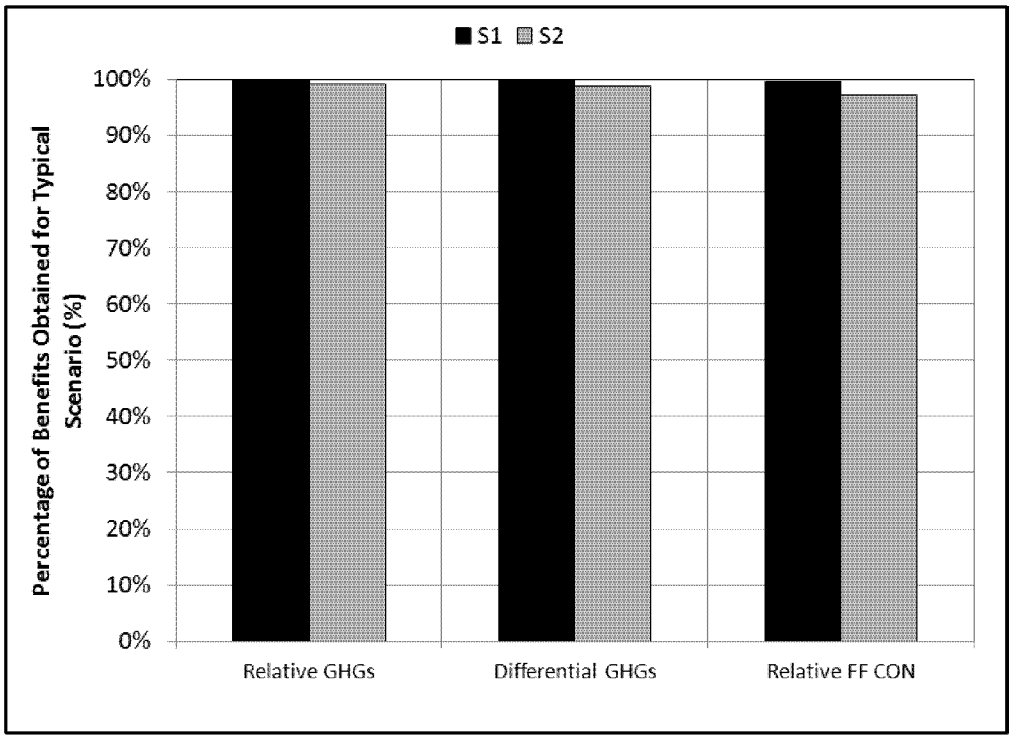


Figure 6.16 Sensitivity Analyses on Air Emission Control Equipment - Manufacturing-Related Woody Biomass Residuals - Typical Scenario

6.7 Life Cycle Results in Context

In this study, the life cycle GHG emissions and non-renewable energy consumption associated with the US forest products industry's use of biomass residuals (biomass energy system) have been compared to the GHG emissions and the non-renewable energy consumption that would occur if fossil fuels were used instead (non-use system). The results have been calculated in terms of the differences between these two systems, expressed in terms of value chain GHG emissions. In this section of the report, the calculated GHG benefits are put in the context of total emissions from the forest products industry value chain.

Table 6.13 presents data that allow calculation of the greenhouse gas benefits of using biomass residuals for energy generation. From this table, it can be seen that kraft black liquor and woody mill residuals represent 24.3% and 34.6%, respectively, of the total energy used by the industry, for an overall total of 58.9%.

ED_000419-0008094

Table 6.14 Various Contextual Data Regarding the US Forest Products Industry

Element	Value			Reference
Total energy consumption	2.58E9 GJ/yr			2010 data collected by AF&PA, NCASI, and AWC and scaled up to total US production* Total energy includes purchased power
Fraction of energy from various sources (may not sum to 100% due to rounding)	**Source**	**Biomass Energy**	**Total Energy**	2010 data collected by AF&PA, NCASI, and AWC and scaled up to total US production*
	Black liquor	52.3%	34.6%	
	Other spent liquor	4.6%	3.0%	
	Woody mill residuals	36.8%	24.3%	
	WWTP residuals	0.63%	0.42%	
	Paper recycling residuals	0.05%	0.03%	
	Others	5.7%	3.9%	
	Fossil fuels	N/A	33.7%†	
GHG benefits from black liquor recovery	Base Case	184 kg CO_2E/GJ in steam		The base case was recalculated in this report; min and max are from Gaudreault et al. (2012)
	Min	98 kg CO_2E/GJ in steam		
	Max	192 kg CO_2E/GJ in steam		
Value chain emissions of the US forest products industry	Scope 1	64.6 million tonnes CO_2E/yr (62.0 million tonnes CO_2E/yr from fossil fuels use)		Heath et al. (2010)
	Scopes 2 and 3	147 million tonnes CO_2E/yr		
	Net biogenic carbon flows	-109 million tonnes CO_2E/yr		
	Net value chain emissions	104 million tonnes CO_2E/yr		

*Together, AF&PA, NCASI, and AWC members comprise 96% of total US pulp production, 86% of total paper and paperboard production and 36% of wood products production. † Including purchased electricity, based on the energy content at the fence line (i.e., 3412 BTU per kWh) and assuming that it is 100% fossil fuel-based.

Based on the data in Table 6.10 and Table 6.14, it is possible to estimate the increase in value chain emissions that would accompany the forest products industry's changing from biomass manufacturing residuals (including black liquor) for energy to fossil fuels. Overall, the use of biomass manufacturing residuals (including black liquor) in the forest products industry for one year avoids, for typical scenarios, the emission of 181 million tonnes CO_2E. In an earlier study, it was determined that direct emissions of GHGs from fossil fuel combustion in the US forest products industry in 2004 were approximately 65 million tonnes CO_2E per year (Heath et al. 2010). The use of biomass-based manufacturing residuals for one year, therefore, avoids a quantity of GHG emissions approximately three times the annual fossil-fuel related direct GHG emissions from the forest products industry.

ED_000419-0008095

7.0 RESULTS AND DISCUSSION: ADDITIONAL ANALYSES

This section presents the results of the gate-to-gate analysis of biogenic GHGs and the analysis of the emissions of GHGs in the context of ongoing practices.

7.1 Gate-to-Gate Analysis of Biogenic GHGs

All the results presented above were computed using a life cycle approach that considered the fossil fuels being displaced by biomass residuals. The typical scenarios for the two product systems (one system using biomass for energy and the other system managing it by some other means) have also been compared in terms of the emissions coming directly out of the units receiving the residuals (i.e., combustion units or landfills). In this analysis, the benefits of fossil fuel substitution were ignored. For this gate-to-gate analysis, paper recycling residuals were analyzed in terms of their fiber fraction only.

Gate-to-gate Differential GHGI results are summarized in Table 7.1. These show that, even in this highly constrained analysis, using the biomass residuals for energy generation resulted in reductions in GHG releases. The results in Table 7.1 also highlight the effects of using dynamic modeling of radiative forcing instead of 100-year GWPs, with the effects being especially significant on estimated break-even times. A significant fraction of the emissions benefits were attributable to avoidance of landfill methane. A previous, similarly constrained analysis on black liquor assumed that the alternative management would likely involve returning the biogenic carbon in the liquor to the atmosphere. In order to be conservative, in that study, it was assumed that the carbon would return to the atmosphere as CO_2 via incineration or treatment in aerobic wastewater treatment plants. This resulted in net zero GHG releases for energy production from black liquor compared to an alternative fate. When not considering fossil fuel substitution, the weighted average reduction in GHG emissions considering all residuals is 4.6 kg CO_2E/GJ.

Because the benefits of displacing fossil fuels are not included, the times required for cumulative emissions impact from the biomass energy system to fall below the cumulative emissions impact from the non-use system are longer than calculated earlier in this report. Depending on the residual, it required 0 to 19.5 years for the cumulative emissions impact from the biomass system to become lower than the cumulative emissions impact from the non-use system.

A sensitivity analysis was also performed that uses the IPCC default value of 50% (instead of 77% in the typical scenario) for the percentage of carbon in woody mill residuals that is non-degradable under landfill anaerobic conditions. These results, presented in parentheses in Table 7.1, show that the results are highly affected by this parameter.

ED_000419-0008096

Table 7.1 Results of the Gate-to-Gate Analysis of Biogenic GHGs

Residual Type	Differential GHGs over 100 Years (kg CO_2E/GJ)		Break-Even Time (years)	
	Dynamic CF	IPCC 100-Year GWPs	Dynamic CF	IPCC 100-Year GWPs
Woody mill residuals	-8.5 (-187)†	-5.1	19.5 (6.6) †	77.0
WWTP residuals	-190	-182	5.9	13.4
Fiber fraction of paper recycling residuals*	-132	-126	7.7	18.2
Spent liquor (incl. black liquor)	0	0	0	0
Weighted average	-4.6 (-74.2) †	-3.3	7.6 (2.6) †	30.1

*In addition to biomass, paper recycling residuals contain plastics which are produced from fossil fuels. For the purpose of the biomass carbon fate analysis, only their fiber fraction was considered. †Numbers in parentheses were derived using IPCC default for fraction of carbon that is non-degradable under anaerobic conditions, that is 50% instead of 77%.

7.2 GHG Emissions from Ongoing Use of Residuals for Energy Production

Table 7.2 shows the times required for cumulative emissions from a facility using residuals for energy to be equal to the emissions from a facility disposing of the residuals, both for the cradle-to-energy (including fossil fuel substitution) and gate-to-gate (excluding fossil fuel substitution) analyses. The results are presented for the dynamic carbon footprint approach only. The table also indicates when in the past the ongoing practice would need to have begun in order for the cumulative emissions from the two systems to be equal in 2014. The table includes text describing the practices in the industry at points in the past. It should be noted that there is considerable uncertainty in the estimates of break-even times, especially where fossil fuel substitution is ignored. This is because, in cases where fossil fuel substitution benefits are ignored, the curve describing the difference in cumulative emissions between the two scenarios is relatively flat as it approaches zero (because the initial difference between the scenarios is large). The break-even time is equal to the point at which the curve passes through zero, so the results are sensitive to small changes in assumptions, particularly assumptions about landfill decay and methane production. By contrast, where fossil fuel substitution is considered, the curve is steeper where it passes through zero because of the smaller initial difference between the two scenarios, thus reducing the uncertainty about break-even time.

ED_000419-0008097

Table 7.2 The Use of Residuals for Energy as an Ongoing Practice

Residual		Years For Emissions from Facility Using Residuals for Energy on an Ongoing Basis to Be Equal to Emissions from a Facility Disposing of These Residuals (Under Typical Scenario)	Year in the Past When Ongoing Practice Would Have Had to Be Initiated for Emissions from the Two Facilities to Be Equal at the in 2014 (Under Typical Scenario)	Past Industry Practice in Using the Residuals for Energy
Woody mill residuals	w/ benefits of the displaced fossil fuels (cradle-to-energy)	1.9 (0.9)*	2012 (2013)*	The literature mentions the use of wood residuals in boilers used for wood drying at sawmills going back to at least 1920 and in steam engines in sawmills going back to the mid-1800s. Based on AF&PA statistics, in 1971, woody mill residuals represented 7% of the fuel (16% of the biomass) burned at pulp and paper mills. By 1980, this had increased to 11% of the fuel (21% of the biomass). Between 1987 and 1999, it varied between 15% and 18% of the fuel (25% to 29% of the biomass).
	w/o benefits of the displaced fossil fuels (gate-to-gate)	34.5 (10.4)*	1979 (2003)*	
WWTP residuals	w/ benefits of the displaced fossil fuels (cradle-to-energy)	0	2014	NCASI statistics on WWTP residuals management go back to 1979, at which point 11% of these residuals was being burned for energy. By 1988, this had increased to 21%.
	w/o benefits of the displaced fossil fuels (gate-to-gate)	9.3	2004	

(Continued on next page. See notes at end of table.)

ED_000419-0008098

Table 7.2 (Cont'd)

Residual		Years For Emissions from Facility Using Residuals for Energy on an Ongoing Basis to Be Equal to Emissions from a Facility Disposing of These Residuals (Under Typical Scenario)	Year in the Past When Ongoing Practice Would Have Had to Be Initiated for Emissions from the Two Facilities to Be Equal in 2014 (Under Typical Scenario)	Past Industry Practice in Using the Residuals for Energy
Paper recycling residuals	w/ benefits of the displaced fossil fuels (cradle-to-energy)	0	2014	There are different types of recycling residuals generated by mills using recovered paper. Some of these are combined with WWTP residuals and managed similarly to what is described above; i.e., in 1979 11% of WWTP residuals were burned for energy, increasing to 21% in 1988. OCC rejects, however, are often managed separately. NCASI has published information showing that using recycling residuals for energy started as early as 1975.
	w/o benefits of the displaced fossil fuels (gate-to-gate)	12.2	2001	
Spent liquor (incl. black liquor)	w/ benefits of the displaced fossil fuels (cradle-to-energy)	0	2014	Based on AF&PA statistics, in 1971, 35% of the fuel (84% of the biomass) burned at pulp and paper mills was black liquor. By 1980, this had increased to 40% of the fuel (79% of the biomass). Between 1987 and 1999, it varied between 43% and 46% of the fuel (71% to 75% of the biomass).
	w/o benefits of the displaced fossil fuels (gate-to-gate)	0	2014	

*Numbers within brackets were derived using IPCC defaults for the fraction of carbon in woody mill residuals that does not degrade under anaerobic conditions (50%) rather than that of U.S. EPA (77%).

ED_000419-0008099

8.0 UNCERTAINTY AND LIMITATIONS

This section provides further interpretation of the robustness of the results presented above.

8.1 Data Accuracy and Uncertainty

Evaluating data accuracy and uncertainty is an important aspect of LCA studies. An LCA is a complex model made up of thousands of data points and the accuracy of these data can significantly affect the results. Analyzing the uncertainty of such a complex model is not straightforward. Techniques such as Monte Carlo analysis can be used to evaluate uncertainty, but an important challenge is the lack of uncertainty data for the different variables that comprise the LCA model. Therefore, in many cases, the robustness of the results and conclusions of LCA studies are assessed using other methods. In this study, the parameters with potential effects on the results were analyzed using sensitivity analyses covering their most probable range of variation and results were discussed given these variations. However, without comprehensive uncertainty data, it was impossible to quantitatively assess the statistical significance of the differences between the compared systems.

The data collection process met the data quality goals as set out in Section 4.4.

8.2 Limitations

The main limitations of this study are summarized in this section. They relate primarily to the conformity of the study with ISO LCA standards (ISO 2006a, b) and to the data used and assumptions made.

8.2.1 ISO Conformity

As mentioned previously, a streamlined LCA methodology was used in this study. As a consequence, it was not possible to fully comply with ISO 14044 requirements for comparative assertions disclosed publicly. The main non-conformances are outlined below.

- Although the assumptions, models, and results were reviewed by a committee of stakeholders, no formal external critical review was performed.
- While the Standard requires that for studies intended to be used for publicly disclosed comparative assertions, a sufficiently comprehensive set of impact categories be employed, only two were used in this study, in accordance with the study objective.
- No formal uncertainty analysis was performed.

In addition, the gate-to-gate analyses need to be understood as additional information rather than as an LCA result.

8.2.2 Data and Assumptions

Some of the generic data sets used in this study were not specific to the US, although the study employed a version of these data sets modified to use US electricity production.

The relevant characteristics related to the residuals analyzed in this study are typically quite variable. This variability was analyzed in sensitivity analyses and results were shown for range of characteristic values sufficiently large to cover most of the variability.

The data identified for size reduction were fixed on a per tonne basis and did not account for the extent of size reduction. That said, size reduction was not found to significantly affect the study results.

ED_000419-0008100

Several assumptions were made regarding WWTP residuals that could have affected the study results. The main ones are discussed here.

- It was assumed that mechanical dewatering can achieve 40% solids, that this was sufficient for combustion, and that the same level of dewatering was also suitable for transporting them to a landfill disposal site. The main reason for this assumption was that no data were available concerning the energy consumption for additional dewatering. Assuming additional dewatering would have had two main effects on the results. First, this would have decreased the overall performance of the biomass energy system by increasing its consumption of energy and related releases. Second, assuming drier WWTP residuals would have increased boiler efficiency, and thus reduced the quantity of residuals required to produce 1 GJ of energy, which would have resulted in lower benefits when analyzing the results on a per gigajoule basis, but greater benefits on a per tonne of residuals basis.
- It was also assumed that WWTP residuals would be co-fired with bark in a 20:80 ratio. Based on this ratio, a boiler efficiency was calculated. Increasing the share of residuals in the mix burned would have decreased the boiler efficiency, while decreasing their share would have increased the efficiency. The effect of boiler efficiency on the results was discussed immediately above. The relationship between the share of WWTP residuals burned and boiler efficiency is also uncertain. The best available information was used.

Because paper recycling residuals are made up of a mix of materials that have characteristics similar to WWTP residuals (negative effect on boiler efficiency compared to woody biomass residuals) and plastic (positive effect on boiler efficiency compared to woody biomass residuals), it was assumed that paper recycling residuals would be burned in boilers with the same efficiency as woody biomass residuals at a given water content. Boiler efficiencies for these kinds of material are not known, however. The effect of boiler efficiency on the results was discussed above. Also, OCC rejects were considered to be representative of paper recycling residuals in general. In cases where, for instance, the plastic fraction of other paper recycling residuals is outside the range studied in this study, results would be slightly different. However, a broad range of characteristics was examined in this study to account for these potential variances.

The best available data for energy production using fossil fuels were used. These data were deemed representative of average US conditions. No sensitivity analyses were performed on that part of the modeling. As a consequence, the results of the study cannot be generalized to a broader set of conditions regarding energy production from fossil fuels. Also, it was assumed that the difference in energy requirements for air emissions control would not vary significantly from one fuel to another. If this were not the case, and in particular if the energy penalty for emissions control were lower for natural gas than for biomass, the benefits calculated for scenarios involving natural gas would be reduced. This is not, however, expected to be significant.

The results are very sensitive to landfill and waste decomposition characteristics and these characteristics are very uncertain. Sensitivity analyses were performed to address this issue. Results appear to be robust within the ranges assessed for those characteristics with the exception of woody mill residuals for which very different results can be obtained depending on the assumption made regarding the fraction of carbon that is non-degradable under anaerobic conditions. In this study, a value of 77% was used, obtained from the U.S. EPA GHG Inventory (2014a, Table 7.50). IPCC recommends using a default value of 50% and specifies that waste-specific information can be used instead but emphasizes that "[t]he reported degradabilities especially for wood, vary over a wide range and [are] yet quite inconclusive" (IPCC 2006b, Chapter 3, pp. 3.13-3.14). Table 8.1 compares the results using the two values. The results show that the selected value has significant effect on the results. Some studies have reported higher fractions of non-degradable carbon in wood than 77%

ED_000419-0008101

(Wang et al. 2011). Assuming a higher non-degradable fraction would significantly reduce the estimated benefits of using this material for energy.

Table 8.1 Comparison of Results Obtained for Woody Mill Residuals Using the EPA and IPCC Values for Fraction of Carbon Non-Degradable Under Anaerobic Conditions and Effect for Industry Average Results

Indicator	Unit	Fraction of Non-Degradable Carbon Under Anaerobic Conditions (FCCND)			
		Including Fossil Fuel Substitution (Cradle-to-Final Energy)		Excluding Fossil Fuel Substitution (Gate-to-Gate)	
		77% (EPA)	50% (IPCC)	77% (EPA)	50% (IPCC)
Woody mill residuals differential GHGI	kg CO_2E/GJ	-116	-295	-8.5	-187
Weighted average differential GHGI	kg CO_2E/GJ	-158	-228	-4.6	-74.2
Break-even time (woody mill residuals)	years	1.2	0.5	19.5	6.6
Weighted average break-even time	years	0.5	0.2	7.6	2.6
Break-even year for ongoing practice (woody mill residuals)	-	2012	2013	1979	2003
Industry-average benefit	million tonnes CO_2E/yr	181	261	5.3	84.9

In addition, the analysis of the timing of emissions depends heavily on landfill characteristics. In the absence of information more specific to forest products manufacturing residuals, U.S. EPA decay rates for municipal landfills were used. These decay rates were derived for a mix of wastes, i.e., not only for woody materials which may degrade more slowly. Therefore, the lower decay rates used in the scenarios are probably more representative of woody materials. Even considering this, the break-even times were short, with the exception of paper recycling residuals that contain a fraction of plastic.

Finally, the results of the assessment of ongoing practice are valid only in the context of two main assumptions: 1) assuming the same quantity and type of energy produced in every year, 2) assuming the same alternative fates and fossil fuels displaced in every year.

9.0 CONCLUSIONS

In this study, the GHG and fossil fuel-related benefits of using woody manufacturing residuals, recycling residuals, and wastewater treatment plant residuals for energy production within the forest products industry were analyzed using life cycle principles and additional analyses. It was shown that using all types of residuals for energy production produces benefits both in terms of reduced fossil fuel consumption and reduced greenhouse gas emissions. This result is valid across a range of system configuration scenarios (boiler type, assumptions about the displaced fossil fuel, the GHG intensity of the electricity grid, and the level of cogeneration at forest products facilities), residual characteristics (e.g., heating value, moisture content), and whether or not the benefits from fossil fuel substitution are considered. These findings hold true whether biogenic CO_2 is included in the analysis or excluded by giving it an emission factor of zero (equivalent to what is sometimes called “carbon neutrality”). The

ED_000419-0008102

benefits occur without affecting the amount of wood harvested or the amount of wood products produced.

It takes 0 to 1.2 years before the cumulative emissions impacts from the biomass energy systems are lower than those in the corresponding non-use systems. Even ignoring the benefits of displacing fossil fuel and limiting the analysis to biogenic emissions, the cumulative emissions impacts from the biomass energy systems associated with producing 1 GJ of energy are lower than those from the non-use systems in 0 to 19.5 years, depending on the residual.

These results were developed by comparing the GHG emissions from systems using manufacturing residuals for energy in the forest products industry to the emissions from alternative systems producing the same amount of energy from fossil fuels while disposing of the residuals by landfilling or a combination of landfilling and incineration. In cases where it is assumed that the alternative to burning manufacturing residuals for energy is incineration, the break-even times for all residuals are zero, whether or not fossil fuel substitution is considered. Where the alternative is assumed to be landfilling, the results can be sensitive to the parameter value describing the extent to which residuals decompose in mill landfills, a parameter with large uncertainty. The impact is especially significant for woody mill residuals.

When considered as an ongoing practice (e.g., ongoing production of 1 GJ energy per year), and when the benefits of displaced fossil fuels are considered, the typical cumulative impact of residuals used for energy in the industry becomes less than that of disposing of the residuals in less than two years. If the benefits of displaced fossil fuels are ignored, the typical cumulative impact of using the residuals becomes smaller than the impact associated with disposing of the residuals in less than 35 years for all of the residuals examined. In all cases, even ignoring the benefits of displaced fossil fuels, the ongoing use of the residuals predates, by a considerable period, the date when the practice would have needed to begin in order for the current use of manufacturing residuals to be showing net benefits.

The emissions benefits of using manufacturing residuals for energy in the forest products industry are large. Given current practice, the use of manufacturing residuals including black liquor in the industry for one year avoids the emission of approximately 181 million tonnes CO_2E, equal to approximately three times the annual direct emissions associated with the combustion of fossil fuels in the forest products industry.

ED_000419-0008103

REFERENCES

Aghamohammadi, B. and Durai-Swamy, K. 1993. A disposal alternative for sludge waste from recycled paper and cardboard. In *TAPPI Engineering Conference*, pp. 877-890. Atlanta, GA: TAPPI Press.

Alvarez, R.A., Pacala, S.W., Winebrake, J.J., Chameides, W.L. and Hamburg, S.P. 2012. Greater focus needed on methane leakage from natural gas infrastructure. *Proceedings of the National Academy of Sciences*109(17): 6435-6440. http://dx.doi.org/10.1073/pnas.1202407109

American Petroleum Institute. 2009. *Compendium of greenhouse gas emissions methodologies for the oil and natural gas industry*. Washington DC: American Petroleum Institute. http://www.api.org/~/media/Files/EHS/climate-change/2009_GHG_COMPENDIUM.pdf

Boman, U.R. and Turnbull, J.H. 1997. Integrated biomass energy systems and emissions of carbon dioxide. *Biomass and Bioenergy* 13(6):333-343. http://dx.doi.org/10.1016/S0961-9534(97)00043-3

Cherubini, F., Bird, N.D., Cowie, A., Jungmeier, G., Schlamadinger, B. and Woess-Gallasch, S. 2009. Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. *Resources, Conservation and Recycling* 53(8):434-447. http://dx.doi.org/10.1016/j.resconrec.2009.03.013

Douglas, M.A., Latva-Somppi, J., Razbin, V., Friedrich, F.D. and Tran, H.N. 1994. Combustion of paper deinking solids in a pilot-scale fluidized bed. *Tappi* 77(5):109-119.

Durai-Swamy, K., Warren, D., W. and Mansour, M.N. 1991. Indirect steam gasification of paper mill sludge waste. *TAPPI Journal* 74(10):137-143.

EarthShift. 2009. US-EI Database. http://www.earthshift.com/software/simapro/USEI-database

Eastern Research Group (ERG). 2002. Memorandum to Jim Eddinger, U.S. Environmental Protection Agency, OAQPS. *Development of model units for the industrial/commercial/ institutional boilers and process heaters national emission standards for hazardous air pollutants*. October 2002. http://www.epa.gov/ttn/atw/nsps/boilernsps/modelunits.pdf

ecoinvent Centre. 2010. ecoinvent Database v.2.2. St. Gallens: Swiss Center for Life Cycle Inventories.

European Commission. 2006. *Integrated pollution prevention and control reference document on best available techniques for large combustion plants.* http://eippcb.jrc.ec.europa.eu/reference/BREF/lcp_bref_0706.pdf

Food and Agriculture Organization of the United Nations (FAO). 2008. *Forest and energy key issues*. FAO Forestry Paper 154. Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/010/i0139e/i0139e00.htm

Frederik, W.J., Iisa, K., Lundy, J.R., O'Connor, W.K., Reis, K., Scott, A.T., Sinquefield, S.A., Sricharoenchaikul, V. and Van Vooren, C.A. 1996. Energy and materials recovery from recycled paper sludge. *TAPPI Journal* 79(6):123-131.

ED_000419-0008104

Froese, R.E., Shonnard, D.R., Miller, C.A., Koers, K.P. and Johnson, D.M. 2010. An evaluation of greenhouse gas mitigation options for coal-fired power plants in the US Great Lakes States. *Biomass and Bioenergy* 34(3):251-262. http://dx.doi.org/10.1016/j.biombioe.2009.10.013

Gaudreault, C., Malmberg, B., Upton, B. and Miner, R. 2012. Life cycle greenhouse gases and non-renewable energy benefits of kraft black liquor recovery. *Biomass and Bioenergy* 46(0):683-692. http://dx.doi.org/10.1016/j.biombioe.2012.06.027

Heath, L.S., Maltby, V., Miner, R., Skog, K.E., Smith, J.E., Unwin, J. and Upton, B. 2010. Greenhouse gas and carbon profile of the U.S. forest products industry value chain. *Environmental Science & Technology* 44(10):3999-4005. http://dx.doi.org/10.1021/es902723x

Heijungs, R. and Kleijn, R. 2001. Numerical approaches towards life cycle interpretation - Five examples. *International Journal of Life Cycle Assessment* 6(3):141-148. http://dx.doi.org/10.1007/BF02978732

Hischier, R. 2007. *Life cycle inventories of packagings and graphical papers*. ecoinvent Report No. 11. Dübendorf: Swiss Center for Life Cycle Inventories.

Hischier, R. and Weidema, B.P. (eds.). 2009. *Implementation of life cycle impact assessment methods*. ecoinvent Report No. 3. Dübendorf: Swiss Center for Life Cycle Inventories.

Intergovernmental Panel on Climate Change (IPCC). 2006a. *General guidance and reporting.* Volume 1 of *2006 IPCC guidelines for national greenhouse gas inventories*. Hayama, Japan: Institute for Global Environmental Strategies. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html

———. 2006b. *Waste*. Volume 5 of *2006 IPCC guidelines for national greenhouse gas inventories*. Hayama, Japan: Institute for Global Environmental Strategies. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html

———. 2006c. *Agriculture, forestry and other land use.* Volume 4 of *2006 IPCC guidelines for national greenhouse gas inventories*. Hayama, Japan: Institute for Global Environmental Strategies. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

———. 2007. *Climate change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change.* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.). Cambridge University Press. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

International Energy Agency (IEA). 2013. Electricity/heat in Mexico in 2009. http://www.iea.org/stats/index.asp (accessed 18 February 2013).

International Organization for Standardization (ISO). 2002. *Environmental management - Life cycle assessment - Data documentation format*. ISO/TS 14048. Geneva: International Organization for Standardization.

———. 2006a. *Environmental management - Life cycle assessment - Principles and framework*. ISO 14040. Geneva: International Organization for Standardization.

———. 2006b. *Environmental management - Life cycle assessment - Requirements and guidelines*. ISO 14044. Geneva: International Organization for Standardization.

———. 2012a. *Environmental management - Life cycle assessment - Illustrative examples on how to apply ISO 14044 to impact assessment situations*. ISO/TR 14047. Geneva: International Organization for Standardization..

———. 2012b. *Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis*. ISO/TR 14049. Geneva: International Organization for Standardization..

James, B.A. and Kane, P.W. 1991. Sludge dewatering and incineration at Westvaco, North Charleston, S.C. *TAPPI Journal* 74(5):131-137.

Johnson, L., Lippke, B. and Oneil, E. 2012. Modeling biomass collection and woods processing life-cycle analysis. *Forest Products Journal* 62(4):258-272.

Jones, G., Loeffler, D., Calkin, D. and Chung, W. 2010. Forest treatment residues for thermal energy compared with disposal by onsite burning: Emissions and energy return. *Biomass and Bioenergy* 34(5):737-746. http://dx.doi.org/10.1016/j.biombioe.2010.01.016

Kellenberger, D., Althaus, H.-J., Künniger, T., Jungbluth, N., Lehmann, M., and Thalmann, P. 2007. *Life cycle inventories of building products*. ecoinvent report No. 7. Dübendorf: Swiss Center for Life Cycle Inventories. http://www.poli.br/~cardim/PEC/Ecoinvent%20LCA/ecoinventReports/07_BuildingProducts.pdf

Kirkinen, J., Palosuo, T., Holmgren, K. and Savolainen, I. 2008. Greenhouse impact due to the use of combustible fuels: Life cycle viewpoint and relative radiative forcing commitment. *Environmental Management* 42(3):458-469. http://dx.doi.org/10.1007/s00267-008-9145-z

Kitto, J.B. 1996. Air pollution control for industrial boiler systems. Presented at ABMA Industrial Boiler Systems Conference, November 6-7, 1996, West Palm Beach, FL.

Kostiuk, A.P. and Pfaff, F. 1997. *Conversion factors for the forest products industry in eastern Canada*. Special Publication SP523E. Forintek Canada Corp.

Kraft, D.L. 1994. Fluidized-bed combustion of sludge and woodwaste. In *TAPPI 1994 Engineering Conference*, 1025-1030. Atlanta, GA: TAPPI Press.

Kraft, D.L. and Orender, H.C. 1993. Considerations for using sludge as a fuel. *Tappi Journal* 76(3):175-183.

La Fond, J.F., Heimrich, J., Hayes, A. and Cameron, A. 1997. Secondary sludge disposal by burning in recovery boilers. In *TAPPI 1997 Engineering & Papermakers Conference*, 1357-1364. Atlanta, GA: TAPPI Press.

Levasseur, A. 2013. *Instruction manual*. DynCO2 Dynamic Carbon Footprinter. Montreal, QC: CIRAIG. http://www.ciraig.org/pdf/DYNCO2_InstructionManual.pdf.

Levasseur, A., Lesage, P., Margni, M., Deschênes, L. and Samson, R. 2010. Considering time in LCA: Dynamic LCA and its application to global warming impact assessments. *Environmental Science & Technology* 44(8):3169-3174. http://dx.doi.org/10.1021/es9030003

Mann, M.K. and Spath, P.L. 2001. A life cycle assessment of biomass cofiring in a coal fired power plant. *Clean Products and Processes* 3: 81-91. http://dx.doi.org/10.1007/s100980100109

Micales, J.A. and Skog, K.E. 1997. The decomposition of forest products in landfills. *International Biodeterioration & Biodegradation* 39(2–3):145-158. http://dx.doi.org/10.1016/S0964-8305(97)83389-6

National Council for Air and Stream Improvement, Inc. (NCASI). 1998. *Estimated CO_2 emissions resulting from compliance with U.S. federal environmental regulations in the forest products industry*. Special Report 98-02. Research Triangle Park, NC: National Council [of the Paper Industry] for Air and Stream Improvement, Inc.

———. 2000. *Beneficial uses of secondary fiber rejects*. Technical Bulletin No. 806. Research Triangle Park, NC: National Council [of the Paper Industry] for Air and Stream Improvement, Inc.

———. 2004. *Critical review of forest products decomposition in municipal solid waste landfills*. Technical Bulletin No. 872. Research Triangle Park, NC: National Council for Air and Steam Improvement, Inc.

———. 2005a. *Alternative fuels used in the forest products industry: Their composition and impact on emissions*. Technical Bulletin No. 906. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

———. 2005b. Calculation tools for estimating greenhouse gas emissions from pulp and paper mills. Version 1.1. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

———. 2008. *Handbook of environmental regulation and control, volume 1: Pulp and paper manufacturing.* Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

———. 2011a. *Beneficial use of woody biomass for energy and other purposes*. Technical Bulletin No. 0994. Research Triangle Park, NC: National Council for Air and Steam Improvement, Inc.

———. 2011b. *Greenhouse gas and non-renewable energy benefits of black liquor recovery*. Technical Bulletin No. 984. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

National Renewable Energy Laboratory. 2008. U.S. Life Cycle Inventory (LCI) Database. http://www.nrel.gov/lci/

Nickull, O., Lehtonen, O. and Mullen, J. 1991. Burning mill sludge in a fluidized bed incinerator and waste-heat-recovery system. *TAPPI Journal* 74(3):119-122.

Pehnt, M. 2006. Dynamic life cycle assessment (LCA) of renewable energy technologies. *Renewable Energy* 31(1):55-71. http://dx.doi.org/10.1016/j.renene.2005.03.002

Petersen Raymer, A.K. 2006. A comparison of avoided greenhouse gas emissions when using different kinds of wood energy. *Biomass and Bioenergy* 30(7):605-617. http://dx.doi.org/10.1016/j.biombioe.2006.01.009

Puettmann, M. and Lippke, B. 2012. Woody biomass substitution for thermal energy at softwood lumber mills in the US Inland Northwest. *Forest Products Journal* 62(4):273-279.

Repo, A., Känkänen, R., Tuovinen, J.-P., Antikainen, R., Tuomi, M., Vanhala, P. and Liski, J. 2012. Forest bioenergy climate impact can be improved by allocating forest residue removal. *GCB Bioenergy* 4(2):202-212. http://dx.doi.org/10.1111/j.1757-1707.2011.01124.x

Robinson, A.L., Rhodes, J.S. and Keith, D.W. 2003. Assessment of Potential Carbon Dioxide Reductions Due to Biomass−Coal Cofiring in the United States. *Environmental Science & Technology* 37(22):5081-5089. http://dx.doi.org/10.1021/es034367q

Ruhul Kabir, M. and Kumar, A. 2012. Comparison of the energy and environmental performances of nine biomass/coal co-firing pathways. *Bioresource Technology* 124(0):394-405. http://dx.doi.org/10.1016/j.biortech.2012.07.106

Skog, K.E. 2008. Sequestration of carbon in harvested wood products for the United States. *Forest Products Journal* 58(6):56-72. http://www.fpl.fs.fed.us/documnts/pdf2008/fpl_2008_skog001.pdf

Statistics Canada. 2013a. *Electric power generation, by class of electricity producer*. Table 127-0007. CANSIM. http://www5.statcan.gc.ca/cansim/pick-choisir?lang=eng&p2=33&id=1270007

Statistics Canada. 2013b. *Electricity generated from fossil fuels*. Table 128-0014. CANSIM. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=1280014&tabMode=dataTable&srchLan=-1&p1=-1&p2=9

Statistics Canada. 2013c. *Supply and disposition of electric power, electric utilities and industry*. Table 127-0008. CANSIM. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=1270008&tabMode=dataTable&srchLan=-1&p1=-1&p2=9

Steierer, F., Fischer-Ankern, A., Francoeur, M., Wall, J. & Prins, K. 2007. *Wood energy in Europe and North America: A new estimate of volumes and flows*. Geneva, Switzerland: UNECE/FAO. http://www.unece.org/fileadmin/DAM/timber/docs/stats-sessions/stats-29/english/report-conclusions-2007-03.pdf

Todd, J.A. and Curran, M.A. 1999. *Streamlined life-cycle assessment: A final report from the SETAC North America Streamlined LCA Workgroup*. Pensacola, FL: Society for Environmental Toxicology and Chemistry (SETAC).

United States Department of Transportation and United States Department of Commerce. 2004. *2002 economic census - Transportation - Commodity flow survey*. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/commodity_flow_survey/2002/united_states/pdf/entire.pdf

United States Energy Information Administration (EIA). 2012. Electricity Detailed State Data. http://www.eia.gov/electricity/data/state/.

ED_000419-0008108

United States Environmental Protection Agency (USEPA). 1995. *Compilation of air pollutant emission factors - Volume I: Stationary point and area sources, fifth edition*. AP-42. Research Triangle Park, NC: United States Environmental Protection Agency.

———. 2002. *EPA air pollution control cost manual, 6th edition*. EPA/452/B-02-001. Research Triangle Park, NC: United States Environmental Protection Agency. http://www.epa.gov/ttn/catc/dir1/c_allchs.pdf

———. 2009. Code of Federal Regulations (CFR) Section 98, Subpart C. *Federal Register* 74(209):56409-56410.

———. 2010a. Code of Federal Regulations (CFR) Section 98, Subpart TT. *Federal Register* 75(132):39736-39777.

———. 2010b. Code of Federal Regulations (CFR) Title 40, Subpart A (Amended). *Federal Register* 75(242):79091-79171.

———. 2010c. Code of Federal Regulations (CFR) Title 40, Subpart C. *Federal Register* 75(242):79091-79171.

———. 2012a. *Documentation for greenhouse gas emission and energy factors used in the Waste Reduction Model (WARM) - Landfilling*. http://epa.gov/epawaste/conserve/tools/warm/pdfs/Landfilling.pdf

———. 2012b. *Inventory of U.S. greenhouse gas emissions and sinks: 1990-2010*. EPA 430-R-13-001. Washington, DC: United States Environmental Protection Agency. http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Main-Text.pdf

———. 2013. Code of Federal Regulations (CFR) Section 98, Subpart TT (Amended). *Federal Register* 78(230):71904-71981.

———. 2014a. *Inventory of U.S. greenhouse gas emissions and sinks: 1990-2012*. 430-R-14-003. Washington, DC: United States Environmental Protection Agency.

———. 2014b. *Municipal solid waste generation, recycling, and disposal in the United States - Tables and figures for 2012*. Washington, DC: United States Environmental Protection Agency. http://www.epa.gov/osw/nonhaz/municipal/pubs/2012_msw_dat_tbls.pdf

Wang, X., Padgett, J.M., De la Cruz, F.B. and Barlaz, M.A. 2011. Wood biodegradation in laboratory-scale landfills. *Environmental Science & Technology* 45(16):6864-6871. http://dx.doi.org/10.1021/es201241g

Werner, F., Althaus, H.-J., Künniger, T., Richter, K., and Jungbluth, N. 2007. *Life cycle inventories of wood as fuel and construction material*. ecoinvent report No. 9. Dübendorf: Swiss Center for Life Cycle Inventories. http://www.upe.poli.br/~cardim/PEC/Ecoinvent%20LCA/ecoinventReports/09_WoodFuelConstruction.pdf

Wihersaari, M. 2005. Greenhouse gas emissions from final harvest fuel chip production in Finland. *Biomass and Bioenergy* 28(5):435-443. http://dx.doi.org/10.1016/j.biombioe.2004.11.007

ED_000419-0008109

Woodruff, E.B., Lammers, H.B. and Lammers, T.F. 2012. *Steam plant operation.* New York, London: McGraw-Hill.

Zanchi, G., Pena, N. and Bird, N. 2012. Is woody bioenergy carbon neutral? A comparative assessment of emissions from consumption of woody bioenergy and fossil fuel. *GCB Bioenergy* 4(6):761-772. http://dx.doi.org/10.1111/j.1757-1707.2011.01149.x

ED_000419-0008110

APPENDIX A

ACRONYMS AND NOMENCLATURE

General Acronyms and Nomenclature:

AF&PA:	American Forest and Paper Association
AWC:	American Wood Council
BC:	Base case
BDmT:	Bone-dry metric tonne
Bio:	Biomass
BioCO_2:	Biogenic CO_2
Biogenic GHGs:	Biogenic CO_2 as well as CH_4 produced from decomposing biomass and CH_4 and N_2O produced in biomass combustion
Biomass energy system:	Product system in which the biomass residuals are used for energy production
Break-even time:	Number of years required for the cumulative emissions from the non-use system to equal the cumulative emissions from the biomass energy system
CHP:	Combined heat and power
CORRIM:	Consortium for Research on Renewable Industrial Materials
CO_2:	Carbon dioxide
CO_2E:	CO_2 equivalents, i.e., measure for describing how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of carbon dioxide (CO_2) as the reference
Cradle-to-final energy analysis:	A cradle-to-final energy analysis can be defined as a specific LCA applied to the production of energy. It generally includes the extraction and production of fuels, their transportation and their combustion to produce energy.
Differential GHGs:	Absolute difference in releases of GHGs, including biogenic CO_2 emissions and removals
Eff:	Efficiency
EPA:	Environmental Protection Agency
FF:	Fossil fuel

Non-use system:	Product system in which the fossil fuels are used for energy production and in which an alternative fate for the biomass residuals is considered or in which only the alternative fate of the biomass residuals is considered
Gate-to-gate analysis:	A gate-to-gate analysis can be described as a partial LCA looking at only one value-added process in the entire production chain
GHG:	Greenhouse gas
GJ:	Gigajoule (1 GJ = 0.948 MMBtu)
GWP:	Global warming potential
HHV:	Higher heating value
H&P:	Heat and power
ISO:	International Organization for Standardization
LCA:	Life cycle assessment
LCI:	Life cycle inventory
LCIA:	Life cycle impact assessment
LHV:	Lower heating value
MSW:	Municipal solid waste
NG:	Natural gas
N/Av.:	Not available
OCC:	Old corrugated containers
OECD:	Organisation for Economic Co-operation and Development
Relative FF CON:	Relative difference in fossil fuel consumption of the biomass energy system compared to the non-use system
Relative Non-Bio CO_2 GHGs:	Relative difference in GHGs, <u>not including biogenic CO_2</u>, of the biomass energy system compared to the non-use system
Removals:	Sequestration or absorption of CO_2 from the atmosphere by the trees
US:	United States
WWTP:	Wastewater treatment plant

System Configuration Scenarios Nomenclature:

Alternative Fate Scenarios

MR1: Landfilling

MR2: Incineration

Boiler Type Scenarios

FB: Fluidized bed boiler

SB: Stoker boiler

Fossil Fuel Scenarios

A: Heat from coal

B: Heat from natural gas

C: US-average electricity

D: Electricity from coal

E: Fossil fuel scenario, electricity from natural gas combined cycle

Size Reduction Scenarios

SR0: Size reduction scenario, no size reduction

SR1: Size reduction scenario, mobile chipper

SR2: Size reduction scenario, stationary chipper

General Nomenclature:

CC: Biogenic carbon content

E_{DC}: Usable energy from direct combustion

E_{Turb}: Steam to turbine

F_{CCND}: Non-degradable carbon content under anaerobic conditions

F_{CH4CB}: Fraction of methane captured and burned

F_{CH4OX}: Fraction of methane oxidized in landfill covers

k: Decay rate

L: Losses

MCF: Methane correction factor

P: Power to process

Q_R: Quantity of residuals required to produced 1 GJ of usable energy

SHP: High pressure steam to process

SMP/LP: Extraction steam to process

WC_R: Water content of residuals

APPENDIX B

REPORT REVISIONS SINCE ORIGINAL PUBLICATION

This is the third version of this report. The first version was published in October 2013. A revised version was published in May 2014 to correct some of the data and make some clarifications to the text. NCASI found that the values describing the composition of biomass energy presented in Table 6.14 were calculated using the wrong method. These numbers affected the various weighted averages calculated throughout the report. In addition, NCASI calculated the total greenhouse gases avoided by the industry's use of woody mill residuals and black liquor to be 110 million tonnes CO_2E for woody mill residuals and 218 million tonnes CO_2E for combined woody mill residuals and black liquor. It was not clear in the report that other residuals were not included in this estimate. If the estimate had included other residuals, the avoided emissions benefit would have been slightly larger. Also, the report text was clarified in a few places. These changes did not affect the general conclusions of the report.

In July 2014, NCASI determined that the calculations pertaining to woody mill residuals were in error due to the use of an incorrect value for the fraction of carbon that degrades in landfills under anaerobic conditions. Specifically, NCASI used a value of 55% for this parameter while it had intended to use 77%, the value used by the United States Environmental Protection Agency in its Inventory of U.S. Greenhouse Gas Emissions and Sinks. NCASI has recalculated all of the results involving woody mill residuals and recomputed all industry-average numbers. The table below lists the changes in results and where they occur in the report. The table only identifies places where the changes involve calculations based on dynamic radiative forcing. The numbers calculated with the Intergovernmental Panel on Climate Change (IPCC) 100-year global warming potentials (GWPs) were also updated but this is not shown in the table. Note that the text of the report was also modified in several places (not listed here) to reflect the changes in these results. NCASI also provided more details concerning the available information on the decay rates of various manufacturing residuals and the fraction of non-degradable carbon in wood. In addition, a sensitivity analysis using the default value from IPCC (i.e., 50% of the carbon non-degradable under anaerobic conditions), also used by EPA in its greenhouse gas reporting rule, was added. (Table 8.1 was added to Section 8.2.2.) Note that many results presented in Table 8.1 were not in the original report.

In the table below, where a value is presented, for instance, in Section ES.6 in the new report, that result is typically presented in Section ES.5 in the previous version of the report. So, where “ES.6” is listed in the table, it pertains to the new version only and, for the previous version, should be “ES.5.” Note also that in some places information was removed from, or added to, a section compared to the previous version of the report.

Indicator	Unit	Including Fossil Fuel Substitution (Cradle-to-Final Energy)			Excluding Fossil Fuel Substitution (Gate-to-Gate)		
		Previous Version of the Report	This Version of the Report	Places in the Report Where the Change Was Made	Previous Version of the Report	This Version of the Report	Places in the Report Where the Change Was Made
Woody mill residuals differential GHGI	kg CO_2E/GJ	-261	-116	Abstract, Table ES.1 and relative text, Section 6.1.1.1	-154	-8.5	Table ES.5 and relative text, Abstract, Table 7.1 and relative text
Weighted average differential GHGI	kg CO_2E/GJ	-215	-158	Table ES.1 and relative text, Table 6.10	-61.4	-4.6	Table ES.5 and relative text, Table 7.1 and relative text
Woody mill residuals relative GHGI	%	-99.1	-98.7	Table ES.2 and relative text, Section 6.1.1.2	Not calculated in the report		
Weighted average mill residuals relative GHGI	%	-93.9	-93.7	Table ES.2 and relative text, Table 6.10			
Break-even time (woody mill residuals)	years	0.6	1.2	Abstract, Table ES.3 and relative text, ES.6, Figure 6.3, Section 6.1.1.3, Section 9.0	7.4	19.5	Abstract, ES.1 Table ES.5 and relative text, ES.6, Table 7.1 and relative text, Section 9.0
Weighted average break-even time	years	0.2	0.5	ES.4.3, Table 6.10, Section 9.0	2.9	7.6	Table ES.5 and relative text, Table 7.1 and relative text, Section 9.0
Break-even year for ongoing practice (woody mill residuals)	-	Unchanged*			1998†	1979†	Table ES.6 and relative text, Table 7.2
Industry-average benefit	million tonnes CO_2E/yr	218	181	President's Note, ES.1, ES.4.1, ES.6, 6.7, 9.0	The number was added to the text as it was not there previously.		

*The number of years to break-even changed from 1.3 to 1.9 but the year did not necessitate updating. †The number of years was also updated from 16.2 to 34.5.

Other analysis pertaining to woody mill residuals were also updated, including

- the contribution analysis depicted in Figure 6.1;
- the explanation of the timing of emissions in Figure 6.2, Table 6.1, Figure 6.3, Table 6.2, and Figure 6.4,
- the perturbation analyses in Figure 6.6, the sensitivity analyses in Table 6.3;
- the system configuration scenarios in Table 6.4;
- the comparison of the residuals in Figure 6.15;
- the industry-wide benefits from using woody mill residuals only (110 MT CO_2 E removed from the report); and
- the weighted average results in Table 6.10.

In addition, the following changes were also made to the report.

- The text of the abstract, executive summary conclusion, and conclusion were modified to better reflect the limitations of the study.
- A "Significance of Findings" section was added to the executive summary.
- The benefits from using black liquor were recalculated using dynamic radiative forcing. The number went from -182 to -184 kg CO_2E/GJ.
- The analyses on ongoing practices for all residuals type were recalculated using the radiative forcing curves instead of CO_2E curves, leading to some changes when excluding fossil fuel substitution (Table ES.6):
    - wastewater treatment plant (WWTP) residuals went from 2001 to 2004; and
    - paper recycling residuals went from 1997 to 2001.
- The weighted averages and annual values were removed from the ongoing practices tables.
- Some values derived from the literature were corrected and/or clarified and some choices made for the base case and sensitivity analyses for the different manufacturing residuals studied in this report were clarified by adding text in Tables 5.2, 5.3, 5.5, 5.6, and 5.7.
- The choice of the decay rates for all residuals was better justified.
- The equations for calculating emissions from landfill were clarified.

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org)
Sent:	11/14/2014 5:37:22 PM
Subject:	deliberative - AF2
Attachments:	Framework for Assessing Biogenic CO2 Emissions_11_11_14so.docx

Hi JB,
This is as far as I can get tonight. When you pick it up, please let me know and we can figure out how to handle version control.
Thanks again,
Sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Williams, Melina
Sent: 11/14/2014 11:31:08 AM
Subject: page 2
Attachments: Framework for Assessing Biogenic CO2 Emissions_11_11_14so.docx

Ex. 5 - Deliberative

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Latane, Annah
To: Ohrel, Sara; Cole, Jefferson
CC: Baker, Justin
Sent: 11/14/2014 3:26:23 PM
Subject: --Deliberate-- Apps I, J,K
Attachments: Appendix_I_Ref Pt CaseStudies_11_12_14_aml.docx; Appendix_I_Ref Pt CaseStudies_11_12_14_aml_clean.docx; Appendix_J_Anticipated Baselines Background_11_12_14_aml.docx; Appendix_J_Anticipated Baselines Background_11_12_14_aml_clean.docx; Appendix_K_Anticipated Baseline Construction Methods_11_13_14_aml.docx; Appendix_K_Anticipated Baseline Construction Methods_11_13_14_aml_clean.docx

Sara and Jeff,

Here are I, J, and K back to you with edits made and clean versions. H is in process.

Cheers,
Annah

--this email and its content are deliberative--do not distribute or cite--
Annah M. Latané
Environmental Economist
Center for Environmental, Technology, and Energy Economics
RTI International
919.541.5976
www.rti.org
Email: alatane@rti.org

From: Latane, Annah
To: Ohrel, Sara; Cole, Jefferson
CC: Baker, Justin
Sent: 11/13/2014 4:35:45 PM
Subject: --Deliberative--App D
Attachments: Appendix_D_Feedstock Categories_11_13_14.docx

Sara and Jeff,

Here's appendix D. Justin is on stand-by to do another look through if needed.

Best,
Annah

--this email and all attachments are deliberative--

Annah M. Latané
Environmental Economist
Center for Environmental, Technology, and Energy Economics
RTI International
919.541.5976
www.rti.org
Email: alatane@rti.org

From: Steller, John
To: Ohrel, Sara
Sent: 11/13/2014 4:24:35 PM
Subject: Sustainable Forestry Definitions
Attachments: Sustainable Forestry (ect) Definitions Index-v2-JS.xlsx

Hi Sara – I have found a few more definitions for “sustainability” and “sustainable forest management” that I have added to the index spreadsheet and have included in this email.

-John

John Steller
ORISE Fellow, Climate Change Division
(202) 343-9319
Steller.John@epa.gov

From: Ohrel, Sara
To: Cole, Jefferson
Sent: 11/13/2014 9:29:34 AM
Subject: RE: Q&A - your turn
Attachments: Biogenic CO2 Framework Internal QAs 11 12 14 v2_jc so.docx

Hi,
Here is my edited version for you to add your final pieces to.
Thanks!

-----Original Message-----
From: Cole, Jefferson
Sent: Thursday, November 13, 2014 12:16 AM
To: Ohrel, Sara
Subject: Q&A - your turn

Hey Sara,

I made some edits to the Q&A doc. You will see that I also added in the Q&As we worked on with OTAQ. Also, I still need to supply a reference for Suzie from the RIA. I can do that first thing in the morning.

Thanks,

Jeff

From: Latane, Annah
To: Ohrel, Sara; Cole, Jefferson; Baker, Justin
Sent: 11/12/2014 2:24:29 PM
Subject: --Deliberative--Main Document
Attachments: Framework for Assessing Biogenic CO2 Emissions_11_11_14.docx

Hi all,

This is the most recent version of the main document for everyone to have. Outstanding: one EIA reference that was unclear to me (highlighted in the reference list).

Annah

__This email and all attachments are deliberative__

Annah M. Latané
Environmental Economist
Center for Environmental, Technology, and Energy Economics
RTI International
919.541.5976
www.rti.org
Email: alatane@rti.org

From: Cole, Jefferson
To: Ohrel, Sara
Sent: 11/13/2014 11:19:08 AM
Subject: RE: Biomass comms docs

Yes. Taking a look now.

From: Ohrel, Sara
Sent: Thursday, November 13, 2014 11:04 AM
To: Cole, Jefferson
Subject: RE: Biomass comms docs

Can you please check the other 2 docs she sent yesterday?

From: Cole, Jefferson
Sent: Thursday, November 13, 2014 10:27 AM
To: DeLuca, Isabel; Ohrel, Sara; Kocchi, Suzanne; Irving, Bill
Cc: Fawcett, Allen
Subject: RE: Biomass comms docs

Isabel et al.,

Attached is the desk statement with edits from Sara and myself.

Thanks,

Jeff

From: DeLuca, Isabel
Sent: Thursday, November 13, 2014 10:09 AM
To: Cole, Jefferson; Ohrel, Sara; Kocchi, Suzanne; Irving, Bill
Cc: Fawcett, Allen
Subject: RE: Biomass comms docs

Thank you!

From: Cole, Jefferson
Sent: Thursday, November 13, 2014 10:08 AM
To: Ohrel, Sara; DeLuca, Isabel; Kocchi, Suzanne; Irving, Bill
Cc: Fawcett, Allen
Subject: RE: Biomass comms docs

Isabel,

Attached are two Q&A docs.

The first is a version of what you sent around with edits from Sara and myself.
(see: "Biogenic CO2 Framework Internal QAs 11 12 14 v2_jc2 so.docx")

The second is a version of the Q&As specifically regarding the case studies that we developed with OTAQ in the summer (with some edits from us to update the language from when this was originally crafted). This would not be

needed to accompany the letter on Friday, rather, it is better suited to accompany the release of the framework. We will need to continue to work with them on this, as well as gather any other technical Q&As that we think we may need. (see: "Biogenic CO2 Framework Internal QAs on Case Studies - 11 13 14.docx")

Also, I will soon be sending a version of the desk statement with edits from Sara and I.

Thanks,

Jeff

From: Ohrel, Sara
Sent: Wednesday, November 12, 2014 5:33 PM
To: DeLuca, Isabel; Kocchi, Suzanne; Irving, Bill
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: Biomass comms docs

Thanks Isabel. Jeff and I just started looking at the Q&As you and Bill sent around earlier but will dig into this version and get back to you with our comments no later than 10am tomorrow if that works for you.
Have a nice night,
Sara

From: DeLuca, Isabel
Sent: Wednesday, November 12, 2014 5:30 PM
To: Kocchi, Suzanne; Irving, Bill
Cc: Fawcett, Allen; Cole, Jefferson; Ohrel, Sara
Subject: Biomass comms docs

Hi all,
Here are draft comms docs.

1) Cleaned up version of the CPP Q&A doc— I added a couple of comments and also added a question that came in from a reporter today (and draft response).
2) Draft desk statement. This focuses on the BAF, and didn't get into to the memo's broader messaging on biomass in CPP and PSD. My thought was to punt to OAQPS to provide some language if they wanted to.
3) Web text. The current site has Biomass-related info spread over several web pages. I've consolidated it into one page with all of the BAF materials listed in reverse-chrono order (most recent on top).
4) Rollout – lists what we're planning to post on the web, and when, plus stakeholder calls TBD

Please take a look and let me know if you have edits, then I'll circulate to OAQPS tomorrow. I think we're ok sending this up to the press office tomorrow.

Thanks,
Isabel

From: Kocchi, Suzanne
Sent: Wednesday, November 12, 2014 3:55 PM
To: Irving, Bill; DeLuca, Isabel
Cc: Fawcett, Allen; Cole, Jefferson; Ohrel, Sara
Subject: RE: CPP questions

A couple of quick edits on top of Bill's, lifting text from the latest version of the Janet Regional Memo.

From: Irving, Bill

Sent: Wednesday, November 12, 2014 3:36 PM
To: DeLuca, Isabel
Cc: Kocchi, Suzanne; Fawcett, Allen; Cole, Jefferson; Ohrel, Sara
Subject: RE: CPP questions

Answers/edits added to most questions – Ex. 5 - Deliberative
Ex. 5 - Deliberative

From: DeLuca, Isabel
Sent: Wednesday, November 12, 2014 2:39 PM
To: Irving, Bill
Cc: Kocchi, Suzanne; Fawcett, Allen; Cole, Jefferson; Ohrel, Sara
Subject: RE: CPP questions

Thanks, Bill. I've merged in some Q&As that Sarah had helped develop earlier. There may be some redundancy, but that's ok.

All—please add any other questions you can think of and circulate again. (This is also on the G drive here: Ex. 6 - Personal Privacy
Ex. 6 - Personal Privacy

In the meantime, Bill, now that you've added a bunch of Qs, can you help with the responses?

Thanks.

From: Irving, Bill
Sent: Wednesday, November 12, 2014 2:09 PM
To: DeLuca, Isabel
Cc: Kocchi, Suzanne; Fawcett, Allen; Cole, Jefferson; Ohrel, Sara
Subject: CPP questions

Isabel – some questions to add. You might have some already.

Ex. 5 - Deliberative

Ex. 5 - Deliberative

From:	Stashwick, Sasha
To:	Ohrel, Sara
CC:	Greene, Nathanael; Yassa, Sami; Jonathan Lewis (jlewis@catf.us); Longstreth, Ben
Sent:	11/11/2014 12:25:04 PM
Subject:	Agenda_EPA-NRDC-CATF mtng on BAF approach to biomass c accounting
Attachments:	Agenda_EPA-NRDC-CATF mtng on BAF approach to biomass c accounting.docx

Hi Sara,

Attached please find an outline/agenda we've written up to guide our continuing discussion tomorrow on a default BAF approach to biogenic carbon accounting.

I've copied the folks from our end that are going to be coming to the meeting in person:

Nathanael Greene, Sami Yassa and Ben Longstreth from NRDC
Jonathan Lewis from CATF

I'll be joining from NRDC by phone.

One other thing to flag - it doesn't look like the calendar invite has been updated with a room # once everyone arrive. Would you be able to send that around today or tomorrow morning?

Thanks very much and looking forward to speaking with you again,

-Sasha

Sasha (Lyutse) Stashwick | Policy Advocate | Natural Resources Defense Council
Office: 310.434.2330 | 1314 Second Street, Santa Monica, CA 90401
slyutse@nrdc.org | www.nrdc.org
Visit my blog on climate, energy & food policy: http://switchboard.nrdc.org/blogs/slyutse/
Follow me on Twitter @SashaLyutse
Follow NRDC's renewables work @NRDCRenewables
Follow NRDC's foodies @NRDCFood

Please don't print this e-mail unless you need to.
SAVE PAPER. THINK BEFORE PRINTING.

TO: Sara Ohrel
FROM: Nathanael Greene, Debbie Hammel, Jonathan Lewis, Sasha Stashwick, Sami Yassa
DATE: November 10, 2014
RE: Outline/Agenda for discussion of "default BAF" approach to biogenic carbon regulation

I. Overview of the "default BAF" approach

The BAF is defined as the ratio of Net Biogenic Emissions and Gross Emission, and is a dimensionless number that describes the proportion of the carbon released from an individual biomass facility that has not been re-sequestered by the terrestrial ecosystem, and therefore contributes to net atmospheric CO_2 loading. The greater its value, the more carbon emitted by a bioenergy facility remains in the atmosphere (on net).

Under a "default BAF" framework, EPA would identify feedstock categories and major regions of analysis. For each region, modeling would determine the net change in stored carbon that results from the removal and combustion of a given feedstock. Knowing this net change, EPA would calculate a "default BAF" for each feedstock by region, producing generalized factors to apply to stack emissions based on a facility's fuel mix.

II. Establishing Conservative Simplifying Assumptions

Critical to the success of a biogenic carbon accounting system is the approach to treating uncertainties in the modeling and implementation. Specifically, even with a robust model that incorporates our proposed methods and parameters below (accurate degree of differentiation for forest types, management regimes, leakage; appropriate regional scale; correct timeframes, etc.), there remains considerable uncertainty as to whether these model assumptions reasonably match conditions on the ground associated with biomass sourcing for a particular facility.

EPA's modeling of counterfactual scenarios should therefore incorporate simple, precautionary assumptions that reduce the risk of undercounting emissions and that ensure any uncertainties in the model are resolved conservatively.

III. Recommendations

EPA should put in place a biogenic carbon accounting framework that will:

- Be independent of the size of the region over which calculations are made;
- Model changes in stored carbon using an anticipated future baseline—i.e. comparing emissions from increased biomass harvesting under a "business as usual" baseline to a scenario absent increased biomass demand for bioenergy;
- Assess, in particular, feedstocks that have large net carbon emissions and long recovery timeframes, especially those derived from forests;
- Use simple, precautionary assumptions that reduce the risk of undercounting emissions and ensure uncertainties in the model are resolved conservatively;

- Emphasize short times frames that are relevant to reducing greenhouse gas emissions in line with the United States' climate goals, both because of regulatory precedents and as a way to minimize uncertainties;
- Appropriately capture and differentiate between key characteristics of biomass feedstocks, land use histories, forest management regimes, and end uses;
- Ensure biomass carbon accounting results reflect what the atmosphere "sees" in terms of emissions; and
- Capture key economic factors without introducing large uncertainties associated with dynamic economic modeling—most importantly, through regular updates of counterfactuals and accounting for displaced demand for trees on a one-for-one basis.

(a) Modeling Inputs

We recommend model specifications that differentiate inputs where the data are available and that capture the important distinctions in climate impacts among fuel types, land management, and end uses.

1. Fuel type: distinguish between boles versus branches/limbs (residues).
2. Size class: for both boles and residues, distinguish between large diameter and small diameter size classes.
3. Land use history: distinguish among major forest types and species; distinguish between planted versus naturally regenerating.
4. Harvest regime: distinguish between complete removal and partial cuts.
5. End uses and alternate fates: divide end uses into short-term uses and long-term structural objects; in the case of harvest residues, distinguish between slash burning and slash decay.

(b) Spatial Scale

A key test of the scientific rigor of any biogenic carbon accounting framework is whether it is able to assess biogenic emissions and reductions consistently, regardless of the region in which they occur. BAFs should be modeled in a way that is independent of the physical fuelshed area. Instead, data to inform BAFs – on fuel type, size class for woody biomass feedstocks, land use history, current harvest regime and alternate biomass uses in existing wood products markets – should be collected at the appropriate scale for each class of data.

Modeling fuelsheds would therefore be "virtual," meaning a facility could be sourcing wood from a number of non-contiguous plots that include different types of forests. However, as long as model inputs for those lands were available, EPA would have the ability to model the necessary BAFs to reflect the facility's biomass sourcing.

(c) Time Horizon

The timeframe chosen should be relevant to greenhouse gas reduction goals and climate policy imperatives. In particular, modeled changes in carbon stocks should be applied over a time period that is consistent with federal, state, and international greenhouse gas reduction policies and commitments.

We propose a 10-20 year horizon, which takes into account important policy and regulatory precedents set forth in the California Low Carbon Fuel Standard; the President's Climate Action Plan; the Massachusetts Renewable Portfolio Standard; the European Union Renewable Energy Directive, and the Federal Renewable Fuel Standard.

This relatively shorter time horizon range has four key benefits:

1. It is in line with efforts to avoid the worst consequences of climate change.
2. It helps to drive consistency across existing climate change policies and emission reduction commitments – including those cited above;
3. It reduces modeling uncertainty, which can increase dramatically over longer time horizons; and
4. It models BAFs on approximately the same timeframe as industry planning horizons for long term-contracts and operations.

(d) Economic Dynamics and Treatment of Leakage

We believe that the uncertainties associated with long-term economic forecasts outweigh any benefits of added market dynamics. We recommend instead two key simplifying assumptions that can sufficiently capture the interactions of demand for wood products:

- *New biomass harvest displaces demand on a full 1-to-1 basis to a new, similar forest stand.*
- *"Leakage" is additive and "new" standing trees are cut in forests that are biologically and climatically identical to the original wood source to meet the original non-biomass needs.*

These assumptions, combined with the short assessment timeframe (summarized above), would allow EPA to rely purely on biophysical models of forests and wood production and avoid the complexity and uncertainty inherent in dynamic economic models.

In addition, updating the BAF every ten years will help ensure that the environmental factors used to establish the BAF for each biomass type are consistent with evolving scientific research, while also promoting the integrity of the Prevention of Significant Deterioration ("PSD") and Title V permitting programs and harmonizing the process with USDA's ten-year update of the Renewable Resource Assessment.

From: Ohrel, Sara
To: Justin Baker (justinbaker@rti.org); Cole, Jefferson
Sent: 11/7/2014 3:26:36 PM
Subject: part 1
Attachments: Appendix_A_IPCC_Emissions Inventory_7 27df_2-psg so 11 5clean.docx; Appendix_B_Temporal Scale_8 7 14_PSG3 so 11 5.docx; Appendix_C_Spatial Scale_7 27df_PSG4 so 11 5.docx; Appendix_D_Feedstock Categories 11 7 clean w addnm.docx; Appendix_E_Discussion of Leakage Literature_7 27df_rhb_jc.docx; Appendix_F_General Algebraic Representation_9 9 14_clean.docx

Most recent versions I have – Justin please use attached App D for RTI's clean up and formatting.

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Steller, John
To: Ohrel, Sara
Sent: 11/6/2014 12:32:50 PM
Subject: RE: another one
Attachments: Sustainable Forestry (ect) Definitions Index-v1-JS.xlsx

Hi Sara – I have attached the current spreadsheet of the sustainable forestry definitions to this email for your review. Please let me know if there is anything else I should include, thanks.
-John

From: Ohrel, Sara
Sent: Wednesday, November 05, 2014 1:13 PM
To: Steller, John
Subject: RE: another one

That sounds great, John – I look forward to checking it out and maybe discussing it later.

From: Steller, John
Sent: Wednesday, November 05, 2014 1:06 PM
To: Ohrel, Sara
Subject: RE: another one

Hey Sara,
It's coming along well. I've cleaned up the document I have been using and am beginning to throw what I've found into the spreadsheet you passed along. It is more focused on the definitions but there are a few programs I have included as well. I should be finished with it by tomorrow.
-John

From: Ohrel, Sara
Sent: Wednesday, November 05, 2014 12:04 PM
To: Steller, John
Subject: RE: another one

Hi John,
Just checking in – how is it coming along?
Thanks,
sara

From: Steller, John
Sent: Friday, October 31, 2014 4:22 PM
To: Ohrel, Sara
Subject: RE: another one

Great! I have one definition from CIFOR already so I will check out this document and include anymore that I find and add this program/guidelines, thanks.

From: Ohrel, Sara
Sent: Friday, October 31, 2014 4:18 PM
To: Steller, John
Subject: another one

Not sure if you found this one
http://www.cifor.org/acm/methods/toolbox1.html

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Michelle Manion
To: Ohrel, Sara
CC: David Cooley; Cole, Jefferson
Sent: 11/6/2014 10:01:14 AM
Subject: South section
Attachments: South_11-5-2014.docx

Hi Sara,

I've attached the next section of the biomass paper for your review – the South RPA region.
We'll look forward to seeing your comments -- thanks!

--Michelle and David

Michelle Manion| Senior Associate | Abt Associates
55 Wheeler Street, Cambridge MA 02138
T: 617.520.2379|C: 617.631.2015| E: Michelle_Manion@abtassoc.com

BOLD THINKERS DRIVING REAL-WORLD IMPACT

www.abtassociates.com

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Wednesday, November 05, 2014 8:52 AM
To: Michelle Manion
Cc: David Cooley; Cole, Jefferson
Subject: RE: Revised U. S. West section

Hi Michelle,
Attached is the West biomass paper with my comments. Happy to discuss if needed.
Thank you!

From: Michelle Manion [mailto:Michelle_Manion@abtassoc.com]
Sent: Thursday, October 30, 2014 10:41 AM
To: Ohrel, Sara; Cole, Jefferson
Subject: Revised U. S. West section

Hi Sara and Jefferson,

Attached please find for your review and comment our revised section covering the U.S. West for the biomass White Paper. In this version, you'll see a new section covering the Rocky Mountain sub-region, as well as expansion of some of the Pacific West (more on residues, economics of thinning projects).
We'll look forward to your feedback and comments,

--Michelle

Michelle Manion| Senior Associate | Abt Associates
55 Wheeler Street, Cambridge MA 02138
T: 617.520.2379|C: 617.631.2015| E: Michelle_Manion@abtassoc.com

BOLD THINKERS DRIVING REAL-WORLD IMPACT

www.abtassociates.com

This message may contain privileged and confidential information intended solely for the addressee. Please do not read, disseminate or copy it unless you are the intended recipient. If this message has been received in error, we kindly ask that you notify the sender immediately by return email and delete all copies of the message from your system.

This message may contain privileged and confidential information intended solely for the addressee. Please do not read, disseminate or copy it unless you are the intended recipient. If this message has been received in error, we kindly ask that you notify the sender immediately by return email and delete all copies of the message from your system.

From:	Baker, Justin
To:	Ohrel, Sara; Cole, Jefferson
Sent:	10/24/2014 11:19:13 AM
Subject:	Deliberative Draft
Attachments:	Framework for Assessing Biogenic CO2 Emissions_10242014.docx

this email and all attachments are deliberative

Sara and Jeff,

Attached is the edited version of the main framework document. Note that our editing team identified some missing references this round that we are currently looking for. However, I did not want to delay delivery of this document for your review.

Thanks,
Justin

From: Ohrel, Sara
To: Baker, Justin; Cole, Jefferson
CC: Hanks, Katie P.
Sent: 9/23/2014 9:18:16 AM
Subject: RE: AppD_Addendum_Black_Liquor_Fate_9-12-14.docx
Attachments: AppD_Addendum_Black_Liquor_Fate_9-12-14_so.docx; AppD_Addendum_Black_Liquor_Fate_9-12-14_so_clean.docx

Hi all,
Here are 2 versions: one with changes tracked and one clean with just a few comments for editors.
Nice work, Katie and Justin!
Once I have App d done, we can add this to that and send the combo to editing.
Thanks again,
Sara

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Tuesday, September 16, 2014 1:42 PM
To: Ohrel, Sara; Cole, Jefferson
Cc: Hanks, Katie P.
Subject: AppD_Addendum_Black_Liquor_Fate_9-12-14.docx

__this email and all attachments are deliberative__

Dear Dara and Jeff,

Please find a revised version of the black liquor addendum.

Thanks, Justin

From: Baker, Justin
To: Ohrel, Sara; Cole, Jefferson
Sent: 9/9/2014 1:24:43 PM
Subject: latest drafts batch two
Attachments: Appendix_J_Anticipated Baselines Background_7 27df_PSG4.docx; Appendix_K_Anticipated Baseline Construction Methods_8_7_2014_PSG4.docx; Appendix_L_Anticipated Baseline Case Studies_08.06.2014_PSG3.docx; Appendix_M_Summary of Illustrative Forest and Ag Case Studies_7 27df_PSG2.docx; Appendix_N_Waste Derived Feedstocks_7 27df_PSG4.docx; SAB_Response_Document_7 27df_jm_clean.docx

this email and all attachments are deliberative

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org)
CC:	Cole, Jefferson
Sent:	9/9/2014 10:49:38 AM
Subject:	BL and LULUCF - deliberative
Attachments:	AppD_Addendum_Black_Liquor_Fate_8-14-14_tracked_so.docx; Summary_EasternUSCarbonStorage_USGS so.docx

Hi Justin,
Attached you will find versions of the BL addendum and the USGS lulucf report summary with my comments. Both look pretty good. We can discuss at 1pm today.
Thanks!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Cole, Jefferson
Sent: 9/8/2014 1:58:27 PM
Subject: main doc - deliberative
Attachments: Framework for Assessing Biogenic CO2 Emissions_9 03 14_v4.docx; Framework for Assessing Biogenic CO2 Emissions_9 03 14_v4_clean.docx

Hi Jeff,
Can you please check the Janet RTC versus this updated doc? Page numbers may have changed (I updated the TOC and Graphics list accordingly). (sending also the tracked version for your FYI and records)

Thanks!

Once you are done, we will send to the crew. I will send them a heads up that it will be coming this pm before COB.

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Cole, Jefferson
Sent: 9/8/2014 10:41:08 AM
Subject: RE: main doc *deliberative*
Attachments: Framework for Assessing Biogenic CO2 Emissions_9 03 14_v3.docx; OTAQ comments on 9 03 14 Main Doc version so.docx

Thanks Jeff. My thoughts on your piece as well as the main doc attached for our upcoming discussion.

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Cole, Jefferson
Sent: Friday, September 05, 2014 5:32 PM
To: Ohrel, Sara
Subject: RE: main doc *deliberative*

This email and all attachments are deliberative

Sara,

I've decided to use a side file for the OTAQ comments. I do not think that any changes are necessary per the old comments (I dug up Aaron's original comments and your responses to them from prior versions). One exception **Ex. 5 - Deliberative** See my note in the attached.

Also, I've included some suggested edits per the two new comments. Edit/change/disagree as you see fit.

Have a great weekend,

Jeff

From: Ohrel, Sara
Sent: Friday, September 05, 2014 2:53 PM
To: Cole, Jefferson
Subject: RE: main doc

Thanks Jeff. I will drop Melina a line now.
On the main doc, yes I will take the pen, but also would like your help – could you please tackle OTAQ's comments? Using the 9_3 AF draft as your basis, can you add suggested edits and/or responses per their comments in either a side document (akin to the Janet RTC) or directly into the 9_3 AF version, for us to discuss and add as needed to the draft later today/Monday am? I will set up a call for us at 10:45am Monday to discuss. In the meantime I will work with Melina and work on small editorial improvements. After we have all this sorted out on Monday, we will then need to update the Janet RTC if needed.

Cool?

From: Cole, Jefferson
Sent: Friday, September 05, 2014 2:43 PM
To: Ohrel, Sara
Subject: main doc

Sara,

I presume you are taking the pen on the main doc now and working with Melina per Suzie's last email. I'm happy to help, so let me know where I can do so.

Thanks,

Jeff

Jefferson Cole
Economist
Climate Change Division
U.S. EPA
Desk: 202.343.9671
Mobile: 202.701.8795
cole.jefferson@epa.gov

From: Ohrel, Sara
To: Ohrel, Sara
Sent: 9/8/2014 9:36:15 AM
Subject: save - deliberative
Attachments: Framework for Assessing Biogenic CO2 Emissions_9 03 14_v3.docx

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Ohrel, Sara
To:	Schrock, Bill; Swanson, Nicholas
Sent:	9/4/2014 12:19:58 PM
Subject:	FW: Review of biogenic CO2 emissions assessment framework main document requested
Attachments:	Framework for Assessing Biogenic CO2 Emissions_9 03 14.docx

Hello,

Attached is the updated main document of the biogenic CO2 assessment framework. It reflects edits from Sarah and Janet, some of which we received this week. We have been asked to: 1) return the updated document up the chain for Janet's review this Friday, 2) request that your team do a quick review of this version see if you have any major issues/red flags before we send it back up to Janet (please no line edits at this point). If you have any red flag issues, please send them to us by close of business tomorrow (Thursday).

We understand that this is quick turnaround time but appreciate your understanding and help with this effort.
Sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Cole, Jefferson
To: Ohrel, Sara
Sent: 9/2/2014 10:21:52 AM
Subject: RE:
Attachments: Framework for Assessing Biogenic CO2 Emissions_2014 08 26_sd.docx

Here it is.

From: Ohrel, Sara
Sent: Tuesday, September 02, 2014 9:58 AM
To: Cole, Jefferson
Subject: RE:

Awesome, thanks!

From: Cole, Jefferson
Sent: Tuesday, September 02, 2014 9:58 AM
To: Ohrel, Sara
Subject: RE:

That sounds fine. Will be done momentarily.

From: Ohrel, Sara
Sent: Tuesday, September 02, 2014 9:56 AM
To: Cole, Jefferson
Subject: FW:

Hi Jeff,
Can you please add Sarah's comments in tracked changes to your most recent draft of the main doc? Then we can go through her changes, as well as comments/changes I have per the round of edits completed while I was out. We can discuss if you have a different proposal forward.
Thanks!

From: Fawcett, Allen
Sent: Tuesday, September 02, 2014 9:46 AM
To: Ohrel, Sara; Cole, Jefferson
Subject: FW:

oops

From: Gunning, Paul
Sent: Friday, August 29, 2014 4:47 PM
To: Irving, Bill; Kocchi, Suzanne; Fawcett, Allen
Subject: Fw:

Here are Sarahs comments. I talked to her a bit on next steps as well and we can touch base on Tuesday. I hope you guys have a great holiday weekend.

Paul

Sent from my BlackBerry 10 smartphone.

From: Dunham, Sarah <Dunham.Sarah@epa.gov>
Sent: Friday, August 29, 2014 4:14 PM
To: Gunning, Paul
Subject: FW:

Fyi, Dorothy pdf'd my accounting framework comments – this is the same thing I gave you a hard copy of.

From: EZTech_Printer [mailto:EZtek@epa.gov]
Sent: Friday, August 29, 2014 1:50 PM
To: Garner, Dorothy; Dunham, Sarah
Subject:

From: Ohrel, Sara
To: Cole, Jefferson; Justin Baker (justinbaker@rti.org); Eschmann, Erich
Sent: 8/29/2014 11:37:27 AM
Subject: RE: for the call - deliberative
Attachments: New Hampshire analysis 8 29 14_v2.docx

Here is what I have- please send comments by noon or sooner.
Thanks!
If you want to chat, I am at 202 341 6748.

From: Cole, Jefferson
Sent: Friday, August 29, 2014 11:03 AM
To: Ohrel, Sara; Justin Baker (justinbaker@rti.org); Eschmann, Erich
Subject: RE: for the call - deliberative

Here's the permit I found.

http://www2.des.state.nh.us/OneStopPub/Air/3301500012FY96-TV049TypeSummary.pdf

---

From: Ohrel, Sara
Sent: Friday, August 29, 2014 10:30 AM
To: Justin Baker (justinbaker@rti.org); Eschmann, Erich; Cole, Jefferson
Subject: for the call - deliberative

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Kocchi, Suzanne; Cole, Jefferson
Sent: 8/28/2014 4:38:48 PM
Subject: Re: NH Biomass - follow up

Just FYI. The one unit at the Schiller plant is all biomass (other 2 are coal or oil), and is referred to the 111d proposal's GHG abatement TSD (per effort to address a comment from DOE reviewer during interagency review process).

From: Kocchi, Suzanne
Sent: Thursday, August 28, 2014 4:32 PM
To: Cole, Jefferson
Cc: Ohrel, Sara
Subject: RE: NH Biomass - follow up

That's cool. Kevin C suggested you check with CAMD as well – Misha, Jeb etc would know if it is included in IPM.

From: Cole, Jefferson
Sent: Thursday, August 28, 2014 4:23 PM
To: Kocchi, Suzanne
Cc: Ohrel, Sara
Subject: RE: NH Biomass - follow up

That may not necessarily be the case. There may be a couple of others. RTI is helping to dig into these with folks there that know 111(d) quite well. I should be able to give you a detailed answer when I hear back from them.

From: Kocchi, Suzanne
Sent: Thursday, August 28, 2014 4:14 PM
To: Cole, Jefferson
Cc: Ohrel, Sara
Subject: RE: NH Biomass - follow up

Looks like based on GHGRP it is only Schiller – that is good news.

From: Cole, Jefferson
Sent: Thursday, August 28, 2014 4:05 PM
To: Kocchi, Suzanne
Cc: Ohrel, Sara
Subject: RE: NH Biomass - follow up

That's helpful, thanks. I'll keep digging in the meantime.

Jeff

From: Kocchi, Suzanne
Sent: Thursday, August 28, 2014 4:03 PM
To: Cole, Jefferson
Cc: Ohrel, Sara
Subject: RE: NH Biomass - follow up

As soon as you can get it but I am not hearing a demand for it cob today (at least so far). Will let you know if that

changes. Paul still hasn't come back from talking to Sarah D so not sure her reaction or additional asks yet.

From: Cole, Jefferson
Sent: Thursday, August 28, 2014 4:01 PM
To: Kocchi, Suzanne
Cc: Ohrel, Sara
Subject: RE: NH Biomass - follow up

Suzie, how soon do you need this info.?

From: Kocchi, Suzanne
Sent: Thursday, August 28, 2014 3:34 PM
To: Ohrel, Sara; Hannan, Michael; Cole, Jefferson; Karimjee, Anhar
Cc: Fawcett, Allen; Irving, Bill
Subject: RE: NH Biomass - follow up

Can we figure out **Ex. 5 - Deliberative** If so, can you please let us know?

From: Ohrel, Sara
Sent: Thursday, August 28, 2014 2:37 PM
To: Hannan, Michael; Cole, Jefferson; Kocchi, Suzanne; Karimjee, Anhar
Cc: Fawcett, Allen
Subject: RE: NH Biomass
Importance: High

Hi all,
The data below is from GHGRP and EIA 2012 (however in the online EIA database, Jeff found one more that went online in 2013: Burgess, using wood, wood waste solids).

Here is our table (also in the attached under sheet 1):

facility	parent company	fuel type
Turnkey Landfill Gas Recovery	WM Renewable Energy LLC	Municipal Solid Waste – Biogenic compone
Nashua Plant	Suncook Energy LLC	Municipal Solid Waste – Biogenic compone
Dunbarton Energy Partners LP	Zapco Energy Tactics Corp	Municipal Solid Waste – Biogenic compone
UNH 7.9 MW Plant	Emcor Energy Services	Municipal Solid Waste – Biogenic compone
Wheelabrator Claremont Facility	Wheelabrator Environmental Systems	Municipal Solid Waste – Biogenic compone
Schiller	Public Service Co of NH	Wood/Wood Waste Solids (paper pellets, ra chips, bark, and other wood waste solids)
		Other Biomass Solids
Bridgewater Power LP	Bridgewater Power Co LP	Wood/Wood Waste Solids (paper pellets, ra chips, bark, and other wood waste solids)
Springfield Power LLC	Springfield Power LLC	Wood/Wood Waste Solids (paper pellets, ra chips, bark, and other wood waste solids)
DG Whitefield LLC	EWP RENEWABLE CORP.	Wood/Wood Waste Solids (paper pellets, ra chips, bark, and other wood waste solids)
Tillotson Rubber	Tillotson Rubber Co Inc	Wood/Wood Waste Solids (paper pellets, ra chips, bark, and other wood waste solids)
Pinetree Power	Pinetree Power Inc	Wood/Wood Waste Solids (paper pellets, ra chips, bark, and other wood waste solids)

Indeck Energy	Indeck Energy-Alexandria, LLC	Wood/Wood Waste Solids (paper pellets, ra chips, bark, and other wood waste solids)

Thanks to Michael and Jeff for their help.
Sara

From: Hannan, Michael
Sent: Thursday, August 28, 2014 2:28 PM
To: Cole, Jefferson; Ohrel, Sara; Kocchi, Suzanne; Karimjee, Anhar
Cc: Fawcett, Allen
Subject: RE: NH Biomass

Makes sense that most of the ones not in the GHGRP database are biomass-only combustors (we might need to look into the couple of biomass/fossil combustors that don't report to us to make sure they're below the threshold).

From: Cole, Jefferson
Sent: Thursday, August 28, 2014 2:16 PM
To: Ohrel, Sara; Kocchi, Suzanne; Hannan, Michael; Karimjee, Anhar
Cc: Fawcett, Allen
Subject: RE: NH Biomass

A bit more information from EIA is attached. These are a listing of biomass plants in New Hampshire, downloaded from here:
http://www.eia.gov/electricity/data/browser/#/topic/1?agg=1,0,2&fuel=0008&geo=001&sec=o3g&freq=M&datecode=201406&rtype=s&start=200101&end=201406&ctype=linechart&ltype=pin&pin=&maptype=0&rse=0

Jeff

From: Ohrel, Sara
Sent: Thursday, August 28, 2014 2:04 PM
To: Kocchi, Suzanne; Hannan, Michael; Karimjee, Anhar
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: NH Biomass

Ok – I have tee Grid stuff together and am now putting in with GHGRP stuff into the categories you asked for. I can have this done before 2:40.

From: Kocchi, Suzanne
Sent: Thursday, August 28, 2014 2:03 PM
To: Hannan, Michael; Ohrel, Sara; Karimjee, Anhar
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: NH Biomass

Thank you everyone – if we can get the simple table described below with any additions we may have found in eGRID or other databases by 2:40 pm. If we don't have time or can't find the info please at least list the other datasets we are going to check.

Thanks again.

From: Hannan, Michael
Sent: Thursday, August 28, 2014 2:01 PM
To: Ohrel, Sara; Kocchi, Suzanne; Karimjee, Anhar
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: NH Biomass

Sorry, hit send a little too soon. Also included in Sarah's file but not mine is Shiller (wood & wood residuals) because they report the bioimass fuel only under subpart D (my file was just subpart C biomass reporters in NH). So, seven facilities is the total count – 6 subpart C and one subpart D.

From: Ohrel, Sara
Sent: Thursday, August 28, 2014 1:53 PM
To: Hannan, Michael; Kocchi, Suzanne; Karimjee, Anhar
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: NH Biomass

Awesome, thanks Michael.

From: Hannan, Michael
Sent: Thursday, August 28, 2014 1:51 PM
To: Kocchi, Suzanne; Ohrel, Sara; Karimjee, Anhar
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: NH Biomass

I happened to have a list already developed, albeit for 2011 data. It confirms what Sarah downloaded from Flight, the only difference being that Gorham Paper & Tissue LLC began combusting landfill gas in 2012, as included in her file.

From: Kocchi, Suzanne
Sent: Thursday, August 28, 2014 1:14 PM
To: Ohrel, Sara; Karimjee, Anhar; Hannan, Michael
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: NH Biomass
Importance: High

Thanks – we just need a simple table of the facility, sector, fuel type, and any other source of biomass that would lead to emissions, and data source

If we can get a preliminary cut of this simple table by 2:40 or so, Paul can bring up to Sarah D to discuss at his general.

Thanks!!!!

From: Ohrel, Sara
Sent: Thursday, August 28, 2014 1:10 PM
To: Kocchi, Suzanne; Karimjee, Anhar; Hannan, Michael
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: NH Biomass

Ok, sure. We can look at other datasets (eg Egrid, other) for other biomass-using entities.

From: Kocchi, Suzanne
Sent: Thursday, August 28, 2014 1:07 PM
To: Ohrel, Sara; Karimjee, Anhar; Hannan, Michael
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: NH Biomass

Adding Mike H (not sure who else Anhar has looking this with Brian out).

For the pulp and paper facilities listed, they still would have black liquor, correct? even if they aren't using biomass for fuel. Not sure how that shows up in GHGRP.

In addition, We need to see if we can figure out if there is a data set that would tell us what other biomass facilities that might be in NH but aren't in our database. Particularly, if there are solely biomass power generation facilities that we don't capture. Can we dig into that? And can we confirm with GHGRP folks and CAMD that these power plants listed in GHGRP really don't use biomass with the exception of the 2 you have highlighted?

From: Ohrel, Sara
Sent: Thursday, August 28, 2014 1:00 PM
To: Kocchi, Suzanne; Karimjee, Anhar
Cc: Fawcett, Allen; Cole, Jefferson
Subject: RE: NH Biomass

Hi all,

I went into the GHGRP database and found the following:
18 total entities in GHGRP database for 2012. 5 use waste-derived feedstocks (biogas, MSW - in blue text), 2 of which use wood and wood residuals (in yellow and orange highlight).

Anhar, is there anyone in your group that can take a look at this to ensure that I have pulled the data correctly (as I am not a frequent user)?

Suzie, Anhar, Allen – please let me know if there is any other information you want me to add/omit.

Thanks,
Sara

From: Fawcett, Allen
Sent: Thursday, August 28, 2014 12:27 PM
To: Ohrel, Sara; Cole, Jefferson
Subject: FW: NH Biomass

See the request below from the Administrator. Could you guys start looking into this?

Thanks,
Allen

From: Gunning, Paul
Sent: Thursday, August 28, 2014 12:26 PM
To: Kocchi, Suzanne; Karimjee, Anhar; Fawcett, Allen
Subject: RE: NH Biomass

Thanks for sending this Suzie. This request from the Administrator was a result of a call she had with the Senator yesterday. Please make this a priority.

Thanks

Paul

From: Kocchi, Suzanne
Sent: Thursday, August 28, 2014 12:24 PM
To: Karimjee, Anhar; Fawcett, Allen
Cc: Gunning, Paul
Subject: FW: NH Biomass
Importance: High

Can we get a list of facilities in NH that report to GHGRP and then try to figure out what fuels they might use? If it is biomass what kind?

Thinking GHGRP and CAMD as good first start but not sure if there are other data sets from EIA that can help?

From: Dunham, Sarah
Sent: Thursday, August 28, 2014 12:16 PM
To: Gunning, Paul; Kocchi, Suzanne; Harvey, Reid
Subject: Fw: NH Biomass

Can we look at this please quickly (at least quickly for the first ask). Reid, it probably needs help from your folks.

Sent from my BlackBerry 10 smartphone.

From: Goffman, Joseph
Sent: Thursday, August 28, 2014 12:08 PM
To: Dunham, Sarah
Subject: Fwd: NH Biomass

- Joseph Goffman
Sent from my iPhone

Begin forwarded message:

From: Ex. 6 - Personal Privacy, Administrator
Date: August 28, 2014 at 11:45:12 AM EDT
To: "Goffman, Joseph" <Goffman.Joseph@epa.gov>
Cc: "Distefano, Nichole" <DiStefano.Nichole@epa.gov>
Subject: NH Biomass

Joe – can your folks take a look at the biomass facilities in NH Ex. 5 - Deliberative

Ex. 5 - Deliberative

Thanks. Happy to talk more when I see you.

From: Ohrel, Sara
To: Justin Baker (justinbaker@rti.org); Cole, Jefferson
Sent: 8/28/2014 2:23:13 PM
Subject: NH list - deliberative
Attachments: NH biogenic FS use 2012 EIA_GHGRP.xlsx

Hi guys,
Please check and send any comments/concerns/edits by 2:32.
S

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Cole, Jefferson
To:	Ohrel, Sara
Sent:	8/27/2014 4:03:43 PM
Subject:	*deliberative* main document recent track changes
Attachments:	Framework for Assessing Biogenic CO2 Emissions_jmclean to 2014 08 26_track changes.docx

This email and all attachments are deliberative

Sara,

Attached is a comparison file that shows the track changes between the "jm_clean" version of the main document, and the "2014 08 26" version I sent out earlier this week.

If you want to look further into who made what changes and when, I can help find that out.

Thanks,

Jeff

Jefferson Cole
Economist
Climate Change Division
U.S. EPA
Desk: 202.343.9671
Mobile: 202.701.8795
cole.jefferson@epa.gov

From: Baker, Justin
To: Hight, Cate; Cole, Jefferson; Ohrel, Sara; Beach, Robert H.; Hanks, Katie P.
Sent: 8/20/2014 4:26:43 PM
Subject: RE: SD comments *Deliberative*
Attachments: Framework for Assessing Biogenic CO2 Emissions_19_Aug_2014_jb.docx

Dear all,

Here are some quick additions to sections 4.1.2 and 4.1.3 for our discussion today.

Justin

From: Hight, Cate [mailto:Hight.Cate@epa.gov]
Sent: Wednesday, August 20, 2014 3:03 PM
To: Cole, Jefferson; Baker, Justin; Ohrel, Sara; Beach, Robert H.; Hanks, Katie P.
Subject: RE: SD comments *Deliberative*

OK guys, I've made it to section 4.2 . Some good edits here – particular kudos to Katie for the totally awesome addition **Ex. 5 - Deliberative** This is exactly what we need to respond to Janet and Sarah's comments **Ex. 5 - Deliberative**
Ex. 5 - Deliberative

What we don't have is something similar for the baselines section, and we need it. **Ex. 5 - Deliberative**

Ex. 5 - Deliberative

Could you please take a crack at this between now and our conversation at 4:30? Please make your edits to the attached draft, which is now the master doc.

Cate

Cate Hight
U.S. Environmental Protection Agency
Climate Change Division, Climate Policy Branch
202.343.9230
TELEWORK Tuesdays and Thursdays: (b)(6) personal privacy

From: Cole, Jefferson
Sent: Wednesday, August 20, 2014 12:55 PM
To: Baker, Justin; Ohrel, Sara; Beach, Robert H.; Hanks, Katie P.
Cc: Hight, Cate
Subject: RE: SD comments *Deliberative*

Thank you, Justin, Robert and Katie! We'll get back to you soon.

Best,

Jeff

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Wednesday, August 20, 2014 12:10 PM
To: Cole, Jefferson; Ohrel, Sara; Beach, Robert H.; Hanks, Katie P.
Cc: Hight, Cate

Subject: RE: SD comments *Deliberative*

This email and all attachments are deliberative

Dear all,

Please find an updated version attached. Here are a few notes about this version:

1) This version was created off of the two version Jeff sent yesterday
2) We have merged Cate's previous edits,
3) We have merged Sara Ohrel's edits as of last Friday,
4) We have merged Robert Beach's comments (also delivered last week).
5) We addressed a number of comments from Robert and Cate
6) We focused our editing efforts on sections 2 and 4 as requested.
    a. While we attempted to address comments from Sarah Dunham, we probably need to discuss a few items at 4:30 today, including section 4.1.3 (which we did not address this round)
7) All edits are in track changes

Thanks, and please let me know if you have any questions.

Justin

From: Cole, Jefferson [mailto:Cole.Jefferson@epa.gov]
Sent: Tuesday, August 19, 2014 3:10 PM
To: Ohrel, Sara; Baker, Justin; Beach, Robert H.; Hanks, Katie P.
Cc: Hight, Cate
Subject: RE: SD comments *Deliberative*

This email and all attachments are deliberative

Everyone,

As we discussed earlier, I am including two versions of the main document here.

The first is a track changes with *only* SD's edits and comments (alongside Sara Ohrel and Janet's comments that she reviewed). This is more for our own internal tracking purposes.

The second file is a track changes version that has Cate's edits on top of Sarah's edits. I did a "combine" in MS Word, I did a spot check and things look okay, but keep an eye out for oddities.

We are going to be making changes based on the file with Cate's and Sarah D's comments. Importantly, I have not reviewed Cate's input in detail. RTI, I will save that for you as you incorporate your edits. Once you have finished with your edits, and Cate incorporates the remainder of her comments, I will conduct a final review.

In terms of making your edits, keep in mind Sarah D's overall comments, as well as the language used in the cover memo (sent earlier). The cover memo language has already been revised to Sarah D's satisfaction, so that will be a good source for us.

Thank you all for everything. If you have any questions or concerns in the meantime, contact me anytime.

Best,

Jeff

Jefferson Cole
Economist
Climate Change Division
U.S. EPA
Desk: 202.343.9671
Mobile: 202.701.8795
cole.jefferson@epa.gov

From: Ohrel, Sara
Sent: Tuesday, August 19, 2014 11:00 AM
To: Cole, Jefferson; Baker, Justin; Robert Beach; Hanks, Katie P.
Cc: Hight, Cate
Subject: Re: SD comments *Deliberative*

Thanks Jeff. A lot of what she is suggesting **Ex. 5 - Deliberative** (just FYI for future conversations with them).
Good luck!

From: Cole, Jefferson
Sent: Tuesday, August 19, 2014 10:57 AM
To: Baker, Justin; Robert Beach; Hanks, Katie P.
Cc: Hight, Cate; Ohrel, Sara
Subject: SD comments *Deliberative*

This email is deliberative

Folks,

In case you don't have it, here is the email text from Sarah Dunham that accompanied her handwritten comments.

Thanks,

Jeff

From: Dunham, Sarah
Sent: Friday, August 15, 2014 2:41 PM
To: Kocchi, Suzanne
Cc: Krieger, Jackie; Irving, Bill; Fawcett, Allen; Gunning, Paul; Friedman, Kristina; Krieger, Jackie
Subject: RE: Next version of Framework Report

Thanks for giving me copies of the framework, and response doc, etc. I read the framework document, and the comment response document, and have hard copy comments which I will figure out how to pass along. But in general, before giving it back to janet, I think we need to take another run at it, in terms of having a good editor go through the whole thing which I talked to bill about already, take a look at my edits, and also be more responsive to janet's comments. I think we kind of did the minimal response to her, there are several places we just answered her question in a comment bubble but didn't change the text much or at all—when she asks a question, I think she really would like to see clarifications in the text.

Here are some "general" observations and comments which you will see in my hard copy edits (although for some of the points below I did not cross out every reference that I think needs to be changed):

Ex. 5 - Deliberative

Thanks.

Jefferson Cole
Economist
Climate Change Division
U.S. EPA
Desk: 202.343.9671
Mobile: 202.701.8795
cole.jefferson@epa.gov

From:	Cole, Jefferson
To:	Ohrel, Sara
Sent:	8/18/2014 6:24:14 PM
Subject:	FW: *Deliberative* FW: Framework Discussion
Attachments:	commentsoncommentresponse.pdf; commentsonframeworkdoc.pdf; Framework_Report_all comments_7 27_draft final_jm_clean_CH.docx

Sara,

FYI, copying you on all the action we have going on this week. No action is required from you. I will continue to copy you on other emails.

Thanks,

Jeff

From: Cole, Jefferson
Sent: Monday, August 18, 2014 12:26 PM
To: Baker, Justin
Subject: *Deliberative* FW: Framework Discussion

This email and all attachments are deliberative

Justin,

For your reference, I've attached comments from Cate on the first 15 pages of the framework, as well as the comments from Sarah Dunham on the main doc and SAB response doc (scanned, handwritten comments). Of course, please keep this as a close hold and do not distribute.

Obviously, we are going to need to help do some translating at times, and figure out the best way to make clarifications and simplifications that are consistent with the work and messages that we need to convey.

We can discuss how to specifically move forward with Cate at our next meeting to be had sometime tomorrow or Wednesday.

Thanks,

Jeff

From: Hight, Cate
Sent: Monday, August 18, 2014 11:56 AM
To: Cole, Jefferson; Kocchi, Suzanne; Fawcett, Allen; Irving, Bill
Subject: RE: Framework Discussion

Hi all,

Here are the language edits I made to the doc on Friday.

Cate

Cate Hight
U.S. Environmental Protection Agency
Climate Change Division, Climate Policy Branch
202.343.9230
TELEWORK Tuesdays and Thursdays: (b)(6) personal privacy

-----Original Appointment-----
From: Cole, Jefferson
Sent: Monday, August 18, 2014 10:35 AM
To: Cole, Jefferson; Kocchi, Suzanne; Fawcett, Allen; Irving, Bill; Hight, Cate; Baker, Justin
Subject: Framework Discussion
When: Monday, August 18, 2014 2:00 PM-3:00 PM (UTC-05:00) Eastern Time (US & Canada).
Where: DCRoomWJCS4228AOAP/DC-OAR-OAP

Call in number: Ex. 6 - Personal Privacy
Conf. Code: Ex. 6 - Personal Privacy

From: Ohrel, Sara
To: Cole, Jefferson; Baker, Justin
Sent: 8/15/2014 9:59:01 AM
Subject: RE: Appendix F edits - and sugg edits to main doc and app G *Deliberative*
Attachments: Appendix_F_General Algebraic Representation_7.26df.docx; Appendix_F_General Algebraic Representation_8 8 14 v2_so.docx; Framework_Report_all comments_7 27_changessavedwcomments_soedits_cleanwcoms_rhb.docx; Framework_Report_all comments_7 27_draft final_jm_clean_so.docx; Suggested Edits to Main Doc and App G 2014 08 08_so.docx

Hi guys,
Thank you Jeff for pulling all this together and reviewing across Apps G and F and main doc. Here is what I have:
- attached is Jeff's doc with suggested edits and my related comments/suggestions.

- attached is App F with Jeff's edits and mine atop his. This is the messy version (previous tracked and commented version). Jeff, can you make our collective edits in the attached messy app f to the clean version attached, make any of the suggested edits in the attached suggested edits doc (I did not do this in my quick review this) and send that to RTI for review and editing? Thanks

- Justin, we had discussed during our call earlier this week that per App G "RTI has edited, will send tracked and edited versions for Sara to compare with Jeff's list", but I haven't seen that come through. So instead, I would like you to make any of the suggested edits in the attached suggested edits doc as needed to App G.

- I am also attaching the current version of the main document (Framework report all comments 7 27 draft final jm clean so). I have added suggested edits from Jeff per time and a couple other items. Justin, can someone there please take the pen and add any of the pertinent suggested edits from the attached suggested edits document to the main document? Also, I am attaching Robert's commented version as well. I am sorry to do this, but I need someone to go through and put all of Robert's suggested edits and comments into this updated (jm_clean_so) version too (please change editor name to 'Robert Beach' or "RB" so I know which edits are from him versus changes you/someone else makes). I will want to review this version to accept/decline Robert's comments (if you go through his comments and they require new text, please feel free to add suggested text to the comments for my review).

- also just FYI – Sarah D is editing this version of the doc (Framework report all comments 7 27 draft final jm clean) and then someone from Bill's team with fresh eyes is going to review that version (most likely Cate H). Once Cate/whoever is done, we will have to merge the two versions (Framework report all comments 7 27 draft final jm clean SD CH) with the one that you are creating per my request above (with the edits from the 'suggested edits' doc attached and Robert's suggested edits and comments').

THANK YOU. Please let me know if you have any questions/would like to discuss.
Best,
Sara

From: Cole, Jefferson
Sent: Friday, August 08, 2014 12:08 PM
To: Ohrel, Sara; Baker, Justin
Subject: Appendix F edits - and sugg edits to main doc and app G *Deliberative*

This email is deliberative

Sara and Justin,

I've attached my edits to Appendix F. This includes updating the footnote to "August 2014" as well as ensuring definitions for terms match those as given in the main doc. These edits were made to the commented on (with edits accepted) version that Sara sent out on 7/26).

Cross-checking this appendix against the main doc (the version that Robert sent on yesterday on 8/7) and appendix G (the version that Sara sent around on Wed, 8/6), I caught a few things that should be edited in those docs. They are listed below, but I go into more detail in the other attachment in this email (see "suggested edits…") since I believe I do not currently have the pen on the main doc or Appendix G.

This includes:

Ex. 5 - Deliberative

Also, I've included an updated excel file of the outstanding items.

Thanks,

Jeff

Jefferson Cole
Economist
Climate Change Division
U.S. EPA
Desk: 202.343.9671
Mobile: 202.701.8795
cole.jefferson@epa.gov

From: Ohrel, Sara
To: Justin Baker (justinbaker@rti.org); Cole, Jefferson
Sent: 8/15/2014 9:14:47 AM
Subject: time app and main doc tracking
Attachments: Appendix_B_Temporal Scale_8 7 14_so.docx; Oustanding Items 2014_8_6 v2_soMainDoc.xlsx; Temporal Scale Only - Main Doc 7 27 - jc_so.docx

Hi Justin and Jeff,
Attached is the current version of App B. There are few checks left and need RTI to add the discounting reference (which I think Annah has been working on). Once you have reviewed, please send us tracked and clean copies and also send along to your editing team.

Also attached is the excel tracking sheet in which Jeff included changes suggested to the main doc for time and other pieces (thanks for doing that, Jeff). I have updated the main doc tracking excel per the edits I have incorporated into the main document. Lastly, attached is the main doc time piece from Jeff with suggested edits along with my comments/responses. The accepted edits from this are also in the updated main doc draft.

Thanks!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Ohrel, Sara
To:	Cole, Jefferson
Sent:	8/14/2014 11:27:04 AM
Subject:	FW: Thank you!
Attachments:	Biogenic Assessment Framework Stakeholder Indext_v1.xlsx; stakeholders and public comments attempt 8 5 14.xls

From: Ohrel, Sara
Sent: Wednesday, August 13, 2014 3:18 PM
To: Steller, John
Subject: Thank you!

Thanks again – the first one is the one you will populate and the second one has some of the stakeholders and perspectives from the Oct 2011 meeting.

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Hanks, Katie P.; Baker, Justin; Cole, Jefferson; Beach, Robert H.
Sent: 8/14/2014 9:53:45 AM
Subject: RE: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx
Attachments: AppD_Addendum_Black_Liquor_Fate_8-13-14 jc_so.docx

Thanks Katie, nice work on this. Further edits and a couple last requests for edits from you in the attached. Mostly just need further clarification on items at the end of page 2. Most of my comments back to you are in green. If need be, we can discuss this today if you like. Once you are done, please again send a tracked and a clean version.
I really appreciate the time and effort, and think that this is really good and very useful for us – thanks again.
Sara

From: Hanks, Katie P. [mailto:kphanks@rti.org]
Sent: Wednesday, August 13, 2014 11:24 AM
To: Ohrel, Sara; Baker, Justin; Cole, Jefferson; Beach, Robert H.
Subject: RE: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx

A revised version is attached, including one version with edits shown and answers to comment-bubble questions and another clean version. Please let me know if we need to make any further changes.

Deliberative

Katie Hanks
RTI International
3040 Cornwallis Road
Research Triangle Park, NC 27709
(919) 316-3732
(919) 541-7155 (fax)

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Tuesday, August 12, 2014 3:42 PM
To: Baker, Justin; Cole, Jefferson; Beach, Robert H.; Hanks, Katie P.
Subject: RE: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx

Hi all,
Nice work! Attached you will find my comments on BL – happy to discuss if needed tomorrow.

From: Ohrel, Sara
Sent: Tuesday, August 12, 2014 10:39 AM
To: 'Baker, Justin'; Cole, Jefferson; Beach, Robert H.; Hanks, Katie P.
Subject: RE: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx

Hi all,
I did get through half of this document this am but got dragged into other things this am. I will send comments as soon as I can this afternoon. So far, it looks really good J

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 4:58 PM
To: Ohrel, Sara; Cole, Jefferson; Beach, Robert H.; Hanks, Katie P.
Subject: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx

this email and all attachments are deliberative

Dear all,

Here is the draft black liquor addendum to Appendix D that Katie drafted. We added the language from Allen up-front. I think it's more appropriate here than as a stand-alone addendum because it sets up the remaining discussion and we don't present any other addendums with different industrial byproducts. If we had multiple case studies as separate addendums, then perhaps we would want to keep this language separate.

There are several comments, some for EPA review, and others that are included for the RTI editing team to address.

Please let us know if you have any questions.

Thanks,
Justin

From: Ohrel, Sara
To: Justin Baker (justinbaker@rti.org); Latane, Annah
Sent: 8/13/2014 2:37:18 PM
Subject: FW: NCASI Slides for Briefing on Mfg Residuals Study
Attachments: Final F2M_AFPA_Mill Residues_2014_0604.pdf; removed.txt

Deliberative do not share

From: Noe, Paul [mailto:Paul_Noe@afandpa.org]
Sent: Tuesday, August 12, 2014 2:47 PM
To: Dunham, Sarah; Krieger, Jackie; Irving, Bill; Hargrove, Anne; Fawcett, Allen; Kocchi, Suzanne; Cole, Jefferson; Ohrel, Sara
Cc: Miner, Reid; Gaudreault, Caroline; Lancey, Stan; Tsang, Linda; Missimer, Katie; Goffman, Joseph
Subject: RE: NCASI Slides for Briefing on Mfg Residuals Study

Hi Sarah et al:

Thank you all again for taking the time to meet with us on Monday to discuss the NCASI study and carbon accounting for forest products manufacturing residuals. One topic that came up in our discussion was the alternative fate of the residuals, including some residuals that potentially could be used for products.

To address this issue, we asked Forest2Market, a well-respected consulting firm that focuses on forest products industry economics, to prepare a short paper documenting the financial and logistical considerations that drive residual use. We sent this earlier in June, but I wanted to resend it so everyone has it.

The bottom line is that pulp and paper mill manufacturing residuals (black liquor, bark, and wood rejects) have few alternative uses and therefore might be landfilled, producing methane, or incinerated without energy recovery. Moreover, these residuals would need to be replaced with fossil fuels.

Some sawmill residuals, on the other hand, could potentially used to make wood panels, such as medium density fiberboard and particle board. The Forest2Market analysis shows that these product-related end-uses can pay much more than energy-related applications for sawmill residuals such as sawdust and shavings. Accordingly, these residuals would only be used for energy "when demand for composite panels is low or when the hauling costs to an MDF or particleboard mill are prohibitive."

Please let us know if you have any questions.

Best regards,

Paul

From: Noe, Paul
Sent: Monday, August 11, 2014 12:11 PM
To: Dunham, Sarah; krieger.jackie@epa.gov; William N. Irving (irving.bill@epa.gov); hargrove.anne@epa.gov; fawcett.allen@epa.gov; Kocchi.Suzanne@epa.gov; Cole, Jefferson; ohrel.sara@epa.gov
Cc: Miner, Reid; Gaudreault, Caroline; Vice, Kirsten; Lavigne, Chantal; Lancey, Stan; Tsang, Linda; Missimer, Katie; Goffman, Joseph
Subject: NCASI Slides for Briefing on Mfg Residuals Study

Hi Sarah et al:

Reid Miner of NCASI asked me to forward a copy of his slides for the briefing today at 3pm.

We look forward to seeing you.

Best regards,

Paul

Paul Noe
Vice President for Public Policy
Paul_Noe@afandpa.org
(202) 463-2777
AMERICAN FOREST & PAPER ASSOCIATION
1101 K Street, N.W., Suite 700
Washington, D.C. 20005

Overview

To support communications between the American Forest & Paper Association (AF&PA)/American Wood Council (AWC) and the U.S. Environmental Protection Agency (EPA) concerning carbon accounting standards for biogenic emissions from stationary sources, this brief outlines the current market for forest products manufacturing residuals--including sawmill secondary chips, shavings, sawdust and bark. The purpose of this brief is to provide the EPA with a factual framework for its decision by outlining the current markets and market drivers for these products, the relative value of this material by type of consumer and the ramifications of these factors for carbon accounting purposes.

Manufacturing residuals are produced by sawmills, pressed wood products facilities such as plywood plants, and pulp and paper mills. Because pulp and paper mills consume the residuals from their manufacturing processes (black liquour, limbs, bark and wood rejects) to generate electricity for their own operations (the pulp and paper sector is a net buyer of fuelwood; their manufacturing residuals are not generally available on the open market), this brief will focus primarily on the disposition of sawmill residuals.

1. Market Price of Sawmill Residuals

The two classes of manufacturing residuals produced by sawmills are:

- Secondary residuals, including secondary chips from cants (rounded slabs), planer shavings and sawdust. Secondary chips are sold on the open market to pulp and paper, composite panel and pellet mills. Shavings and sawdust are purchased by medium-density fiberboard (MDF), particle board and wood pellet manufacturers.
- Fuelwood is used by pulp & paper mills, sawmills, pellet manufacturers and mulch distributors. *Fuelwood* generally refers to the bark and other rejects from logs used in manufacturing **and** in-woods logging residuals; because this brief specifically address manufacturing residuals only, *fuelwood* herein refers to bark and other manufacturing rejects only.

Currently, the cost of bark on a delivered basis is one-third to one-half the cost of secondary chips, shavings and sawdust in U.S. markets. In the South (the largest wood basin in the U.S.), for instance, the cost of secondary chips averaged $37 per short green ton (ranging from $34 - $38 per ton) in 1Q2014. The cost of fuelwood averaged $22 per short green ton (ranging from $19 - $25 per ton).

2. The Supply of Sawmill Residuals

- The yield of sawmill manufacturing residuals from logs varies by species, product class (determined by height and diameter of tree) and is mill-efficiency dependent. Over the last 15 years, the volume of residuals has decreased by 20-25% due to increased efficiencies made possible by the new technologies being employed by sawmills. The industry continues to make improvements in this area.
- In general, a sawmill's output is 50-60% lumber, 30-33% secondary chips, 3-5% shavings and dust and 7-12% bark.

© 2014 Forest2Market, Inc.

3. **Sawmill Residuals Consumption**

- MDF and particle board manufacturers do not consume roundwood (cost-related reasons) or bark (process-related reasons). While the raw material mix varies by mill and region, the raw material mix for these manufacturers is roughly 90-100% sawmill residuals (secondary chips, shavings and sawdust). Mills in the Northwest U.S. use close to 100% shavings and sawdust, though some use secondary chips. Mills in the U.S. South use closer to a 50% secondary chips/50% shavings and sawdust mix, though some use a small percentage of primary (whole tree) chips.
- Approximately 95% of secondary chips on the open market are consumed by composite panel and pulp and paper manufacturers; the remaining 5% is consumed by pellet mills.
- Shavings and sawdust available on the open market are consumed by composite panel manufacturers (100%).
- Roughly 95% of the bark available on the open market is consumed by pulp and paper mills, 2% is purchased by sawmill and veneer mills, 2% goes to energy production (pellets and electricity) and the remaining 1% goes to mulch.
- Any material that is not used by one or the other of these consumers--either because of seasonal demand factors or because the distance to market is too great--would be incinerated or landfilled. Sawmills have a vested interest in finding alternative uses for their remaining residuals as tipping fees for landfills erode profits.

4. **Sawmill Residuals Market Drivers**

Current markets for sawmill residuals are driven by economic factors. These factors—capacity to pay, the higher costs of other raw materials and the distance between the sawmill and the secondary market and seasonal factors—will continue to drive the market regardless of whether the EPA designates manufacturing residuals as carbon neutral or not.

- The price paid to the manufacturer for the end product minus the cost of production (or cash break even) points to the fact that the capacity to pay for sawmill residuals advantages panel manufacturers. Forest2Market calculates the capacity of composite panel manufacturers to pay for raw materials at $72/ton. By comparison, the capacity of a pellet manufacturer to pay for raw materials is $39/ton. Due to the number of variables affecting biomass electricity plants, including size and efficiency of plant and state-based regulatory requirements, capacity to pay varies significantly among these facilities.
- Because of their higher capacity to pay, MDF and particleboard manufacturers are likely to continue being the major consumers of sawmill residuals even in light of any regulations or incentives enacted to encourage biomass energy production.
- The average haul distance between the sawmill and the secondary market in 1Q2014 in the South averaged 66 miles (with a range of 56 - 78 miles) for secondary chips and 60 miles (with a range of 50 - 75 miles) for fuelwood. In the Midwest and the Northwest, the average distance from the sawmill to the secondary mill is approximately 90 miles; for fuelwood, the average distance is 60 miles. In general, haul distances longer than these ranges make it economically infeasible to ship sawmill residuals to a secondary consumer. In these cases, mill residuals are more likely to be used for energy production.
- Demand can be seasonal. Mills using their own residuals to manufacture pellets for the domestic heating market will either produce an alternative product during the summer, or the small volume of shavings and dust they produce will be available on the open market. As a result, only when there is no local market for pellets will the shavings and dust produced by these mills find alternative uses. Mulch is also subject to seasonal shifts in demand; little is sold during winter months.
- Mulch demand is limited by location: in urban/suburban areas demand is higher, while little is used in rural areas.

© 2014 Forest2Market, Inc.

Implications for Biogenic Carbon Emissions and EPA Standards

- When manufacturing residuals are used to manufacture composite panels, they become long-lived wood products that continue to store carbon. This table was sourced from the Forest Service's Northeastern Research Sation. It specifies both the fraction of the carbon sequestered in the primary wood product (i.e., the debarked tree) used to manufacture MDF and particleboard that is still sequestered in the panel for each decade following its manufacture.

MDF/Particle Board		
Year after production	Fraction of carbon in primary wood product sequestered	Fraction of primary wood product in landfill
10	0.741	0.163
20	0.569	0.261
30	0.450	0.321
40	0.364	0.361
50	0.301	0.388
60	0.252	0.408
70	0.214	0.424
80	0.183	0.436
90	0.159	0.446
100	0.138	0.454

Source: USDA Forest Service Northeastern Research Station, "Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types in the United States" Gen. Tech. Rep. NE-343

- From a carbon release perspective, the use of both sawmill and pulp and paper mill residuals for energy is the next most logical use for them when demand for composite panels is low or when the hauling costs to an MDF or particleboard mill are prohibitive.
  - Harvest levels are driven by demand for pulp and paper and lumber, not by demand for residuals. As a result, the amount of manufacturing residuals eventually used for energy production has no effect on the volume of wood harvested from forests. From this perspective, when this material is used for energy production, the amount of carbon released into the atmosphere is the equivalent of what would be released even if the material was not used for energy production.
  - In addition, biomass energy displaces energy generated from fossil fuels, which are non-biogenenic sources of carbon and increase the net amount of carbon in the atmosphere.
- When mill residuals are not used for the production of panels or energy, they are disposed of through incineration (without energy production) or landfilling.

© 2014 Forest2Market, Inc.

From: Ohrel, Sara
To: Baker, Justin
Sent: 8/13/2014 9:58:11 AM
Subject: RE: Deliberative-- Biomass for electricity generation 8 12 14_RTI.xlsx

Thanks again, Justin. I am sorry to have to ask that of you with everything else on your plate yesterday.
Do you have 15 mins to touch base today on biomass?

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Wednesday, August 13, 2014 9:56 AM
To: Fawcett, Allen; Ohrel, Sara; Cole, Jefferson
Cc: Hanks, Katie P.
Subject: RE: Deliberative-- Biomass for electricity generation 8 12 14_RTI.xlsx

Thanks, all, and apologies for the confusion. Yes, I was definitely just focused on centering the totals and did not try to line up with the different feedstock categories.

I hope the briefing goes well.

Justin

From: Fawcett, Allen [mailto:Fawcett.Allen@epa.gov]
Sent: Tuesday, August 12, 2014 5:41 PM
To: Ohrel, Sara; Baker, Justin; Cole, Jefferson
Cc: Hanks, Katie P.
Subject: RE: Deliberative-- Biomass for electricity generation 8 12 14_RTI.xlsx

Thanks Sara. Here's an updated version we'll use.

Allen

From: Ohrel, Sara
Sent: Tuesday, August 12, 2014 5:38 PM
To: Fawcett, Allen; Baker, Justin; Cole, Jefferson
Cc: Hanks, Katie P.
Subject: Re: Deliberative-- Biomass for electricity generation 8 12 14_RTI.xlsx

Hi Allen,
I believe that your assessment is correct. **Ex. 5 - Deliberative**
Ex. 5 - Deliberative Justin will be sending the underlying calculations tomorrow am, as it was directly in the big downloaded EIA excel. But for now, please run with your estimation for now unless we hear from Justin soon.

From: Fawcett, Allen
Sent: Tuesday, August 12, 2014 5:26 PM
To: Baker, Justin; Ohrel, Sara; Cole, Jefferson
Cc: Hanks, Katie P.
Subject: RE: Deliberative-- Biomass for electricity generation 8 12 14_RTI.xlsx

Thanks Justin.

Ex. 5 - Deliberative

Ex. 5 - Deliberative

If both of those are totals, is the below version right?

Thanks,
Allen

Ex. 5 - Deliberative

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Tuesday, August 12, 2014 5:06 PM
To: Ohrel, Sara; Cole, Jefferson; Fawcett, Allen
Cc: Hanks, Katie P.
Subject: Deliberative-- Biomass for electricity generation 8 12 14_RTI.xlsx

__this email and all attachments are deliberative__

Dear all,

Ex. 5 - Deliberative

Thanks, and let me know if you have any questions.

From: Cole, Jefferson
To: Ohrel, Sara
Sent: 8/13/2014 1:50:27 PM
Subject: RE: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx
Attachments: AppD_Addendum_Black_Liquor_Fate_8-13-14 jc.docx

This email is deliberative

Sara,

I have a couple suggested edits in the paragraph that spans the bottom of page 1 and top of page 2 on something that caught my eye.

Sending it to just you for now for your feedback. Can send to the wider group if you wish.

Jeff

From: Ohrel, Sara
Sent: Wednesday, August 13, 2014 11:26 AM
To: Hanks, Katie P.; Baker, Justin; Cole, Jefferson; Beach, Robert H.
Subject: RE: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx

Great, thank you Katie!!

From: Hanks, Katie P. [mailto:kphanks@rti.org]
Sent: Wednesday, August 13, 2014 11:24 AM
To: Ohrel, Sara; Baker, Justin; Cole, Jefferson; Beach, Robert H.
Subject: RE: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx

A revised version is attached, including one version with edits shown and answers to comment-bubble questions and another clean version. Please let me know if we need to make any further changes.

Deliberative

Katie Hanks
RTI International
3040 Cornwallis Road
Research Triangle Park, NC 27709
(919) 316-3732
(919) 541-7155 (fax)

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Tuesday, August 12, 2014 3:42 PM
To: Baker, Justin; Cole, Jefferson; Beach, Robert H.; Hanks, Katie P.
Subject: RE: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx

Hi all,
Nice work! Attached you will find my comments on BL – happy to discuss if needed tomorrow.

From: Ohrel, Sara
Sent: Tuesday, August 12, 2014 10:39 AM

To: 'Baker, Justin'; Cole, Jefferson; Beach, Robert H.; Hanks, Katie P.
Subject: RE: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx

Hi all,
I did get through half of this document this am but got dragged into other things this am. I will send comments as soon as I can this afternoon. So far, it looks really good J

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 4:58 PM
To: Ohrel, Sara; Cole, Jefferson; Beach, Robert H.; Hanks, Katie P.
Subject: Deliberative-- AppD_Addendum_Black_Liquor_Fate_8-11-14.docx

__this email and all attachments are deliberative__

Dear all,

Here is the draft black liquor addendum to Appendix D that Katie drafted. We added the language from Allen up-front. I think it's more appropriate here than as a stand-alone addendum because it sets up the remaining discussion and we don't present any other addendums with different industrial byproducts. If we had multiple case studies as separate addendums, then perhaps we would want to keep this language separate.

There are several comments, some for EPA review, and others that are included for the RTI editing team to address.

Please let us know if you have any questions.

Thanks,
Justin

From: Ohrel, Sara
To: Baker, Justin
Sent: 8/11/2014 2:31:36 PM
Subject: RE: EIA 923 - Biomass for Elect Consumption.xlsx - deliberative

Just biogenic please

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 2:30 PM
To: Ohrel, Sara
Subject: RE: EIA 923 - Biomass for Elect Consumption.xlsx - deliberative

MSW—include just the biogenic portion, or non-biogenic as well?

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Monday, August 11, 2014 2:04 PM
To: Baker, Justin
Subject: RE: EIA 923 - Biomass for Elect Consumption.xlsx - deliberative

Thanks Justin.
What I am trying to do is fill in this table (attached).

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 1:55 PM
To: Ohrel, Sara
Subject: RE: EIA 923 - Biomass for Elect Consumption.xlsx

OBS is not clearly defined by EIA, as it is a value that users plug into the survey (and provide comments on) if they feel that the biomass source they are using does not fall into the clearly defined categories. So, this could include hog-waste, which could come from a number of biomass sources and the facility operator might not be able to categorize this as one specific feedstock sources. Here is the EIA table with some biomass groupings:

Renewable Fuels			
AB	tons	ORW	Agricultural Crop Byproducts/Straw/Energy Crops
MSB	tons	MLG	Municipal Solid Waste – Biogenic component
OBS	tons	ORW	Other Biomass Solids
WDS	tons	WWW	Wood/Wood Waste Solids (paper pellets, railroad ties, utility poles, wood chips, bark, an other wood waste solids)
OBL	barrels	ORW	Other Biomass Liquids (specify in Comments)
BLQ	tons	WWW	Black Liquor

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Monday, August 11, 2014 1:33 PM
To: Baker, Justin
Subject: RE: EIA 923 - Biomass for Elect Consumption.xlsx

What does the 'other biomass solids' include?

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 1:04 PM
To: Ohrel, Sara
Subject: EIA 923 - Biomass for Elect Consumption.xlsx

Just back from a meeting. Here is the file with the sorted table. I can't attach the entire EIA-923 dataset because it is way too large.

Ex. 5 - Deliberative

Happy to discuss further, but I have another quick meeting. Back in the office by 1:30 at the latest.

From: Ohrel, Sara
To: Baker, Justin
CC: Cole, Jefferson
Sent: 8/11/2014 1:34:49 PM
Subject: RE: heads up - biomass

http://maps.nrel.gov/biopower seems they use info from EIA 2007

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 10:48 AM
To: Ohrel, Sara
Cc: Cole, Jefferson
Subject: RE: heads up - biomass

Yes, we can work on that this week. You mentioned earlier that the NREL database has some of this information? Can you send me a link to that so that we're using the same file?

Thanks,
Justin

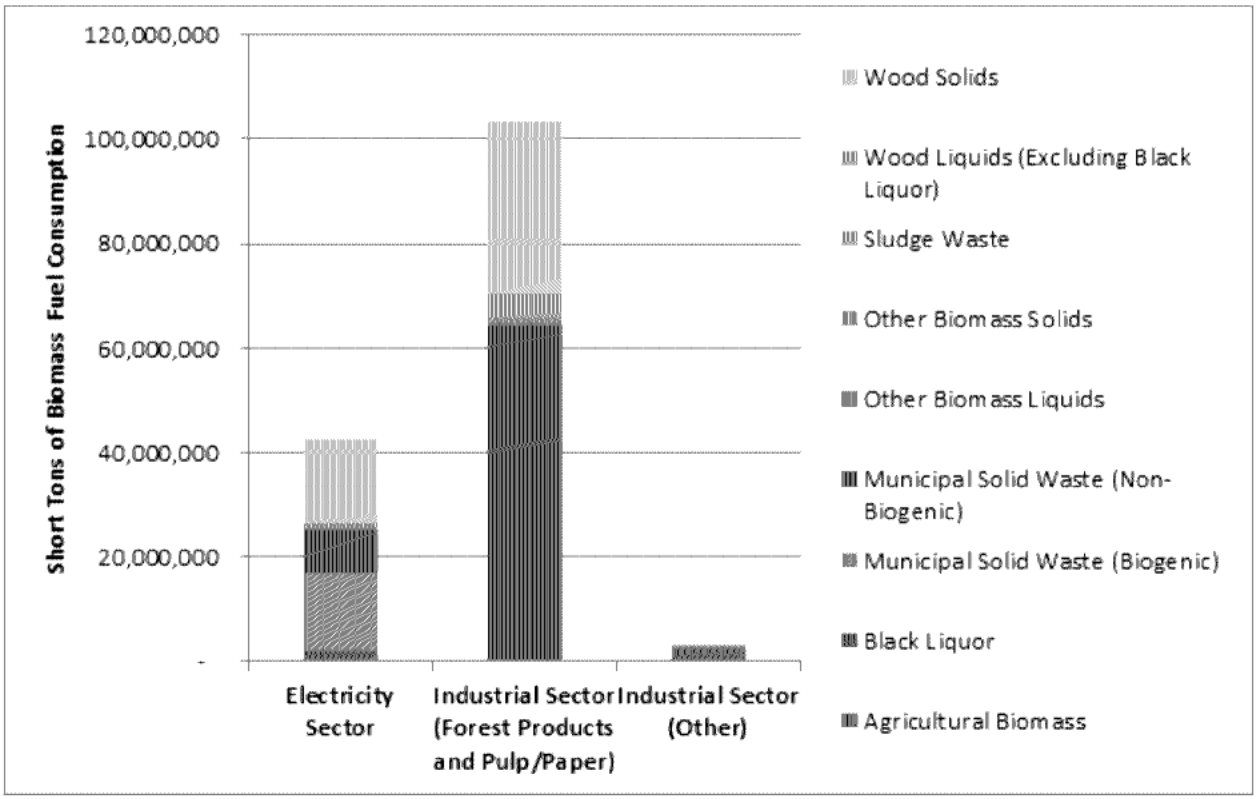
From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Monday, August 11, 2014 10:38 AM
To: Baker, Justin
Cc: Cole, Jefferson
Subject: RE: heads up - biomass

Thanks again Justin.
Just to get prepared for other such questions that are sure to come, we need to break this data out in different ways if possible: **Ex. 5 - Deliberative** so we can have all it onhand, ready for data requests like this. Can you help put this together this week?

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 10:21 AM
To: Ohrel, Sara
Subject: RE: heads up - biomass

Here is a table and a figure that you can plug in asap. I will send another email with the raw data and explanation. Note

Ex. 5 - Deliberative



	Electricity Sector	Industrial Sector (Forest Products and Pulp/Paper)	Industrial Sector (Other)	TOTAL
Agricultural Biomass	1,275,071	155,207	2,135,103	3,565,381
Black Liquor	715,330	64,369,461	-	65,084,791
Municipal Solid Waste (Biogenic)	14,973,215	-	202,601	15,175,816
Municipal Solid Waste (Non-Biogenic)	8,422,418	-	113,963	8,536,381
Other Biomass Liquids	-	35,550	47,076	82,626
Other Biomass Solids	898,830	1,147,796	474,565	2,521,191
Sludge Waste	41,295	551,929	109,009	702,233
Wood Liquids (Excluding Black Liquor)	-	4,297,904	-	4,297,904
Wood Solids	16,135,395	32,734,105	1,068	48,870,568
TOTAL	**42,461,554**	**103,291,952**	**3,083,385**	**148,836,891**

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Monday, August 11, 2014 10:11 AM
To: Baker, Justin
Subject: FW: heads up - biomass

FYI in case it relates to what you are putting together

From: Cole, Jefferson
Sent: Monday, August 11, 2014 10:10 AM
To: Irving, Bill; Ohrel, Sara; Kocchi, Suzanne; DeLuca, Isabel
Cc: Fawcett, Allen
Subject: RE: heads up - biomass

Something I found from the Electric Power Annual – 2012 report (published in Dec. 2013)
http://www.eia.gov/electricity/annual/?src=Electricity-f5

The data from Sara and Justin will be more detailed.

Not quite the disaggregation/feedstocks you were looking for, but for 2012:

% of Total Electricity Production in U.S. in 2012

Wood and Wood-Derived Fuels	0.93%
Landfill Gas	0.24%
Biogenic Municipal Solid Waste	0.18%
Other Waste Biomass	0.07%

Jeff

From: Irving, Bill
Sent: Monday, August 11, 2014 9:44 AM
To: Ohrel, Sara; Kocchi, Suzanne; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen
Subject: RE: heads up - biomass

Sara, Jeff

Is there something quick from EIA or another source that would give us information on the share of current power production provided by different feedstocks? E.g.,

MSW – X%
Wood pellets – Y%
Ag Residues – Z%
Logging & mill residues –
etc

It might be useful as background for Sarah to understand what States are likely to care most about. All I could find was this: http://biomassmagazine.com/plants/listplants/biomass/US/

From: Ohrel, Sara
Sent: Monday, August 11, 2014 9:28 AM
To: Kocchi, Suzanne; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen; Irving, Bill
Subject: RE: heads up - biomass

Hi Suzie,
Here is what I have put together for meeting this am.

NOTE: **Ex. 5 - Deliberative**

Ex. 5 - Deliberative

Ex. 5 - Deliberative

From: Kocchi, Suzanne
Sent: Monday, August 11, 2014 8:31 AM

To: Ohrel, Sara; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen; Irving, Bill
Subject: heads up - biomass
Importance: High

Hi All – Just a warning this is likely to be another crazy week on biomass. Sarah has forwarded 2 emails to me from the weekend. First one said there was interest in briefing Gina (this week) and WH (first week of Sep) on our path forward. The second one said there will be a small meeting with Janet this week (not sure if that supplants or is in addition to Gina this week). Janet wants to talk specifically on **Ex. 5 - Deliberative** **Ex. 5 - Deliberative** It is likely Bill and I will be holding the pen on most of the materials but I will let you know when I hear more from Sarah this am (at the OAP mgmt mtg).

In the meantime can you please give me **Ex. 5 - Deliberative**

Ex. 5 - Deliberative

Stay tuned and thanks again in advance for your patience this week –
Suzie

Ps: FYI - Attached above is the "cover memo" Sarah sent up to Janet. I am sure there is another version now but that is the latest we have. I have saved it on the G drive also.

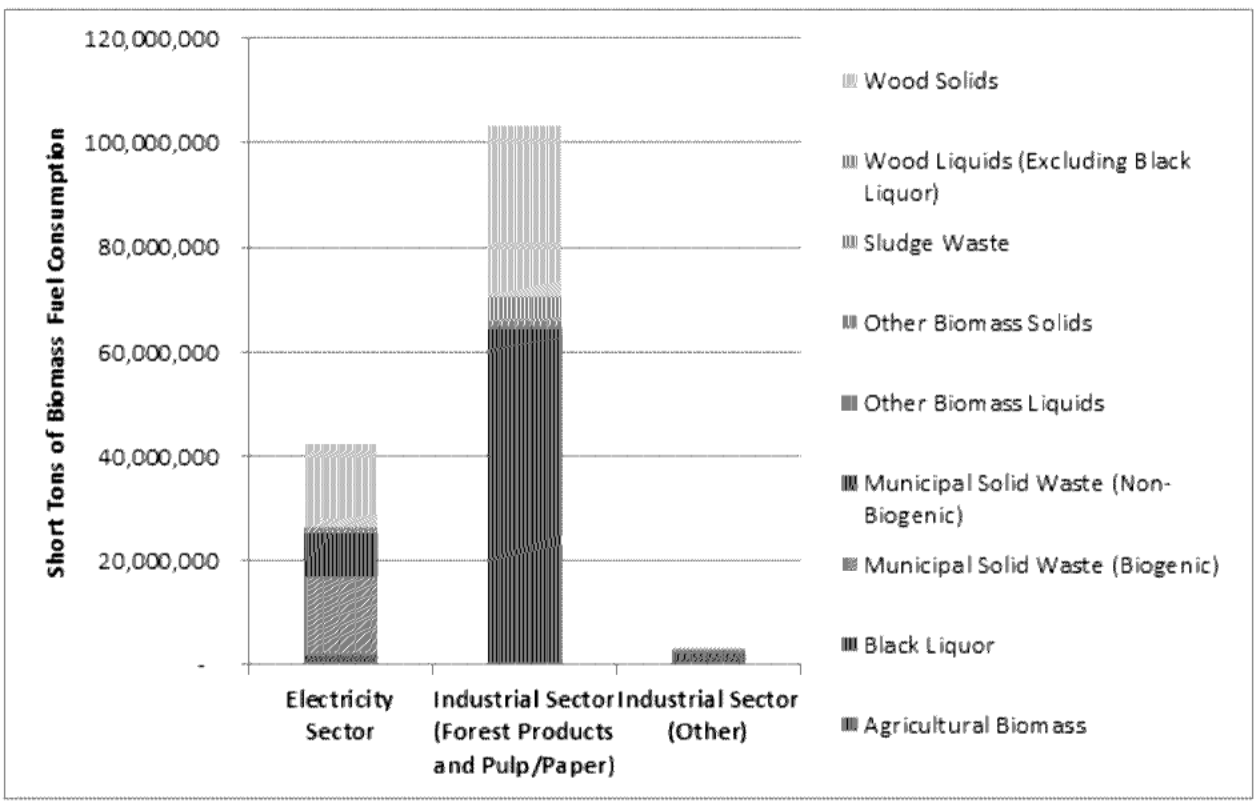
From: Ohrel, Sara
To: Baker, Justin
Sent: 8/11/2014 12:43:01 PM
Subject: RE: heads up - biomass

Hi Justin,
Please let me know when you are sending the raw info and explanation. I would like to look at it to see what I can use for this new table request – thanks!

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 10:21 AM
To: Ohrel, Sara
Subject: RE: heads up - biomass

Here is a table and a figure that you can plug in asap. I will send another email with the raw data and explanation. Note

Ex. 5 - Deliberative



	Electricity Sector	Industrial Sector (Forest Products and Pulp/Paper)	Industrial Sector (Other)	TOTAL
Agricultural Biomass	1,275,071	155,207	2,135,103	3,565,381
Black Liquor	715,330	64,369,461	-	65,084,791
Municipal Solid Waste (Biogenic)	14,973,215	-	202,601	15,175,816
Municipal Solid Waste (Non-Biogenic)	8,422,418	-	113,963	8,536,381
Other Biomass Liquids	-	35,550	47,076	82,626
Other Biomass Solids	898,830	1,147,796	474,565	2,521,191
Sludge Waste	41,295	551,929	109,009	702,233

Wood Liquids (Excluding Black Liquor)	-	4,297,904	-	4,297,904
Wood Solids	16,135,395	32,734,105	1,068	48,870,568
TOTAL	**42,461,554**	**103,291,952**	**3,083,385**	**148,836,891**

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Monday, August 11, 2014 10:11 AM
To: Baker, Justin
Subject: FW: heads up - biomass

FYI in case it relates to what you are putting together

From: Cole, Jefferson
Sent: Monday, August 11, 2014 10:10 AM
To: Irving, Bill; Ohrel, Sara; Kocchi, Suzanne; DeLuca, Isabel
Cc: Fawcett, Allen
Subject: RE: heads up - biomass

Something I found from the Electric Power Annual – 2012 report (published in Dec. 2013)
http://www.eia.gov/electricity/annual/?src=Electricity-f5

The data from Sara and Justin will be more detailed.

Not quite the disaggregation/feedstocks you were looking for, but for 2012:

% of Total Electricity Production in U.S. in 2012
Wood and Wood-Derived Fuels 0.93%
Landfill Gas 0.24%
Biogenic Municipal Solid Waste 0.18%
Other Waste Biomass 0.07%

Jeff

From: Irving, Bill
Sent: Monday, August 11, 2014 9:44 AM
To: Ohrel, Sara; Kocchi, Suzanne; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen
Subject: RE: heads up - biomass

Sara, Jeff

Is there something quick from EIA or another source that would give us information on the share of current power production provided by different feedstocks? E.g.,

MSW – X%
Wood pellets – Y%
Ag Residues – Z%
Logging & mill residues –
etc

It might be useful as background for Sarah to understand what States are likely to care most about. All I could find was this: http://biomassmagazine.com/plants/listplants/biomass/US/

From: Ohrel, Sara
Sent: Monday, August 11, 2014 9:28 AM
To: Kocchi, Suzanne; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen; Irving, Bill
Subject: RE: heads up - biomass

Hi Suzie,
Here is what I have put together for meeting this am.

NOTE: **Ex. 5 - Deliberative**
Ex. 5 - Deliberative
Ex. 5 - Deliberative

From: Kocchi, Suzanne
Sent: Monday, August 11, 2014 8:31 AM
To: Ohrel, Sara; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen; Irving, Bill
Subject: heads up - biomass
Importance: High

Hi All – Just a warning this is likely to be another crazy week on biomass. Sarah has forwarded 2 emails to me from the weekend. First one said there was interest in briefing Gina (this week) and WH (first week of Sep) on our path forward. The second one said there will be a small meeting with Janet this week (not sure if that supplants or is in addition to Gina this week). Janet wants to talk specifically on **Ex. 5 - Deliberative**
Ex. 5 - Deliberative It is likely Bill and I will be holding the pen on most of the materials but I will let you know when I hear more from Sarah this am (at the OAP mgmt mtg).

In the meantime can you please give me **Ex. 5 - Deliberative**
Ex. 5 - Deliberative

Stay tuned and thanks again in advance for your patience this week –
Suzie

Ps: FYI - Attached above is the "cover memo" Sarah sent up to Janet. I am sure there is another version now but that is the latest we have. I have saved it on the G drive also.

From: Ohrel, Sara
To: Baker, Justin
CC: Cole, Jefferson
Sent: 8/11/2014 10:49:51 AM
Subject: Re: heads up - biomass

Thanks. It looks like they use older EIA data so not very helpful. Will keep digging and send you what I find.

From: Baker, Justin
Sent: Monday, August 11, 2014 10:47 AM
To: Ohrel, Sara
Cc: Cole, Jefferson
Subject: RE: heads up - biomass

Yes, we can work on that this week. You mentioned earlier that the NREL database has some of this information? Can you send me a link to that so that we're using the same file?

Thanks,
Justin

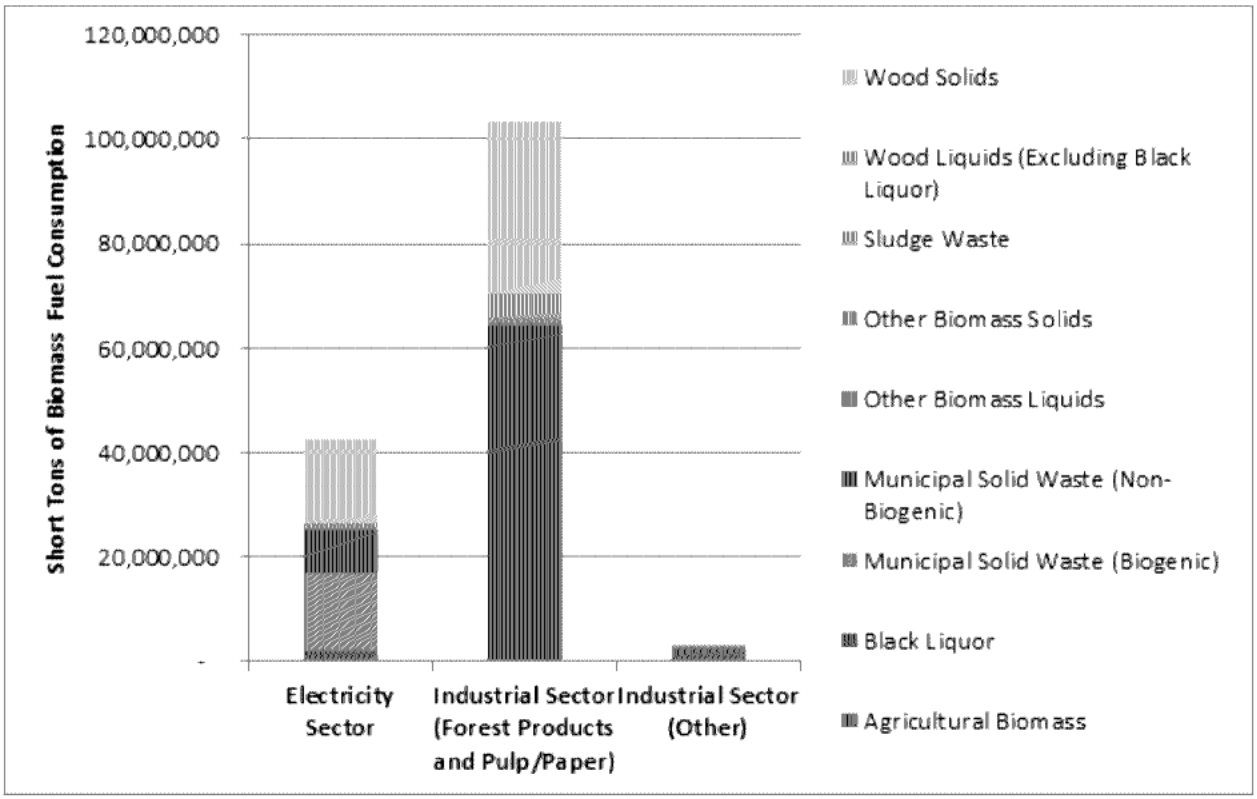
From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Monday, August 11, 2014 10:38 AM
To: Baker, Justin
Cc: Cole, Jefferson
Subject: RE: heads up - biomass

Thanks again Justin.
Just to get prepared for other such questions that are sure to come, we need to break this data out in different ways if possible: **Ex. 5 - Deliberative** so we can have all it onhand, ready for data requests like this. Can you help put this together this week?

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 10:21 AM
To: Ohrel, Sara
Subject: RE: heads up - biomass

Here is a table and a figure that you can plug in asap. I will send another email with the raw data and explanation. Note

Ex. 5 - Deliberative



	Electricity Sector	Industrial Sector (Forest Products and Pulp/Paper)	Industrial Sector (Other)	TOTAL
Agricultural Biomass	1,275,071	155,207	2,135,103	3,565,381
Black Liquor	715,330	64,369,461	-	65,084,791
Municipal Solid Waste (Biogenic)	14,973,215	-	202,601	15,175,816
Municipal Solid Waste (Non-Biogenic)	8,422,418	-	113,963	8,536,381
Other Biomass Liquids	-	35,550	47,076	82,626
Other Biomass Solids	898,830	1,147,796	474,565	2,521,191
Sludge Waste	41,295	551,929	109,009	702,233
Wood Liquids (Excluding Black Liquor)	-	4,297,904	-	4,297,904
Wood Solids	16,135,395	32,734,105	1,068	48,870,568
TOTAL	**42,461,554**	**103,291,952**	**3,083,385**	**148,836,891**

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Monday, August 11, 2014 10:11 AM
To: Baker, Justin
Subject: FW: heads up - biomass

FYI in case it relates to what you are putting together

From: Cole, Jefferson
Sent: Monday, August 11, 2014 10:10 AM
To: Irving, Bill; Ohrel, Sara; Kocchi, Suzanne; DeLuca, Isabel
Cc: Fawcett, Allen
Subject: RE: heads up - biomass

Something I found from the Electric Power Annual – 2012 report (published in Dec. 2013)
http://www.eia.gov/electricity/annual/?src=Electricity-f5

The data from Sara and Justin will be more detailed.

Not quite the disaggregation/feedstocks you were looking for, but for 2012:

% of Total Electricity Production in U.S. in 2012

Wood and Wood-Derived Fuels	0.93%
Landfill Gas	0.24%
Biogenic Municipal Solid Waste	0.18%
Other Waste Biomass	0.07%

Jeff

From: Irving, Bill
Sent: Monday, August 11, 2014 9:44 AM
To: Ohrel, Sara; Kocchi, Suzanne; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen
Subject: RE: heads up - biomass

Sara, Jeff

Is there something quick from EIA or another source that would give us information on the share of current power production provided by different feedstocks? E.g.,

MSW – X%
Wood pellets – Y%
Ag Residues – Z%
Logging & mill residues –
etc

It might be useful as background for Sarah to understand what States are likely to care most about. All I could find was this: http://biomassmagazine.com/plants/listplants/biomass/US/

From: Ohrel, Sara
Sent: Monday, August 11, 2014 9:28 AM
To: Kocchi, Suzanne; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen; Irving, Bill
Subject: RE: heads up - biomass

Hi Suzie,
Here is what I have put together for meeting this am.

NOTE: **Ex. 5 - Deliberative**
Ex. 5 - Deliberative
Ex. 5 - Deliberative

From: Kocchi, Suzanne
Sent: Monday, August 11, 2014 8:31 AM

To: Ohrel, Sara; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen; Irving, Bill
Subject: heads up - biomass
Importance: High

Hi All – Just a warning this is likely to be another crazy week on biomass. Sarah has forwarded 2 emails to me from the weekend. First one said there was interest in briefing Gina (this week) and WH (first week of Sep) on our path forward. The second one said there will be a small meeting with Janet this week (not sure if that supplants or is in addition to Gina this week). Janet wants to talk specifically on **Ex. 5 - Deliberative** **Ex. 5 - Deliberative** It is likely Bill and I will be holding the pen on most of the materials but I will let you know when I hear more from Sarah this am (at the OAP mgmt mtg).

In the meantime can you please give me **Ex. 5 - Deliberative**

Ex. 5 - Deliberative

Stay tuned and thanks again in advance for your patience this week –
Suzie

Ps: FYI - Attached above is the "cover memo" Sarah sent up to Janet. I am sure there is another version now but that is the latest we have. I have saved it on the G drive also.

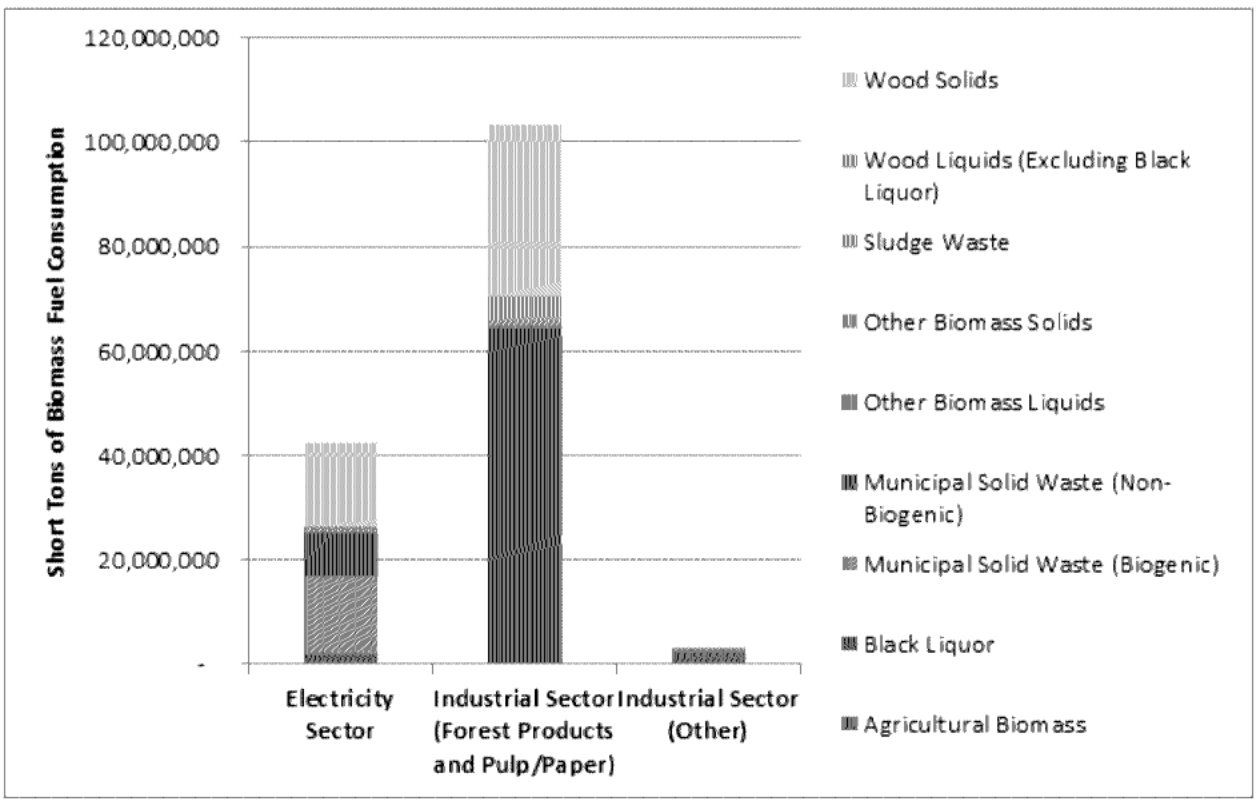
From: Ohrel, Sara
To: Baker, Justin
Sent: 8/11/2014 10:21:42 AM
Subject: RE: heads up - biomass

From 2012 correct?
THANK YOU!

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 10:21 AM
To: Ohrel, Sara
Subject: RE: heads up - biomass

Here is a table and a figure that you can plug in asap. I will send another email with the raw data and explanation. Note

Ex. 5 - Deliberative



	Electricity Sector	Industrial Sector (Forest Products and Pulp/Paper)	Industrial Sector (Other)	TOTAL
Agricultural Biomass	1,275,071	155,207	2,135,103	3,565,381
Black Liquor	715,330	64,369,461	-	65,084,791
Municipal Solid Waste (Biogenic)	14,973,215	-	202,601	15,175,816
Municipal Solid Waste (Non-Biogenic)	8,422,418	-	113,963	8,536,381
Other Biomass Liquids	-	35,550	47,076	82,626
Other Biomass Solids	898,830	1,147,796	474,565	2,521,191
Sludge Waste	41,295	551,929	109,009	702,233
Wood Liquids (Excluding Black Liquor)	-	4,297,904	-	4,297,904

Wood Solids	16,135,395	32,734,105	1,068	48,870,568
TOTAL	**42,461,554**	**103,291,952**	**3,083,385**	**148,836,891**

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Monday, August 11, 2014 10:11 AM
To: Baker, Justin
Subject: FW: heads up - biomass

FYI in case it relates to what you are putting together

From: Cole, Jefferson
Sent: Monday, August 11, 2014 10:10 AM
To: Irving, Bill; Ohrel, Sara; Kocchi, Suzanne; DeLuca, Isabel
Cc: Fawcett, Allen
Subject: RE: heads up - biomass

Something I found from the Electric Power Annual – 2012 report (published in Dec. 2013)
http://www.eia.gov/electricity/annual/?src=Electricity-f5

The data from Sara and Justin will be more detailed.

Not quite the disaggregation/feedstocks you were looking for, but for 2012:

% of Total Electricity Production in U.S. in 2012
Wood and Wood-Derived Fuels 0.93%
Landfill Gas 0.24%
Biogenic Municipal Solid Waste 0.18%
Other Waste Biomass 0.07%

Jeff

From: Irving, Bill
Sent: Monday, August 11, 2014 9:44 AM
To: Ohrel, Sara; Kocchi, Suzanne; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen
Subject: RE: heads up - biomass

Sara, Jeff

Is there something quick from EIA or another source that would give us information on the share of current power production provided by different feedstocks? E.g.,

MSW – X%
Wood pellets – Y%
Ag Residues – Z%
Logging & mill residues –
etc

It might be useful as background for Sarah to understand what States are likely to care most about. All I could find was this: http://biomassmagazine.com/plants/listplants/biomass/US/

From: Ohrel, Sara
Sent: Monday, August 11, 2014 9:28 AM
To: Kocchi, Suzanne; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen; Irving, Bill
Subject: RE: heads up - biomass

Hi Suzie,
Here is what I have put together for meeting this am.

NOTE: we will need to find a way to **Ex. 5 - Deliberative**
Ex. 5 - Deliberative
Ex. 5 - Deliberative

From: Kocchi, Suzanne
Sent: Monday, August 11, 2014 8:31 AM
To: Ohrel, Sara; Cole, Jefferson; DeLuca, Isabel
Cc: Fawcett, Allen; Irving, Bill
Subject: heads up - biomass
Importance: High

Hi All – Just a warning this is likely to be another crazy week on biomass. Sarah has forwarded 2 emails to me from the weekend. First one said there was interest in briefing Gina (this week) and WH (first week of Sep) on our path forward. The second one said there will be a small meeting with Janet this week (not sure if that supplants or is in addition to Gina this week). Janet wants to talk specifically on **Ex. 5 - Deliberative**
Ex. 5 - Deliberative It is likely Bill and I will be holding the pen on most of the materials but I will let you know when I hear more from Sarah this am (at the OAP mgmt mtg).

In the meantime can you please give me **Ex. 5 - Deliberative**
Ex. 5 - Deliberative

Stay tuned and thanks again in advance for your patience this week –
Suzie

Ps: FYI - Attached above is the "cover memo" Sarah sent up to Janet. I am sure there is another version now but that is the latest we have. I have saved it on the G drive also.

From: Baker, Justin
To: Ohrel, Sara; Cole, Jefferson
Sent: 8/11/2014 2:37:41 PM
Subject: EIA 923 - Biomass for Elect Consumption.xlsx
Attachments: EIA 923 - Biomass for Elect Consumption.xlsx

Here is the updated EIA-923 biomass consumption table with landfill gas, other biomass gas, and wood liquids.

Justin

From: Cole, Jefferson
To: Ohrel, Sara; Justin Baker (justinbaker@rti.org)
Sent: 8/11/2014 11:56:33 AM
Subject: RE: heads up - biomass - deliberative

Thanks, Sara.

I concur with your thoughts and concerns. I'll look into Ex. 5 - Deliberative

Jeff

From: Ohrel, Sara
Sent: Monday, August 11, 2014 11:54 AM
To: Justin Baker (justinbaker@rti.org); Cole, Jefferson
Subject: FW: heads up - biomass - deliberative

Hi Justin and Jeff,
This is what we are now being asked to do (BELOW). I will come up with a template we can use.

Ex. 5 - Deliberative

So we will need:

Ex. 5 - Deliberative

From: Fawcett, Allen
Sent: Monday, August 11, 2014 11:29 AM
To: Ohrel, Sara
Cc: Cole, Jefferson
Subject: Re: heads up - biomass

So the first ask from the Sarah meeting is a table that we can use for the Gina/WH meeting that shows Ex. 5 - Deliberative

Ex. 5 - Deliberative

Ex. 5 - Deliberative

The Gina meeting isn't on the calendar yet, but we're expecting it to be this week. Sarah would like to see a draft of this table by COB today, and we'll work on the slides to get her for tomorrow.
I'm in another meeting until noon, but we can chat when I'm back to further discuss.

Thanks,
Allen

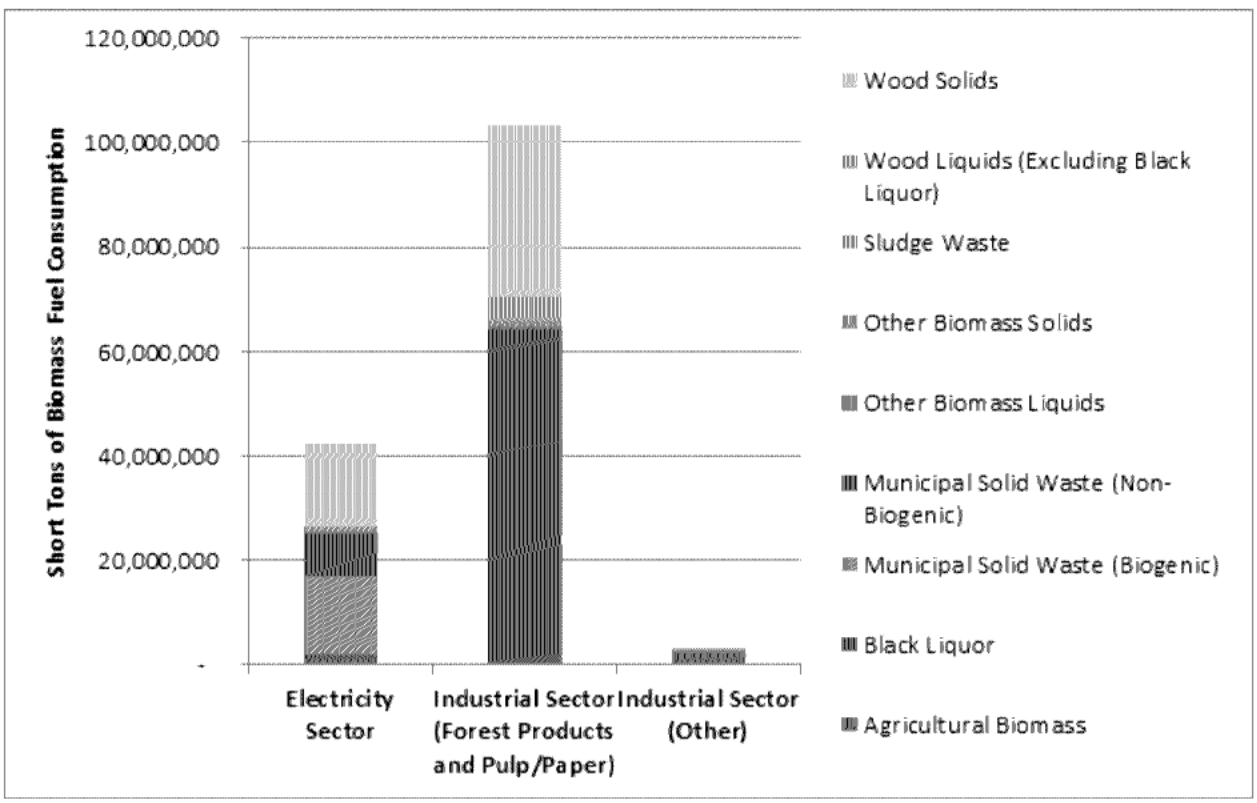
From: Ohrel, Sara
Sent: Monday, August 11, 2014 10:24 AM
To: Irving, Bill; Fawcett, Allen; Kocchi, Suzanne
Cc: Cole, Jefferson
Subject: FW: heads up - biomass

Data per various feedstock categories in 2012 per short ton utilized. Pellets and other subcategories included in wood solids.

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Monday, August 11, 2014 10:21 AM
To: Ohrel, Sara
Subject: RE: heads up - biomass

Here is a table and a figure that you can plug in asap. I will send another email with the raw data and explanation. Note

Ex. 5 - Deliberative



	Electricity Sector	Industrial Sector (Forest Products and Pulp/Paper)	Industrial Sector (Other)	TOTAL
Agricultural Biomass	1,275,071	155,207	2,135,103	3,565,381
Black Liquor	715,330	64,369,461	-	65,084,791
Municipal Solid Waste (Biogenic)	14,973,215	-	202,601	15,175,816
Municipal Solid Waste (Non-Biogenic)	8,422,418	-	113,963	8,536,381
Other Biomass Liquids	-	35,550	47,076	82,626
Other Biomass Solids	898,830	1,147,796	474,565	2,521,191

Sludge Waste	41,295	551,929	109,009	702,233
Wood Liquids (Excluding Black Liquor)	-	4,297,904	-	4,297,904
Wood Solids	16,135,395	32,734,105	1,068	48,870,568
TOTAL	**42,461,554**	**103,291,952**	**3,083,385**	**148,836,891**

From: Michelle Manion
To: Ohrel, Sara; Cole, Jefferson
CC: David Cooley
Sent: 8/9/2014 8:32:38 AM
Subject: Biomass White Paper
Attachments: DRAFT WHITE PAPER - Biogenic Carbon 2014-08-08.docx

Hi Sara and Jefferson,

Here is our latest draft of the Biomass White Paper, with Ex. 5 - Deliberative

Ex. 5 - Deliberative

We'll be in touch next week to set up a time to discuss feedback, next steps, etc.

Have a great weekend,

--Michelle

Michelle Manion| **Senior Associate** | Abt Associates
55 Wheeler Street, Cambridge MA 02138
T: 617.520.2379|C: 617.631.2015| E: Michelle_Manion@abtassoc.com

BOLD THINKERS DRIVING REAL-WORLD IMPACT

www.abtassociates.com

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Friday, August 08, 2014 3:49 PM
To: David Cooley; Cole, Jefferson
Cc: Michelle Manion
Subject: RE: Biomass White Paper

Sounds great, thanks David. I had a reminder about this pop up in my calendar today, so I was hoping to hear from you all J
Thank you and have a good weekend,
Sara

From: David Cooley [mailto:David_Cooley@abtassoc.com]
Sent: Friday, August 08, 2014 3:39 PM
To: Ohrel, Sara; Cole, Jefferson
Cc: Michelle Manion
Subject: Biomass White Paper

Hi Sara and Jeff,

Michelle and I wanted to give you a heads up that we'll be sending you the draft white paper today, but it will probably be later this evening. Since it's pretty long and you might not have time to get through it before Wednesday, we thought we'd reschedule our normal check-in call. I'll be in touch early next week to schedule a time to discuss the draft.

Thanks,
David

David Cooley
Senior Analyst | Environment and Resources Division | Abt Associates
5001 South Miami Boulevard, Suite 210, Durham, NC 27703
T: 919-294-7793 | F: 617-386-7613
www.abtassociates.com

This message may contain privileged and confidential information intended solely for the addressee. Please do not read, disseminate or copy it unless you are the intended recipient. If this message has been received in error, we kindly ask that you notify the sender immediately by return email and delete all copies of the message from your system.

This message may contain privileged and confidential information intended solely for the addressee. Please do not read, disseminate or copy it unless you are the intended recipient. If this message has been received in error, we kindly ask that you notify the sender immediately by return email and delete all copies of the message from your system.

From: Ohrel, Sara
To: Cole, Jefferson; Baker, Justin
Sent: 8/8/2014 12:32:55 PM
Subject: RE: Appendix F edits - and sugg edits to main doc and app G *Deliberative*
Attachments: Oustanding Items 8 4 14.xlsx

Thanks Jeff. I had sent around an updated tasks excel task list on 8/5 (attached again, but just for reference. I will use the older one you both updated henceforth) that gave comparing main doc, F and G to RTI, but it seems that Justin and you both used the older one to send around your status updates, which complicates things for me a bit since I was tracking everyone's tasks in my head using the most recent list from Monday. Nonetheless, thank you for taking it on - I am not sure if Katie or Justin have done it yet, so this may save them some time.

Right now, RTI has the pen on App G.
On app F, we had discussed using the commented versions for reference but making edits in the clean versions, as I told you that in some documents I made final minor editing/updating. Nonetheless, we will use the app F you sent and hope we catch all those other changes. RTI, please do a check on this document, against app G for now and then editorial, and I will work on the main document changes after I have the final F and G back from you.

Robert has the leakage app E. H-N I believe are being edited/finalized by RTI – Justin please confirm or update status.

Apps A and C are considered done (Justin, do you still need to editorial review those?). App B I need to take a look at along with the main doc time text from Jeff.

Kate is on black liquor, Jeff is on thinnings – both of these items will need to be incorporated in App D. I have the most recent version of that document and will share soon, so RTI and Jeff can add their respective pieces.

Right now, I am working on the main document adding upper management comments, which I then need to send to Bill and Suzie. After that, I will work on Robert's comments as well as the time and process attributes parts of the main doc.

Justin, please let me know when we should expect to start receiving the final edited appendices from RTI.

THANK YOU!
Sara

From: Cole, Jefferson
Sent: Friday, August 08, 2014 12:08 PM
To: Ohrel, Sara; Baker, Justin
Subject: Appendix F edits - and sugg edits to main doc and app G *Deliberative*

This email is deliberative

Sara and Justin,

I've attached my edits to Appendix F. This includes updating the footnote to "August 2014" as well as ensuring definitions for terms match those as given in the main doc. These edits were made to the commented on (with edits accepted) version that Sara sent out on 7/26).

Cross-checking this appendix against the main doc (the version that Robert sent on yesterday on 8/7) and appendix G (the version that Sara sent around on Wed, 8/6), I caught a few things that should be edited in those docs. They are listed below, but I go into more detail in the other attachment in this email (see "suggested edits…") since I believe I do not currently have the pen on the main doc or Appendix G.

This includes:

Ex. 5 - Deliberative

Also, I've included an updated excel file of the outstanding items.

Thanks,

Jeff

Jefferson Cole
Economist
Climate Change Division
U.S. EPA
Desk: 202.343.9671
Mobile: 202.701.8795
cole.jefferson@epa.gov

From: Cole, Jefferson
To: Baker, Justin; Ohrel, Sara; Beach, Robert H.
CC: Greg Latta (Ex. 6 - Personal Privacy); Hanks, Katie P.; Latane, Annah
Sent: 8/7/2014 5:52:34 PM
Subject: RE: Comments on Main Framework Report *Deliberative*
Attachments: Appendix_B_Temporal Scale_8 7 14.docx

This email is deliberative

All,

Attached is Appendix B: Temporal Scale. Sara has the pen.

Edits I made include Ex. 5 - Deliberative updating Figure 3, and other edits as specified in the spreadsheet.

For RTI, Annah had a good suggestion to insert a Ex. 5 - Deliberative

Ex. 5 - Deliberative

Thanks,

Jeff

From: Cole, Jefferson
Sent: Thursday, August 07, 2014 5:11 PM
To: 'Baker, Justin'; Ohrel, Sara; Beach, Robert H.
Cc: Greg Latta (Ex. 6 - Personal Privacy); Hanks, Katie P.; Latane, Annah
Subject: RE: Comments on Main Framework Report *Deliberative*

Many thanks, Justin.

App. B is in my hands now. I will be sending it around soon.

Jeff

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Thursday, August 07, 2014 5:09 PM
To: Ohrel, Sara; Beach, Robert H.
Cc: Cole, Jefferson; Greg Latta (Ex. 6 - Personal Privacy); Hanks, Katie P.; Latane, Annah
Subject: RE: Comments on Main Framework Report *Deliberative*

All,

Here is an update on where we're at. We've finished all edits to all appendices that RTI had the pen for except for the Leakage App, which Robert and I will take a look at tomorrow. Katie and I are now working on the black liquor addendum to App D. Our editing team is working on overall editing issues, reference checks, etc.

Jeff, I wanted to follow up on your email from yesterday—does RTI need to work on App B now, or is that still in your hands?

Thanks, everyone.

Justin

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Thursday, August 07, 2014 4:51 PM
To: Beach, Robert H.
Cc: Cole, Jefferson; Baker, Justin; Greg Latta (Ex. 6 - Personal Privacy)
Subject: Re: Comments on Main Framework Report *Deliberative*

Marvelous thank you so much Robert!

From: Beach, Robert H.
Sent: Thursday, August 7, 2014 4:26 PM
To: Ohrel, Sara
Cc: Cole, Jefferson; Baker, Justin; Greg Latta (Ex. 6 - Personal Privacy)
Subject: RE:Comments on Main Framework Report *Deliberative*

Hi Sara,

I finally finished going through and adding comments into the main body of the report on top of the version that already had other comments included. Just let me know if you have any questions about any of them.

Thanks,
Robert

Robert H. Beach, Ph.D.
Director
Agricultural, Resource & Energy Economics and Policy Program
Global Climate Change and Environmental Sciences Unit
RTI International
3040 Cornwallis Road
P.O. Box 12194
Research Triangle Park, NC 27709-2194
Phone: (919)485-5579 Fax: (919)541-7155
Email: rbeach@rti.org Website: www.rti.org/rbeach

Adjunct Assistant Professor
Department of Agricultural and Resource Economics
North Carolina State University
Email: rhbeach@ncsu.edu

From:	Baker, Justin
To:	Ohrel, Sara; Beach, Robert H.
CC:	Cole, Jefferson; Greg Latta (lattaforestry@gmail.com); Hanks, Katie P.; Latane, Annah
Sent:	8/7/2014 5:09:25 PM
Subject:	RE: Comments on Main Framework Report *Deliberative*
Attachments:	Oustanding Items 2014_8_7.xlsx

All,

Here is an update on where we're at. We've finished all edits to all appendices that RTI had the pen for except for the Leakage App, which Robert and I will take a look at tomorrow. Katie and I are now working on the black liquor addendum to App D. Our editing team is working on overall editing issues, reference checks, etc.

Jeff, I wanted to follow up on your email from yesterday—does RTI need to work on App B now, or is that still in your hands?

Thanks, everyone.

Justin

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Thursday, August 07, 2014 4:51 PM
To: Beach, Robert H.
Cc: Cole, Jefferson; Baker, Justin; Greg Latta (lattaforestry@gmail.com)
Subject: Re: Comments on Main Framework Report *Deliberative*

Marvelous thank you so much Robert!

From: Beach, Robert H.
Sent: Thursday, August 7, 2014 4:26 PM
To: Ohrel, Sara
Cc: Cole, Jefferson; Baker, Justin; Greg Latta (lattaforestry@gmail.com)
Subject: RE:Comments on Main Framework Report *Deliberative*

Hi Sara,

I finally finished going through and adding comments into the main body of the report on top of the version that already had other comments included. Just let me know if you have any questions about any of them.

Thanks,
Robert

Robert H. Beach, Ph.D.
Director
Agricultural, Resource & Energy Economics and Policy Program
Global Climate Change and Environmental Sciences Unit
RTI International
3040 Cornwallis Road
P.O. Box 12194
Research Triangle Park, NC 27709-2194
Phone: (919)485-5579 Fax: (919)541-7155
Email: rbeach@rti.org Website: www.rti.org/rbeach

Adjunct Assistant Professor
Department of Agricultural and Resource Economics
North Carolina State University

Email: rhbeach@ncsu.edu

From: Ohrel, Sara
To: Hanks, Katie P.
CC: Baker, Justin
Sent: 8/8/2014 8:48:28 AM
Subject: RE: NCASI mention of WW treatment

Perfect, thanks Katie. Let's just go with **Ex. 5 - Deliberative**
Ex. 5 - Deliberative

Also, on another topic, I forgot to ask you yesterday, what is the name of the EPA person you work with on the pulp and paper stuff, including the survey?
Thanks!

From: Hanks, Katie P. [mailto:kphanks@rti.org]
Sent: Thursday, August 07, 2014 4:20 PM
To: Ohrel, Sara
Cc: Baker, Justin
Subject: NCASI mention of WW treatment

NCASI did briefly mention aerobic wastewater treatment as a hypothetical scenario for black liquor, but performed their analysis on incineration.

NCASI TB 1016 (October 2013)

6.4 Black Liquor
In a previous study by NCASI (Gaudreault et al. 2012; NCASI 2011b), the benefits of recovering black liquor for production of energy and pulping chemicals that would otherwise need to be produced from other resources were analyzed. In that study, it was determined that developing a detailed model of the alternative fate of black liquor would have required too much speculation because black liquor is not disposed. Its use in the kraft recovery cycle is integral to pulp production. Nonetheless, it was reasonable to assume that alternative management would involve returning the biogenic carbon in the liquor to the atmosphere, [redacted](in which case the carbon would be emitted over a period of hours to months depending on the type of treatment system in use). In either case, the carbon is returned to the atmosphere far too quickly to make carbon storage a significant factor in the calculations. To be conservative, it was also assumed that all of the carbon in the black liquor would be emitted as CO_2. If, in the alternative management scenario, some of the carbon was emitted as methane, the benefits of using black liquor in the kraft recovery cycle would be larger than estimated in the study.
The detailed results obtained for black liquor can be found in NCASI (2011b) and Gaudreault et al. (2012). These are summarized in Table 6.9. At the time of this earlier study, no dynamic carbon footprint approach was applied and the results were not limited to 100 years. The break-even time would remain zero using dynamic carbon footprint but limiting the analysis to 100 years would slightly reduce the GHG benefits.

Table 6.9 Summary of Indicator Results for Black Liquor

Indicator	Unit	Typical	Min	Max
Differential GHGI*	kg CO_2E/GJ	-182	-97.9	-192
Relative Non-BioCO_2 GHGI*	%	-90.5	-69.0	-92.4
Break-even time*,†	years	0	Not available	
Relative FF CON	%	-89.8	-71.1	-90.7

* Based on 100-year GWPs. † Break-even time was not analyzed in NCASI (2011b) and Gaudreault et al. (2012). However, assuming that the most likely alternative fate for black liquor is incineration, consistent with the conservative assumption made regarding carbon emission from this alternative fate, the break-even time would be zero years.

From the earlier NCASI TB 984 (2011b) and related *Biomass & Bioenergy* paper Gaudreault 2012 (same quote in both):

(No mention of wastewater treatment in earlier study.)

3.2.3 *Alternative Management of Black Liquor Solids*

The recovery of black liquor not only provides energy and chemicals for the pulp and paper process, it also allows disposing of the organic matter. For this reason, to make the fossil fuel- and black liquor-based kraft recovery systems equivalent, it is necessary to include an equivalent management of black liquor solids in the fossil fuel-based system.

A detailed model of alternative management of black liquor solids would have required too much speculation, but the management would almost certainly ultimately involve returning the biogenic carbon in the liquor to the atmosphere. In the best case, it would return as CO_2, so this is what has been modeled. The alternative management may involve greater emissions of GHGs if, for instance, some the biogenic carbon is returned to the atmosphere as methane or if fossil fuels were required. For this reason, the approach taken is conservative.

Katie Hanks
RTI International
3040 Cornwallis Road
Research Triangle Park, NC 27709
(919) 316-3732
(919) 541-7155 (fax)

From: Ohrel, Sara
To: Justin Baker (justinbaker@rti.org); Hanks, Katie P.
CC: Cole, Jefferson
Sent: 8/7/2014 3:08:57 PM
Subject: FW: concept characterization

deliberative

From: Fawcett, Allen
Sent: Thursday, July 17, 2014 9:58 AM
To: Ohrel, Sara
Cc: Cole, Jefferson
Subject: RE: concept characterization

Here are my thoughts. Let me know if this is helpful.

Thanks,
Allen

Ex. 5 - Deliberative

From: Ohrel, Sara
Sent: Wednesday, July 16, 2014 5:51 PM

To: Fawcett, Allen
Subject: concept characterization

Hi Allen,
Can you check this to see if I have the general concept correct? If not, please set me straight.

Ex. 5 - Deliberative

Thanks.
And thanks again for all the support and patience today. It is deeply appreciated.

Sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Ohrel, Sara
To:	Hanks, Katie P.
CC:	Justin Baker (justinbaker@rti.org); Cole, Jefferson
Sent:	8/7/2014 3:07:35 PM
Subject:	
Attachments:	Copy of Black_liquor4-18-14_rev7-7-14so.xlsx

Hi Katie,
Here is that excel I mentioned where I did some recalculations, and added a check versus the waste app framework equation (row 95).
Thanks again!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org); Hanks, Katie P.
CC:	Cole, Jefferson
Sent:	8/7/2014 1:03:07 PM
Subject:	black liquor piece - deliberative
Attachments:	Black_Liquor_Fate_4-18-14_8 7 14so.docx

Hi All,
Here is the piece with comments and some instructions. We will be adding this as an addendum to the feedstock cat. App (D). Please take a look and let me know when you are both available for a call to discuss.
Thank you,
Sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Cole, Jefferson
To: Ohrel, Sara; Baker, Justin
Sent: 8/6/2014 5:19:54 PM
Subject: RE: update
Attachments: Oustanding Items 2014_8_6 v2.xlsx; Temporal Scale Only - Main Doc 7 27 - jc.docx

Thanks, Justin.

I've added the changes I've made to the spreadsheet. I've detailed most of my edits/responses to main doc items for me in this spreadsheet. For more detailed edits to be made in the temporal scale section of the main doc, I split off that portion of the text only into another word doc and made edits in track changes.

I can go in and make these changes anytime the main doc is free for me to work on.

Jeff

From: Ohrel, Sara
Sent: Wednesday, August 06, 2014 5:07 PM
To: Baker, Justin; Cole, Jefferson
Subject: RE: update

Great, thanks for the update and all the work, Justin.

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Wednesday, August 06, 2014 5:06 PM
To: Ohrel, Sara; Cole, Jefferson
Subject: RE: update

All,

Here is an updated task list.

Sara— **Ex. 5 - Deliberative**

Ex. 5 - Deliberative

Also, I do have one outstanding item on App K that Annah reminded me of that I need to sort out.

Thanks,
Justin

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Wednesday, August 06, 2014 4:44 PM
To: Baker, Justin; Cole, Jefferson
Subject: RE: update

Sure drop me a line

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Wednesday, August 06, 2014 4:43 PM
To: Ohrel, Sara; Cole, Jefferson

Subject: RE: update

Yes, I'm a little confused on that. Are either of you available to chat?

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Wednesday, August 06, 2014 4:42 PM
To: Baker, Justin; Cole, Jefferson
Subject: RE: update

Marvelous thanks. On App D, you mean the citation for the black liquor production function stuff right? Thanks!

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Wednesday, August 06, 2014 4:40 PM
To: Ohrel, Sara; Cole, Jefferson
Subject: RE: update

Sara,

In addition to the edits sent on App G, the RTI team has completed Apps H, J, K, and L.

I will send copies of these soon.

We are addressing additional App G comments, and I'm working on App D now.

Justin

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Wednesday, August 06, 2014 2:54 PM
To: Baker, Justin; Cole, Jefferson
Subject: update

Hi all,
Please send an update as to where you/your team is on your parts of the framework by COB today, just so we all are on the same page.
Justin, I will have to get back to you on black liquor tomorrow. Sorry.
Thanks,
Sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Kocchi, Suzanne
To:	Ohrel, Sara; Cole, Jefferson; DeLuca, Isabel
Sent:	8/7/2014 9:47:40 AM
Subject:	FW: Biomass drafts
Attachments:	Biomass Accounting Framework outreach list_v9.xlsx; biomass cover text 080614.docx; Draft Biomass Rollout Plan 080714.doc

FYI – thanks again everyone!

From: Kocchi, Suzanne
Sent: Thursday, August 07, 2014 9:47 AM
To: Dunham, Sarah
Cc: Irving, Bill; Gunning, Paul; Krieger, Jackie
Subject: Biomass drafts

Sarah – We have attached 3 documents for your review (and I will bring copies for you to OAP management mtg)

1) **Draft of the cover memo**. We left some comment bubbles in specifically for you. FYI - we didn't do a review here beyond Bill and me and definitely didn't get OGC, OAQPS review because we wanted to get your reaction first and see if this was heading in the right direction before we spent a lot of time polishing.
2) **Draft roll out plan**. Some of the this, like the overview, key messages etc is still TBD because that text will largely be lifted from the memo once that is approved. But you can see what we are suggesting for stakeholders and review etc.
3) **Detailed stakeholder outreach list**. This in an attachment to the roll out plan that includes all the vocal stakeholders that have met with us repeatedly, provided comment etc. This is so you are aware that we are thinking about who needs to be called, their likely reaction etc.

Bill and I are in tomorrow (although I am out for an appt in the afternoon) and all next week if you want to discuss further.

Suzie Kocchi, Chief of Staff
Climate Change Division
US Environmental Protection Agency
(202) 343-9387

From:	Ohrel, Sara
To:	Cole, Jefferson
Sent:	8/7/2014 10:15:18 AM
Subject:	FW: Thinning analysis meeting tomorrow
Attachments:	Abt-NAFO_plantation_thinning.docx; Gonzalez-Benecke et al 2011b.pdf; Markewitz.pdf; Thinning for Bioenergy Feedstock.pptx; ThinningLoblollyDougfir Combined Draft June25.docx

From: Browne, Cynthia
Sent: Wednesday, June 25, 2014 1:35 PM
To: Wood, Anna; Santiago, Juan; Kornylak, Vera S.; Dunham, Sarah; Gunning, Paul; Karisa Smith; Ohrel, Sara; Cole, Jefferson; Irving, Bill; Fawcett, Allen
Cc: Goffman, Joseph
Subject: FW: Thinning analysis meeting tomorrow

Hi Karisa, thank you sending these attachments our way for the meeting tomorrow at 9:00 am. I am forwarding our EPA folks on this so everyone will have the attachments.

Cynthia Browne

From: Karisa Smith [mailto:ksmith@nafoalliance.org]
Sent: Wednesday, June 25, 2014 1:26 PM
To: Browne, Cynthia
Subject: Thinning analysis meeting tomorrow

Hi Cynthia,

Attached are the materials for tomorrow's meeting on thinnings with Chip Murray, Rob Olszewski, and Dan Markewitz. Would you please distribute to the EPA participants in the meeting? Thanks!

For background, Dan is a Professor of Soil Site Productivity at Warnell School of Forestry and Natural Resources, University of Georgia. I have attached his curriculum vita, the paper he prepared with colleagues from the Warnell School and a research forester from the USDA Southern Research Station, and the slides he prepared for this presentation. I have also attached the paper prepared on this topic by Bob Abt, Professor of Natural Resource Management/Economics at North Carolina State University. Finally, I have attached a paper on this topic recently published by professors from the School of Forest Resources and Conservation, University of Florida, and a forest finance expert with Arborgen Inc.

Thanks,
Karisa

Karisa Smith
Administrative Coordinator
National Alliance of Forest Owners
122 C Street N.W., Suite 630
Washington, DC 20001
Ph: (202)747-0753
Fax: (202)824-0770
ksmith@nafoalliance.org
http://nafoalliance.org/

Effect of Plantation Thinning Intensity on Forest Carbon in the U.S. South

Robert Abt
Co-director SOFAC
NC State University

Summary

This monograph briefly explores the effect of changes in thinning intensity in pine plantations on forest carbon over time. The study uses the Sub-Regional Timber Supply (SRTS) model. This model is described in Abt, et al. 2009 and has been supported by and used for similar assessments by members of the Southern Forest Resource Assessment Consortium (SOFAC) at NC State University. This consortium includes most of the major wood product consumers and corporate timberland investment management organizations (TIMOs) and real estate investment trusts (REITS) in the region.

The results from this analysis are complimentary to a plot based approach but consider the age class distribution and market effects across the southeastern coastal plain. Increasing thinning intensity leads to more forest carbon in the short run by delaying average harvest age for current stands. Over the longer run this effect is partially offset by delaying the high growth (sequestration) phase of the next rotation (Figures 6 & 7). The net effect of increased thinnings on forest carbon after 100 years is near zero.

Methods

There are major differences between a stand level perspective on thinning changes and the regional level explored here. At a stand level changes in thinning regimes interact with optimal rotation, planting density, stocking levels, site quality, and growth responses. In SRTS the harvest pattern is based on current data, site quality is reflected in average growth in specific regions, and growth is based on survey unit plot measurements. What the regional perspective offers is a sensitivity of results to the current age class distribution, plantations in the context of total timberland, and projected demand and harvest levels by product.

The SRTS model uses data from the US Forest Service Forest Inventory and Analysis (FIA) unit which consists of plot data collected annually. Only 15 to 20 percent of the plots are visited each year so that the "2012" dataset, for example, might represent plot data from the 2008-2012 survey cycle. Data on growth and removals can only come from "remeasurement plots" that represent a sub-sample of the database. Given recent transitions in the plot design, the remeasurement cycle often covers a different and longer time span than the standard inventory cycle. For this analysis, "2012" data was available for all states included except Florida where "2011" data was used. Figure 1 shows the region used for this study. It was chosen to capture impacts from announced pellet mill capacity for an upcoming US Forest Service overview of potential pellet impacts. This region covers most of the major pine producing areas and includes those most likely to be impacted by EU bioenergy demand.

Details of the demand assumptions and other model parameters are not described in this document since they simply provide a basis for a "with and without" analysis of thinning effects. In this application the focus is on the effects of policies or other forces that might favor or disfavor thinning on plantations. It is, however, important to understand how thinning changes are implemented in the SRTS model. SRTS models inventory as "cells" that consist of an ownership class (corporate or non-corporate), forest type (planted pine, natural, mixed oak-pine, upland hardwood, lowland hardwood, species group (hardwood or pine), 5-year age class, and region (in this case the survey units shown in Figure 1). Each cell is characterized by FIA growing stock volumes, growth per acre, removals, diameter distribution, and starting acreage. The models harvesting routine allocates harvest to forest types and age classes in a way that meets projected product demands while maintaining consistency with existing harvest patterns.

The model moves acres through age classes by adding the appropriate growth and subtracting allocated harvest. Acres are tracked at ages less than 10 years old. At age 10 those acres receive the volume associated with 10 year old stands for that cell. Future inventory then depends on accumulated growth and removals. Thinning versus final harvest allocations are based on the stocking standard for that cell. The default stocking standard is the starting volume per acre in the FIA plot data. If accumulated growth leads to a cell stocking level above the stocking standard, stands are assumed to be thinned until volume per acre is equal to the stocking standard. If additional harvest in that cell is required then final harvest is assumed which maintains the stocking standard. One consequence of using the starting volume per acre as the benchmark is that the model initially thins very little since all stands start at the benchmark. This can be addressed by lowering the benchmark, especially for younger stands, but that option was not used for this analysis. To change thinning levels in SRTS, the stocking standard is adjusted. Raising the volume per acre benchmark means that less (more) thinning (final harvest) is required. A higher proportion of thinning means average stand age increases which increases forest carbon (Figure 2). Forest carbon estimates are estimated by applying the Smith et al. FORCARB parameter to the corresponding projected cells in SRTS, including adjustments for stocking levels.

In these runs, which assumed relatively high demand for pulpwood from pellets and traditional uses, forest prices go through a boom and bust cycle peaking around year 2025 and returning to near current levels by 2040. Timberland acreage trends are affected by these prices with a gain in plantation acres partially offsetting losses of natural timberland to urbanization. The gain in carbon due to longer rotations is somewhat offset by losses in timberland toward the end of the rotations (Figure 3) as prices drop. In fact total forest carbon would have declined during this period without the increase in plantation forest carbon.

Since the change in average age affects the product mix from the stands, product prices and harvests level also differ between the runs. This means that while average stand age is fairly uniformly influenced by thinning, plantation forest carbon also reflects adjustments in product markets and land use change. The initial impacts on carbon sequestration are also influenced by the current age class distribution of the forest, since it determines the timing of thinning. These factors explain why stand-level analyses and regional market simulations will differ. Nevertheless,

using the latest FIA data and a high demand scenario over the next 40 years the "more" thinning scenario shows increased forest carbon, especially relative to a "less" thinning scenario.

To test the sensitivity of forest carbon to markets, landuse, and projection period, two additional sets of projections were made where increased bioenergy demand, market responses and land use change were not included. These runs excluded: 1) additional bioenergy demand, 2) feedback between sawmill residues and pulpwood roundwood demand, 3) landuse change, and 4) harvest response to price changes. The plantation forest carbon cycles simply reflect the age class distribution and harvest patterns in the latest data.

Figures 4 shows that plantation ages are increased with thinning, but rather than continuously increasing as before, the rise slightly and fall back to starting levels through the 40 year projection. Figure 5 shows that increased thinning sequesters significantly more carbon as the current inventory moves through one rotation cycle. It also appears that the carbon advantage lessens toward the end of the cycle.

Figures 6 and 7 show the impact of continuing these runs over a 100 year period. From these long term runs it is clear that inventory age and carbon follow long wave patterns. But the longer rotations with more thinning lead to offsets between cycles. The combination of longer rotations and lower stocking means that the forest carbon cycle with increased thinning lags the forest carbon cycle relative to shorter rotations (Figure 7). Integrating forest carbon over two complete cycles indicates that sequestered plantation carbon is approximately the same across thinning scenarios (< .01% difference).

References

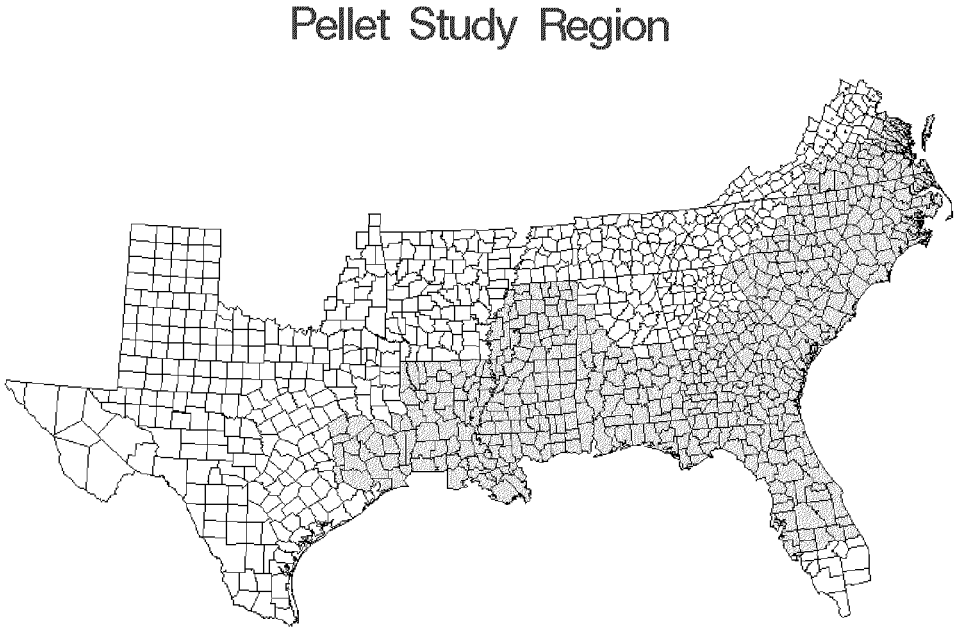
Abt, R. C., Cubbage, F. W., & Abt, K. L. (2009). Projecting southern timber supply for multiple products by subregion. Forest Products Journal, 59(7-8), 7-16.

Southern Forest Resource Assessment Consortium. NC State University http://www.cnr.ncsu.edu/sofac/

U.S. Department of Agriculture, Forest Service. (2014). Forest Inventory and Analysis (FIA) Reports. Knoxville, TN: U.S. Department of Agriculture Forest Service, Southern Research Station. http://srsfia2.fs.fed.us

Smith, James E.; Heath, Linda S.; Nichols, Michael C. 2007. U.S. forest carbon calculation tool: forest-land carbon stocks and net annual stock change. Revised. Gen. Tech. Rep. NRS-13. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 34 p.

Figure 1. Study Area



Abt Pellet Study

Figure 2. Average Plantation Age by Thinning Intensity

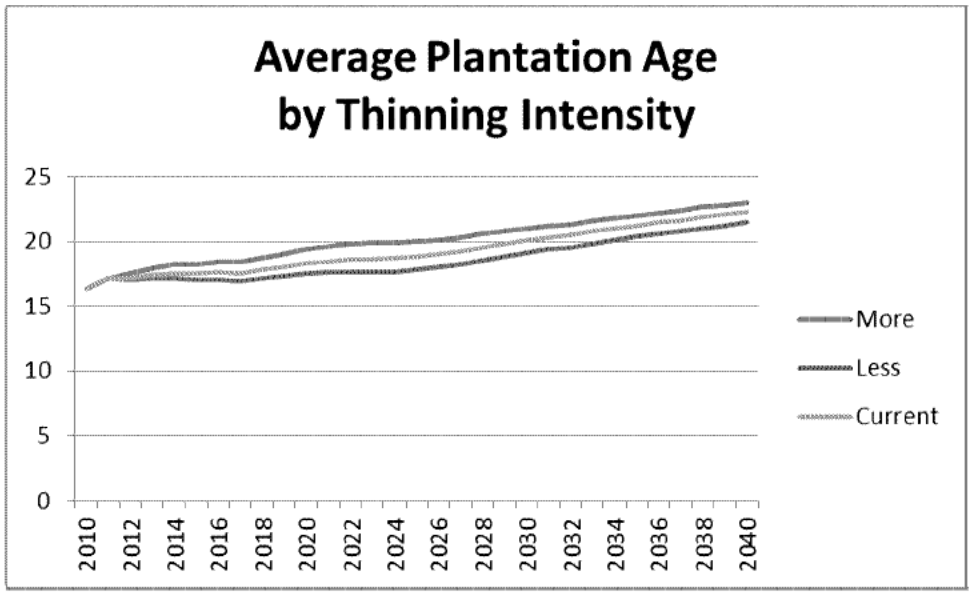


Figure 3. Forest Carbon by Thinning Intensity

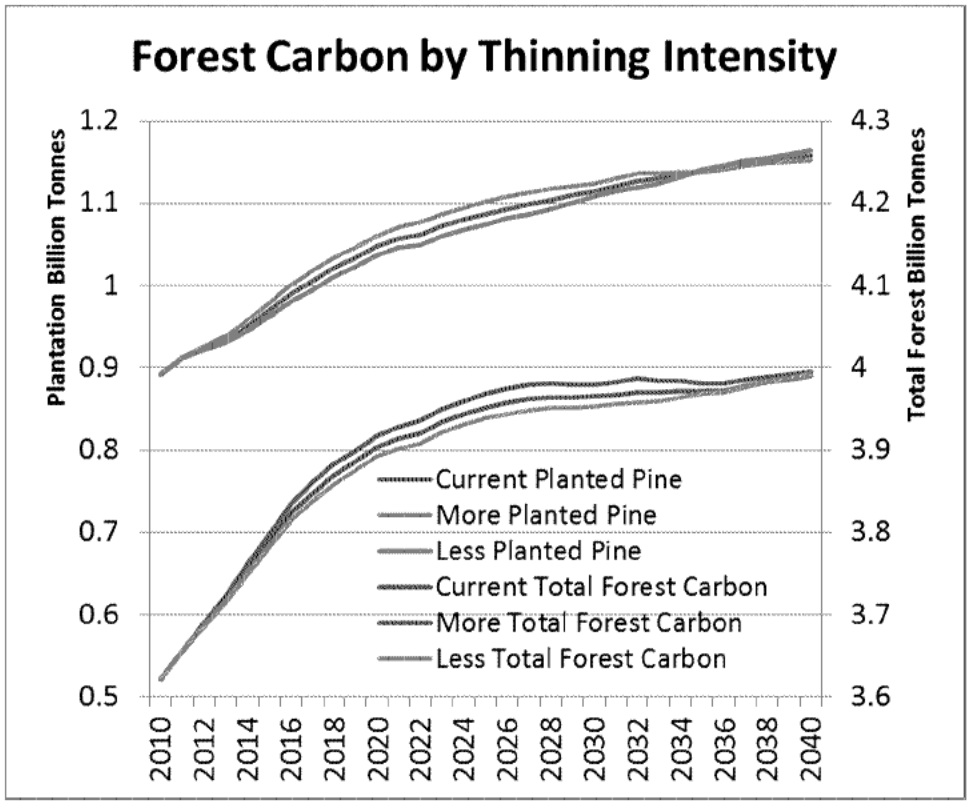


Figure 4. Average Plantation Age by Thinning Intensity without Market and Landuse Change Effects

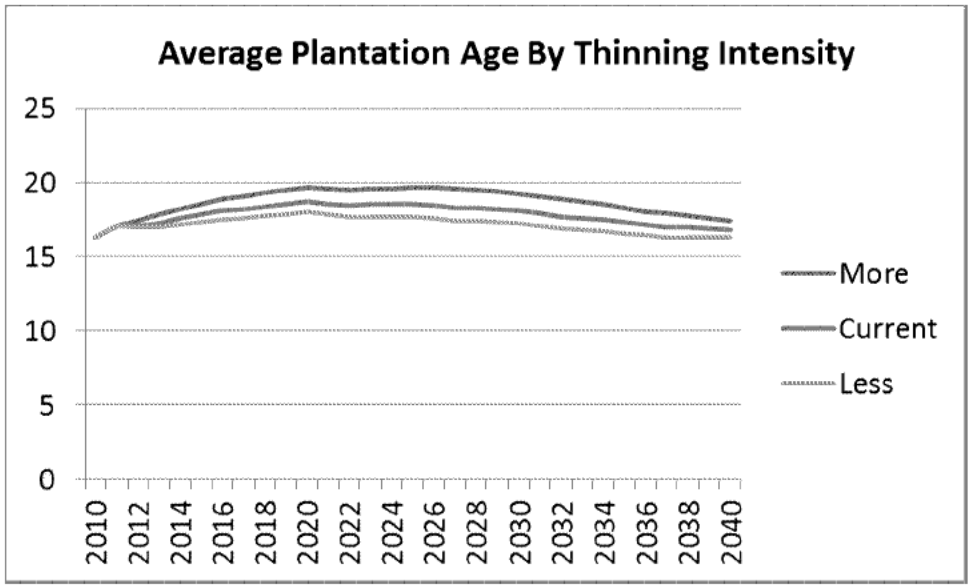


Figure 5. Plantation Carbon by Thinning Intensity without Market and Landuse Change Effects

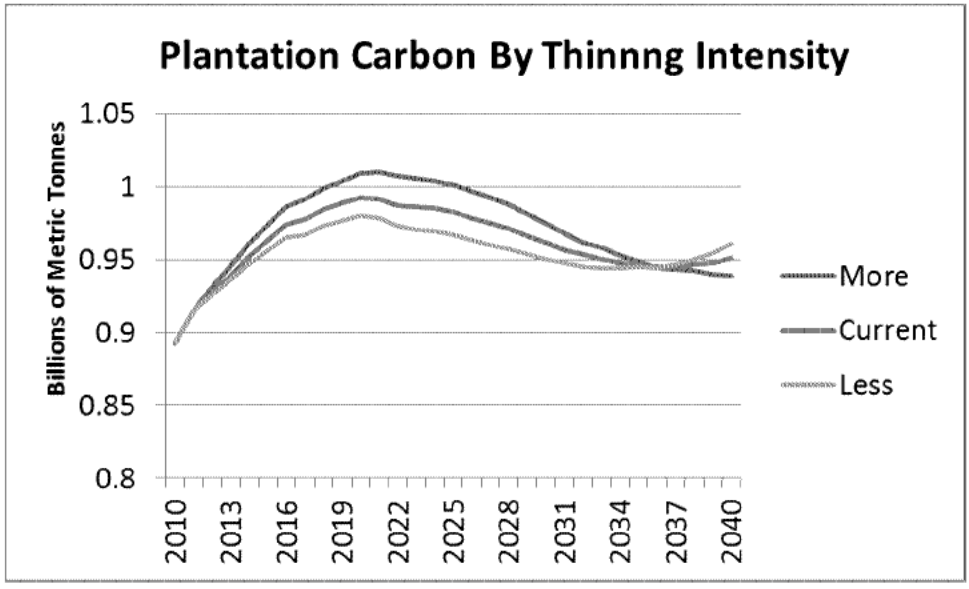


Figure 6. Average Plantation Age by Thinning Intensity without Market and Landuse Change Effects over 100 Years

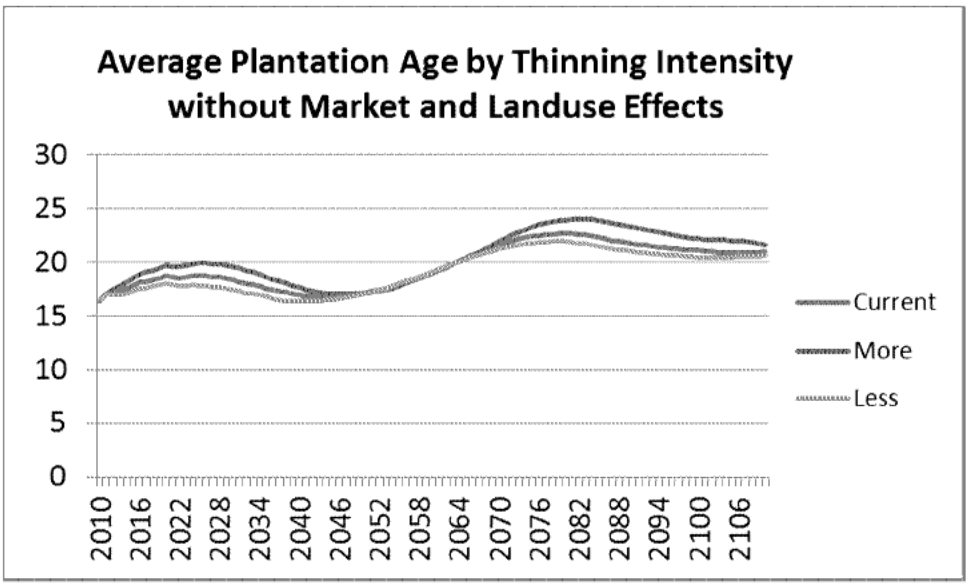
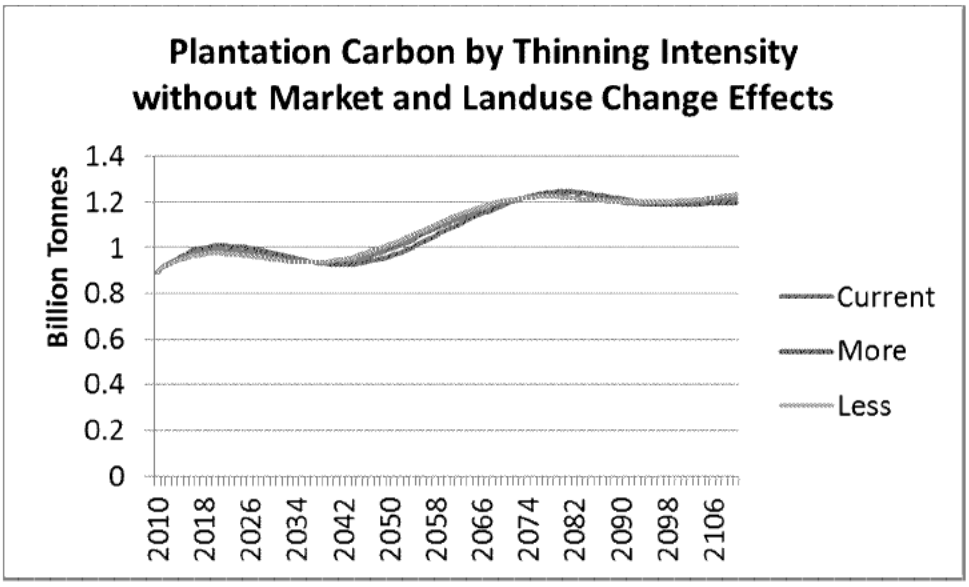


Figure 7. Plantation Carbon by Thinning Intensity without Market and Landuse Change Effects over 100 Years



Forests **2011**, *2*, 749-776; doi:10.3390/f2030749

OPEN ACCESS

forests

ISSN 1999-4907

www.mdpi.com/journal/forests

Article

A Flexible Hybrid Model of Life Cycle Carbon Balance for Loblolly Pine (*Pinus taeda* L.) Management Systems

Carlos A. Gonzalez-Benecke [1,*], Timothy A. Martin [1], Eric J. Jokela [1] and Rafael De La Torre [2]

[1] School of Forest Resources and Conservation, University of Florida, P.O. Box 110410, Gainesville, FL 32611-0410, USA; E-Mails: tamartin@ufl.edu (T.A.M.); ejokela@ufl.edu (E.J.J.)

[2] Cellfor Corporation, 817 West Peachtree Street, Suite 210, Atlanta, GA 30308, USA; E-Mail: rdelatorre@cellfor.com

* Author to whom correspondence should be addressed; E-Mail: cgonzabe@ufl.edu; Tel.: +1-352-846-0851; Fax: +1-352-846-1277.

Received: 13 May 2011; in revised form: 3 August 2011 /Accepted: 1 September 2011/ Published: 15 September 2011

Abstract: In this study we analyzed the effects of silvicultural treatments on carbon (C) budgets in *Pinus taeda* L. (loblolly pine) plantations in the southeastern United States. We developed a hybrid model that integrated a widely used growth and yield model for loblolly pine with published allometric and biometric equations to simulate *in situ* C pools. The model used current values of forest product conversion efficiencies and forest product decay rates to calculate *ex situ* C pools. Using the model to evaluate the effects of silvicultural management systems on C sequestration over a 200 year simulation period, we concluded that site productivity (site quality), which can be altered by silviculture and genetic improvement, was the major factor controlling stand C density. On low productivity sites, average net C stocks were about 35% lower than in stands with the default average site quality; in contrast, on high quality sites, C stocks were about 38% greater than average productivity stands. If woody products were incorporated into the accounting, thinning was C positive because of the larger positive effects on *ex situ* C storage, rather than smaller reductions on *in situ* C storage. The use of biological rotation age (18 years) was not suitable for C sequestration, and extended rotation ages were found to increase stand C stock density. Stands with an 18-year-rotation length had 7% lower net C density than stands with a 22-year-rotation length; stands with a 35-year-rotation length had only 4% more C than stands harvested at age 22 years. The C sequestered in woody products was an important pool of C storage, accounting for ~34% of the average net C stock. Changes in decomposition rate, associated with possible environmental changes

resulting from global climate change, affected C storage capacity of the forest. When decay rate was reduced to 10% or increased to 20%, the C stock in the dead pool (forest floor and coarse woody debris) was reduced about 11.8 $MgC \cdot ha^{-1}$ or increased about 13.3 $MgC \cdot ha^{-1}$, respectively, compared to the average decay rate of 15%. The C emissions due to silvicultural and harvest activities were small (~1.6% of the gross C stock) compared to the magnitude of total stand C stock. The C model, based on empirical and biological relationships, appears appropriate for use in regional C stock assessments for loblolly pine plantation ecosystems in the southern U.S.

Keywords: loblolly pine; silviculture; stand dynamics; forest floor; life cycle analysis; carbon stock modeling

1. Introduction

Carbon dioxide (CO_2) emissions from fossil fuels have increased on average at a rate of 1.9% per year over the last decades [1], with atmospheric CO_2 concentration rising at approximately 1.4 parts per million by volume per year [2]. As Sundquist *et al.* [3] pointed-out, mitigation of atmospheric CO_2 requires an approach that combines reductions in CO_2 emissions with increasing CO_2 storage. One of the most effective mechanisms for offsetting carbon (C) emissions is the fixation of atmospheric CO_2 into plant tissues [3,4]. In the United States (U.S.), forests represent over 90% of the terrestrial C sink, equivalent to 12 to 16% of the U.S. greenhouse gas (GHG) emissions [2], and southern pines represent around 36% of the terrestrial C stock in the conterminous U.S. [5]. The applications of sustainable forest management systems can increase C sequestration potential of managed forests [6]. For example, forests in the southeast and south-central U.S. could potentially capture CO_2 equivalent to about 23% of GHG emissions of that region [7].

Managed southern pine forests have played a large role in C sequestration in the U.S. [8]. The land area of southern pine plantations has increased steadily over the past half century [6], with plantations today occupying more than 13 million ha [9]. Intensive management of southern pine plantations, using competition control, fertilization, and superior genotypes, can now increase productivity four-fold, compared to mid-1950s plantations [9]. Rotation length is known to affect C stored in forest stands [10,11] and the use of extended rotations has been proposed as an effective way to increase C sequestration for different forest types such as scots pine (*Pinus sylvestris* L.) [12], Douglas-fir (*Pseudotsuga menziesi (Mirb.) Franco*) [13] or slash pine (*Pinus elliottii* Engelm. var. *elliottii*) [14].

In managed forests, C stocks can be divided into two major pools: *in situ* C in standing biomass (above and below ground) and soil organic matter, and *ex situ* C sequestered in products created from harvested wood [15]. Sustainable forest management has the potential to greatly influence both *in situ* and *ex situ* C pools [6].

In this study, we assessed the effects of silvicultural treatments on forest C stocks per unit area in *Pinus taeda* L. (loblolly pine) plantations established in the southeastern U.S. Coastal Plain and Piedmont physiographic regions. Following the approach of Gonzalez-Benecke *et al.* [14], we developed a hybrid model that accounted for both *in situ* and *ex situ* C stocks. *In situ* C pool dynamics

were determined using growth and yield models for loblolly pine [16,17], combined with allometric and biometric equations; *ex situ* C pool dynamics were determined using current values of industrial conversion efficiencies and product-specific decay rates [14]. The model, which also accounted for C costs of silvicultural operations, did not include changes in soil C. We used the model to investigate net C balance, expecting that: (i) extended rotation lengths would increase time-averaged C stocks; (ii) regimes that incorporated longer rotations and thinning would maximize C accumulation in *ex situ* C pools; (iii) increasing stand productivity through intensive silviculture would increase net C storage; and (iv) under similar site and silvicultural treatments, loblolly pine would accumulate more C than slash pine plantations.

2. Materials and Methods

2.1. Models

Allometric and biometric equations were combined with growth and yield models to estimate C stocks and dynamics for loblolly pine plantations in the southeast U.S. We used published loblolly pine growth and yield equations that could be broadly applied to Lower Coastal Plain, Upper Coastal Plain and Piedmont regions [16-18]. These equations predicted stand growth in basal area (BA, $m^2 \cdot ha^{-1}$), dominant height (H_d, m), number of surviving trees per hectare (N_{ha}, $trees \cdot ha^{-1}$), quadratic mean diameter (QMD, the diameter of the trees of mean BA, cm) and total stem volume (V, $m^3 \cdot ha^{-1}$) , using as inputs number of trees planted per hectare (N_{ha}), site index (SI, the height (m) reached by the stand's dominant trees at a reference age of 25 years), type of site preparation (no soil preparation or bedding), weed control treatment (age and method of application, broadcast or banded), fertilization treatment (age and amount of N and P applied), and thinning timing and intensity (as a removal percentage from the surviving trees before thinning).

At each age, allometric equations (Table 1) [19-21] were used to estimate coarse root, stem, crown and total aboveground stand biomass from QMD and N_{ha} simulated by the growth and yield model. Biomass estimations were corrected using log-bias correction following back-transformations [22]. Fine root biomass was estimated from fine root/needle mass ratios reported for stands younger than 5 years [23], and for stands 5 years and older [21]. Loblolly pine projected leaf area index (LAI, the ratio of leaf surface area supported by a plant to its corresponding horizontal projection on the ground, $m^2 \cdot m^{-2}$) and litterfall (B_L; $Mg \cdot ha^{-1} \cdot year^{-1}$) were estimated from the model reported by Gonzalez-Benecke *et al.* [24]. Forest floor biomass accumulation (B_F; $Mg \cdot ha^{-1}$) was determined as in Gonzalez-Benecke *et al.* [24] as the sum of yearly litterfall inputs corrected for decay loss using an equation to estimate decay rate of the forest floor [25]. This equation used site coordinates (latitude and longitude, in decimal units) as inputs to estimate decay rate and was in good agreement with decay rates reported for southern pines in the southeastern U.S. [26-28]. Understory biomass accumulation (B_U; $Mg \cdot ha^{-1}$) was estimated from published equations [14] that used a 17-year chronosequence of understory and litterfall biomass [29].

Table 1. Allometric equations used to estimate loblolly pine aboveground (needles, branches and stem plus bark) and belowground (tap, coarse and fine roots), forest floor and understory biomass.

Component	Equation	Source	
B_F	If DBH < 26 cm: $\ln(B_F) = -3.982 + 1.010 \times \ln(DBH^2)$	Jokela and Martin 2000	[20]
	If DBH ≥ 26 cm: $\log_{10}(B_C) = 1.927 + 1.567 \times \log_{10}(DBH)$	Naidu *et al.* 1998	[19]
B_B	If DBH < 26 cm: $\ln(B_F) = -5.024 + 1.357 \times \ln(DBH^2)$	Jokela and Martin 2000	[20]
	If DBH ≥ 26 cm: $\log_{10}(B_C) = 1.122 + 2.308 \times \log_{10}(DBH)$	Naidu *et al.* 1998	[19]
B_C	$B_F + B_B$		
B_S	If DBH < 26 cm: $\ln(B_S) = -3.651 + 1.342 \times \ln(DBH^2)$	Jokela and Martin 2000	[20]
	If DBH ≥ 26 cm: $\log_{10}(B_{AG}) = 1.333 + 2.708 \times \log_{10}(DBH)$	Naidu *et al.* 1998	[19]
B_{AG}	If DBH < 26 cm: $\ln(B_{AG}) = -2.886 + 1.284 \times \ln(DBH^2)$	Jokela and Martin 2000	[20]
	If DBH ≥ 26 cm: $\log_{10}(B_{AG}) = 1.830 + 2.464 \times \log_{10}(DBH)$	Naidu *et al.* 1998	[19]
B_{TR}	$\log_{10}B_{TR} = -2.2760 + 1.742 \times \log_{10}(DBH)$	Samuelson *et al.* 2004	[21]
B_{CR}	$\log_{10}B_{CR} = -4.9500 + 2.211 \times \log_{10}(DBH)$	Samuelson *et al.* 2004	[21]
B_{FR}	If Age ≤ 4 years: $B_{FR} = \left(1.1401397 \times Age^{\frac{-5.559825}{Age}}\right) \times B_F^*$	Adegbidi *et al.* 2004	[23]
	If Age > 4 years: $B_{FR} = 0.202594 \times B_F^*$	Samuelson *et al.* 2004	[21]
LAI	$LAI = \beta_0/(1 + \exp(-(SDI - \beta_2)/\beta_1))$	Gonzalez-Benecke *et al.* 2011	[24]
	$\beta_0 = -2.01424307 + 0.19323226 \times SI$		
	$\beta_1 = 23.4519 + 2.1389 \times SI$		
	$\beta_2 = 327.2346/[1 + (SI / 18.5717)^{-4.929}]$		
B_N	$\ln(B_N) = 0.62455 + 0.97146 \times \ln(LAI^*)$	Gonzalez-Benecke *et al.* 2011	[24]
B_N/B_L	For stands without weed control at planting and Age <10 years:	Gonzalez-Benecke *et al.* 2011	[24]
	$B_N/B_L = 0.0005 \times Age^3 - 0.022 \times Age^2 + 0.2592 \times Age - 0.0122$		
	For stands without weed control at planting and Age ≥10 years; for stands with weed control at planting at any age:		
	$B_N/B_L = 1/(0.96294 + 0.019426 \times Age - 0.000262 \times Age^2)$		
B_U	$B_U = (0.88242377 + 14.925223)/(1 + 1.5801704 \times LAI + 0.8650196 \times LAI^2)$	Gonzalez-Benecke *et al.* 2010	[14]
SG	$SG = 0.3758081 \times Age^{0.0821216}$	Harrison and Borders 1996	[16]

Note: B_F is foliage biomass (kg·tree^{-1}); B_B is branch biomass (kg·tree^{-1}); B_C is crown biomass (kg·tree^{-1}); B_S is stem plus bark biomass (kg·tree^{-1}); B_{AG} is aboveground biomass (kg·tree^{-1}); B_{TR} is tap root biomass (kg·tree^{-1}); B_{CR} is coarse root biomass (kg·tree^{-1}); B_{FR} is fine root biomass at land area basis (Mg·ha^{-1}); B_F^* is foliage biomass at land area basis (Mg·ha^{-1}); LAI is mean annual projected leaf area index (m^2·m^{-2}); SDI is Reinecke's stand density index in metric units; β_0, β_1 and β_2 are sigmoidal fit parameters; SI is site index (m); LAI* is previous year LAI (m^2·m^{-2}); B_L is current year needlefall biomass (Mg·ha^{-1}·year^{-1}); B_N is current year litterfall biomass (Mg·ha^{-1}·year^{-1}) ; B_U is understory biomass (Mg·ha^{-1}); SG is specific gravity (derived from stem volume and dry weight equations reported by Harrison and Borders 1996); DBH is diameter at breast height (cm); Age is stand age (years).

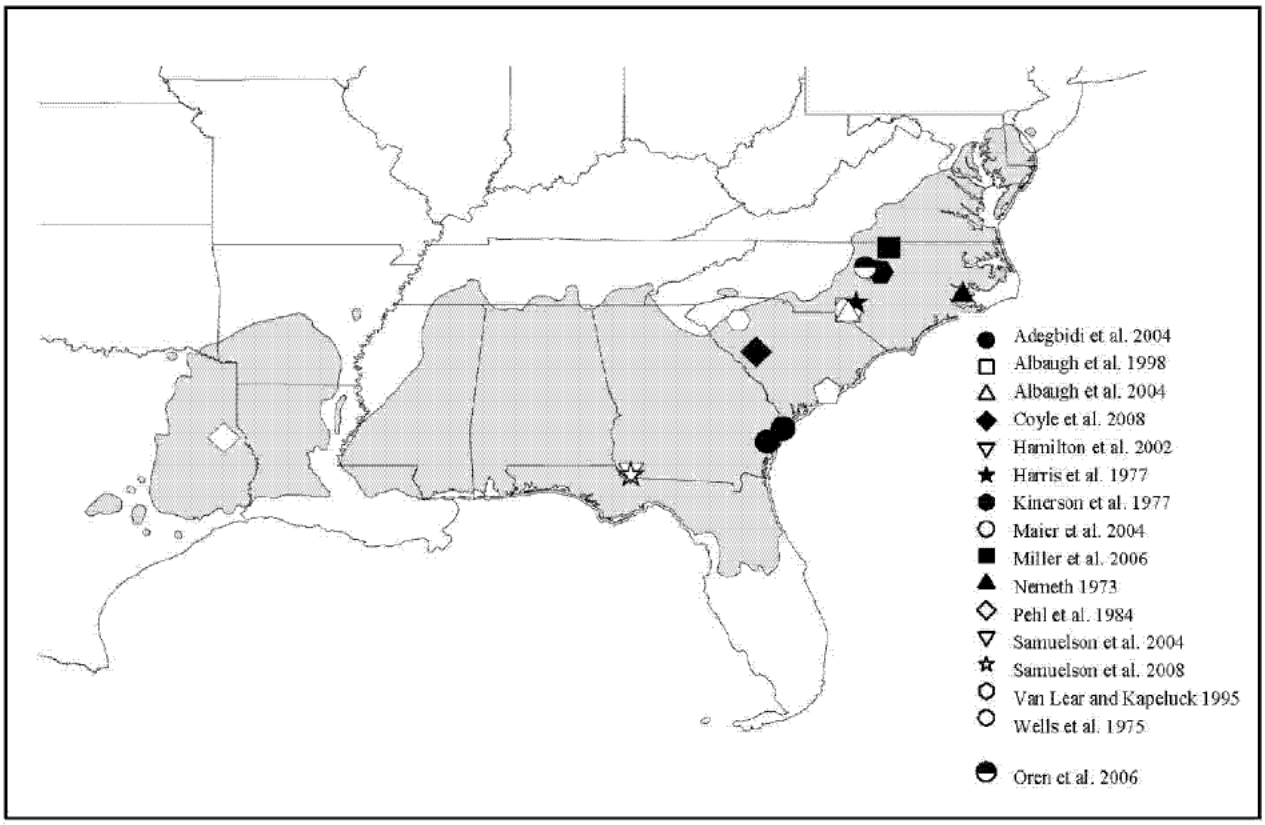
Standing dead trees, estimated from mortality equations [19], were incorporated into the dead component of total biomass. A large fraction of the stand mortality occurred in diameter classes below the median, due to the effects of resource competition of suppressed and weakened trees [4,30]. Using diameter distribution models reported for unthinned and thinned plantations [16], the diameters at the 25th percentile (cm) were determined for each age. This diameter class was assumed to better represent the observed diameter class of dying trees [30]. Biomass of dying trees was computed in the same way as standing biomass, but diameters at the 25th percentile from the previous year were used instead of QMD to estimate individual tree biomass.

At the time of thinning, reductions in loblolly pine LAI were set to be proportional to reductions in BA due to thinning and, therefore, litterfall, forest floor and understory biomass were affected due to their LAI-dependence [24]. At thinning and final harvest (clear-cut), logging slash (root and crown biomass plus stem residues) from harvested tress were also included into flux calculations and incorporated into the dead biomass pool. Stem residues were obtained by assuming a harvest efficiency of 88% of V [31-34]. It was assumed that C storage in soil was not affected by forest management in southern pines plantations [7,35-38], therefore the model did not include changes in soil C. Carbon mass ($MgC \cdot ha^{-1}$) was calculated by using an average C content of 50% for loblolly pine and understory biomass components [6,39,40].

2.2. Model Validation

Validation of model results was carried out by comparing model outputs against data reported in the peer-reviewed literature for: (i) total above-plus belowground C accumulation in loblolly pine biomass (T_C, $MgC \cdot ha^{-1}$); (ii) aboveground C accumulation in live loblolly pine biomass (AG_C, $MgC \cdot ha^{-1}$); (iii) belowground C accumulation in live loblolly pine biomass (BG_C, $MgC \cdot ha^{-1}$); and (iv) net ecosystem production (NEP; $MgC \cdot ha^{-1} \cdot year^{-1}$). Results reported in 15 publications including both above- and belowground loblolly pine biomass, for stands between 3 and 48 years old, were considered in our approach. On each validation study, the authors estimated biomass directly using inventory and local biomass functions. For each literature value, the reported initial stand characteristics such as planting density, SI and management activities (site preparation, weed control, fertilization and thinning) were used as model inputs. Loblolly pine's T_C, AG_C and BG_C were validated in two ways, depending on the availability of information: (i) whole-model validation, using reports that included planting density, SI and management activities [25,41-48]; or (ii) allometry validation, using reports where SI was not reported [27,49-53]. The former enabled us to run the model from planting year to age when biomass was determined. For allometry validation from papers which did not report initial stand characteristics, initial model inputs were adjusted to achieve the final stand characteristics of each report, such as H_d, DBH, BA, N_{ha}. The latter approach can be considered a validation of the biomass equations used by the model. Even though two of the studies used for validation [21,23] utilized some of the equations included in the model (see Table 1), we contend that the independent estimation of N_{ha}, DBH and all other C pool components validate the inclusion of those cases. The values of NEP reported by Oren *et al.* [54] for 16 to 21-year old stands were compared with our model estimates. A summary table of all data used for C accumulation validations is reported in Appendix 1. Locations of validation sites are also shown in Figure 1. Validation of litterfall and forest floor outputs were developed/tested in related research by Gonzalez-Benecke, *et al.* 2011 [24]. Validation simulations were performed with the growth and yield functions appropriate for the physiographic region of each validation study.

Figure 1. Location of data validation sources in the southeastern U.S. Shaded area indicates the natural range of loblolly pine. Sites with black-filled symbols were used for the allometric validation, sites with white symbols were used for the whole model validation, and sites with black and white circles were used for the NEP validation.



2.3. Ex Situ *Wood Products Pools*

Depending on stem DBH and merchantable diameter, harvested roundwood (from thinnings or clear-cuts) was assigned to three main product classes: sawtimber (ST), chip-and-saw (CNS) and pulpwood (PW), using the model proposed by Harrison and Borders [16]. Merchantable outside-bark stem volume was calculated at each stand age and product volume was transformed to biomass ($Mg \cdot ha^{-1}$) by multiplying the volume by the average specific gravity (SG) at a given age from equations derived from the model [7]. The exponential model that correlates SG and age is shown in Table 1. A C content of 50% was used to calculate C mass of each product type.

Similar to Gonzalez-Benecke *et al.* [14], industrial conversion efficiencies of 65%, 65% and 58% were assigned to ST, CNS and PW, respectively [25,40,55]. In addition, all the product types were divided into four life span categories (Table 2) [12,56] and adapted to loblolly pine utilization patterns in the southeastern U.S. [57-60].

Table 2. Proportions of wood products by life-span category.

Product	Product proportions by life span category (%)			
	Long (50)	**Medium-long** (16)	**Medium-short** (4)	**Short** (1)
ST	50	25	0	25
CNS	25	25	0	50
PW	0	0	33	67

Note: ST is Sawtimber; CNS is Chip and Saw; PW is Pulpwood; Values in parenthesis indicate average life span for class (years).

2.4. Silvicultural Management Scenarios

The effects of silvicultural treatments and rotation lengths on C sequestration were analyzed by simulating C flux under four different scenarios for standard conditions of loblolly pine plantations established in the southeastern US lower Coastal Plain. Initial variables were set as follow: base SI = 22 m, N_{ha} = 1500 trees·ha^{-1}, bedding, weed control at planting and at age 1, and NP fertilization at age 5 (135 Kg·ha^{-1} N + 28 Kg·ha^{-1} P), 10 (225 Kg·ha^{-1} N + 28 Kg·ha^{-1} P) and 15 years (225 Kg·ha^{-1} N + 28 Kg·ha^{-1} P). After fertilization and weed control treatments, the model estimated that the effective SI was increased to 24.3 m. Initial C accumulated from the previous rotation in coarse root debris (~21.6 MgC·ha^{-1}; [41,42,49]) and the forest floor and aboveground coarse woody debris (~33.83 MgC·ha^{-1}; [61]) was assumed to be 55.4 MgC·ha^{-1}. This value was similar to the amount of 60.0 MgC·ha^{-1} reported for a slash pine plantation following a clearcut harvest [62]. Thinning intensity removal was set at 33% of the living trees. Details of the four management scenarios used in the modeling effort are shown in Table 3. Silvicultural-scenario simulations were performed with the growth and yield functions for the lower Coastal Plain physiographic region.

Table 3. Stand management scenarios.

Scenario	Rotation length (years)	Thinning
1. Pulpwood production (PP)	22	-
2. Sawtimber production short rotation (ST1)	22	Th_{10}
3. Sawtimber production long rotation (ST2)	35	Th_{10}
4. Sawtimber production long rotation (ST3)	35	Th_{10} + Th_{17}

Note: Th_{10} is commercial thinning of 33% of living trees at age 10 yr; Th_{17} is commercial thinning of 33% of living trees at age 17 yr. All scenarios included bedding, weed control at planting and at age 1, and NP fertilization at age 5, 10 and 15 yr.

2.5. Carbon Emissions of Transportation and Silvicultural Activities

Emissions of C by silvicultural activities were determined from Markewitz [63] and White *et al.* [64]. Carbon release in transportation of raw material from the forest to the mill was estimated according to White *et al.* [64], assuming an average haul distance of 100 km from the forest to the mill, load per logging truck of 24 m^3, and fuel economy of the diesel logging truck of 2.6 km l^{-1}. Details of C emissions are presented in Table 4.

Table 4. Carbon used in silvicultural activities and product transportation to mill gate.

Activity	Description	C use (MgC·ha^{-1})
Site Preparation	Raking or spot piling + Weed control (aerial application + product) + Bedding	0.237
Planting	Machine planting	0.101
Banded Weed Control	Banded Herbicide (backpack application + product)	0.091
Initial fertilization (age 5)	120 kg·ha^{-1} diamonium phosphate + 210 kg·ha^{-1} urea	0.216 (1)
Mid-rotation fertilization (age 10 and up)	120 kg·ha^{-1} diamonium phosphate + 430 kg·ha^{-1} urea	0.350 (1)
Thinning	Commercial thinning	0.156
Final harvest	Clear cutting at rotation age	0.156
Transportation	Average for 24 m^3 load capacity	0.0026 (2)

Note: (1) Carbon use in fertilization includes production, packing, transportation and application [63]; (2) Carbon use for transportation is expressed in MgC used per m^3 transported [64].

2.6. Sensitivity Analyses

Sensitivity analyses were carried out to determine the effects of changes in key parameter estimates on total C balance. The effects of site quality were assessed by evaluating the model under contrasting SI values of 15 and 30 m, which corresponded to the full range of site qualities observed in loblolly pine plantations in the southeastern US. After fertilization and weed control treatments, the model estimated that the effective SI increased from 15 to 18.2 m, and from 30 to 32.3 m. Initial stand density effects were evaluated by running the model under contrasting planting densities of 750 and 2250 trees·ha^{-1}. Forest floor accumulation and total net C stock were evaluated by using decomposition rates of 10 and 20%; values beyond the extremes of 12 and 17% reported for this region [26,27,65]. In addition to the silvicultural management scenarios tested, rotation length effects were assessed by evaluating the model under the PP scenario for 18 and 35 years. Average product life span was evaluated by changing the proportion of products in different life span classes. In the case of ST and CNS, the proportion of products in the long life classes (50 years) were changed by 25% (step up and down), distributing the residual proportion in equal parts to the rest of the life span classes. Sensitivity analyses to industrial conversion efficiencies were not considered due to their low impact on *ex situ* C stocks [14].

2.7. Thinning Effects on Loblolly Pine C Stocks

The effects of thinning (as a percentage of living trees removed) were assessed by evaluating the model under different combinations of thinning age (8, 12 and 16 years) and intensity (20, 40 and 60% of living trees removal). Stand and management characteristics were set as those described previously for ST1 (*i.e.*, base SI = 22 m, N = 1500 trees·ha^{-1}, bedding, weed control at planting and at age 1, and NP fertilization at age 5–10–15 years).

2.8. Comparison Between Loblolly and Slash Pine C Stocks

We compared estimates of loblolly pine C stocks with those of slash pine using a previously reported model [14] that was updated with relationships used to estimate LAI, litterfall and forest floor accumulation [24]. Initial parameter estimates such as site index, planting density, site preparation, weed control, fertilization and rotation length were set equal for both species. An analysis for unthinned stands with rotations length of 22 and 35 years was performed. For both species, two NP fertilizations were set at ages 5 and at age 10 years (120 $kg \cdot ha^{-1}$ diamonium phosphate + 210 $kg \cdot ha^{-1}$ urea, and 120 $kg \cdot ha^{-1}$ diamonium phosphate + 430 $kg \cdot ha^{-1}$ urea, respectively).

2.9. Model

Net C stock was defined as: Net C stock = Total C *in situ* (C stored in living loblolly pine trees + understory + forest floor + coarse woody debris + standing dead trees) + Total C *ex situ* (C stored in wood products ST + CNS + PW) − Total C cost (silvicultural activities, including transportation of supplies). For all simulations, estimates of average C stock were reported as the average of all yearly values from the first ~200 years of management, stopping the simulation at the end of the rotation closest to the 200 year endpoint (not stopping the simulations midway into a rotation). For the scenarios with rotation length of 18, 22 and 35 years, the number of rotations simulated was 11, 9 and 6, respectively. This simulation length was chosen to be sufficiently long to approach steady state values for *ex situ* pools, while remaining within plausible bounds for consideration of future forest management scenarios. While it is likely that "true" steady state would be achieved for simulations of 500–1000 years, these time periods are far beyond the time horizon over which forest management planning occurs.

2.10. Statistical Analysis

Four measures of accuracy were used to evaluate the "goodness of fit" between observed and predicted (simulated) values for each variable from the dataset obtained in the model validation [66-70]: (i) Mean absolute error (MAE); (ii) Root mean square error (RMSE); (iii) Mean bias error (*Bias*); and (iv) Pearson product-moment correlation coefficient (R).

3. Results

3.1. Model Validation

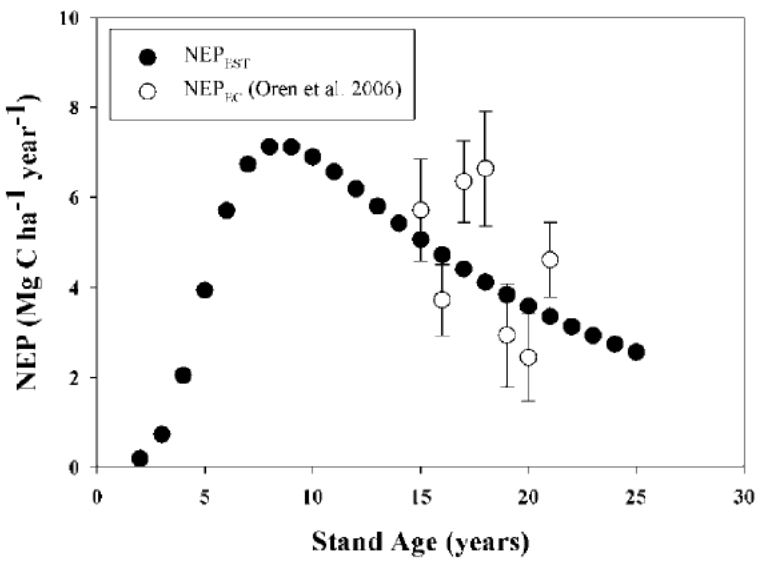
There was no statistical difference between average NEP modeled (NEP_{EST}) and measured NEP (NEP_{EC}) from ages 15 to 21 years (P = 0.77), averaging 4.46 and 4.63 $MgC \cdot ha^{-1} \cdot year^{-1}$ for NEP_{EST} and NEP_{EC}, respectively (Table 5; Figure 2). Predicted values were in the mid-range of variation of observed values.

Table 5. Summary of model evaluation statistics.

Type of validation	Variable	$\bar{O}$	$\bar{P}$	*n*	MAE	RMSE	*Bias*	R
Whole Model	NEP	4.63	4.46	7	1.30	1.41	−0.17	0.42
	AG_C	40.53	40.47	10	5.53	6.75	−0.06	0.97
	BG_C	9.65	10.47	10	1.38	1.55	0.82	0.98
	T_C	50.17	50.94	10	6.41	7.67	0.76	0.98
Allometry	AG_C	36.29	36.82	16	3.11	4.17	−0.53	0.98
	BG_C	9.76	9.12	16	2.09	2.27	0.64	0.94
	T_C	51.08	50.01	16	4.51	5.69	1.08	0.98

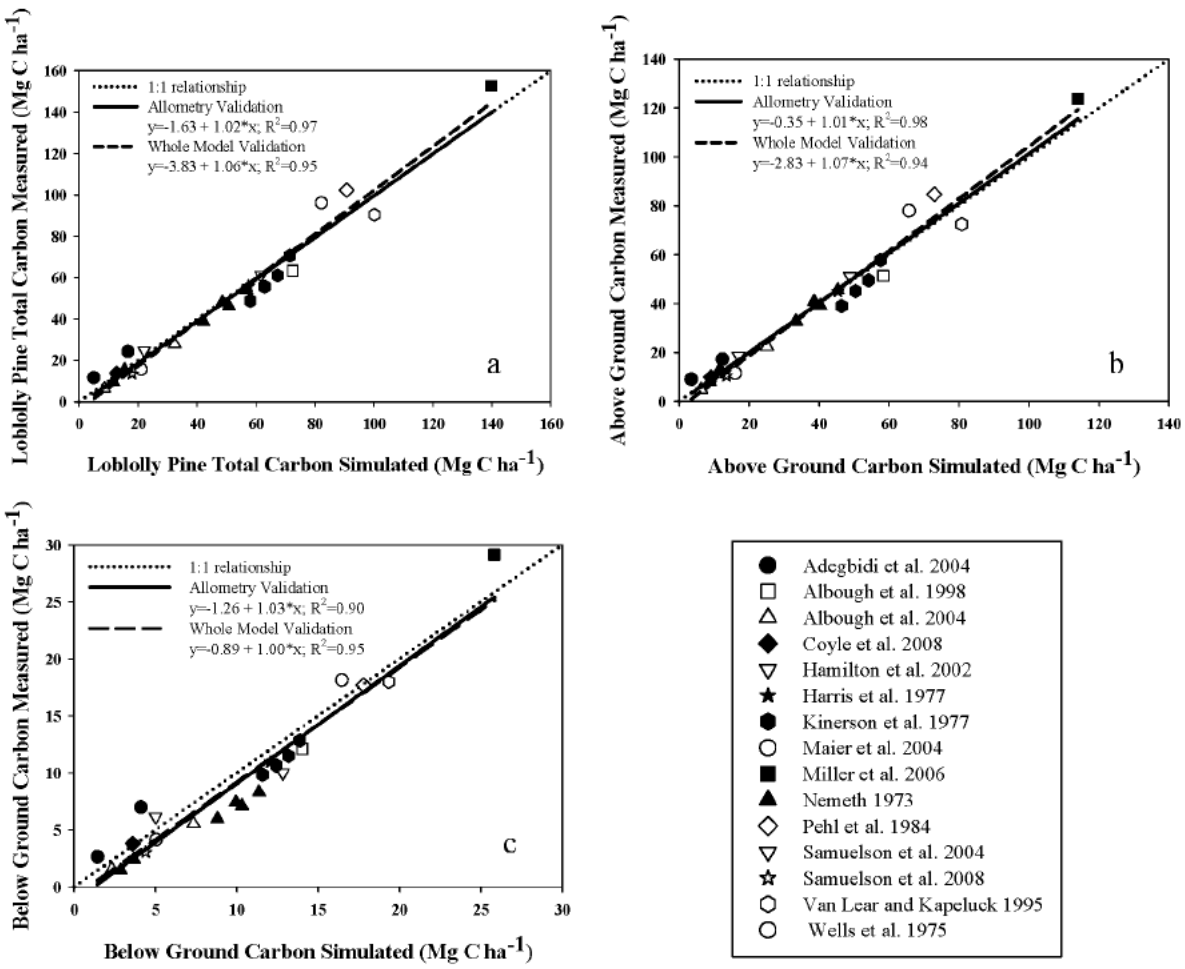
Note: NEP is net ecosystem production ($MgC \cdot ha^{-1} \cdot year^{-1}$); AG_C is loblolly pine aboveground C accumulation ($MgC \cdot ha^{-1}$); BG_C is loblolly pine belowground C accumulation ($MgC \cdot ha^{-1}$); T_C is loblolly pine total C accumulation ($MgC \cdot ha^{-1}$); $\bar{O}$ is the mean observed value; $\bar{P}$ is the mean predicted value; *n* is the number of observations; MAE is the mean absolute error; RMSE is the root of mean square error; *Bias* is the absolute bias estimator; R is the Pearson's correlation coefficient.

Figure 2. Time series of simulated *versus* observed NEP for a loblolly pine plantation located in the transition between the upper Coastal Plain and Piedmont regions in North Carolina.



Estimations of C stock in aboveground (AG_C), belowground (BG_C) and total (T_C) live pine were well correlated with values reported for stands of different ages and productivity ($R^2 > 0.94$; Figure 3a, b and c). In all cases, the intercept and slope of these relationships were not different from zero and one, respectively ($P > 0.27$).

Figure 3. Validation of allometric equations (black filled symbols) and whole model (open symbols) outputs: (**a**) Simulated *versus* measured total C stock (T_C) in living loblolly pine; (**b**) Simulated *versus* measured aboveground (AG_C) living loblolly pine C stock; (**c**) Simulated *versus* measured belowground (BG_C) living loblolly pine C stock.

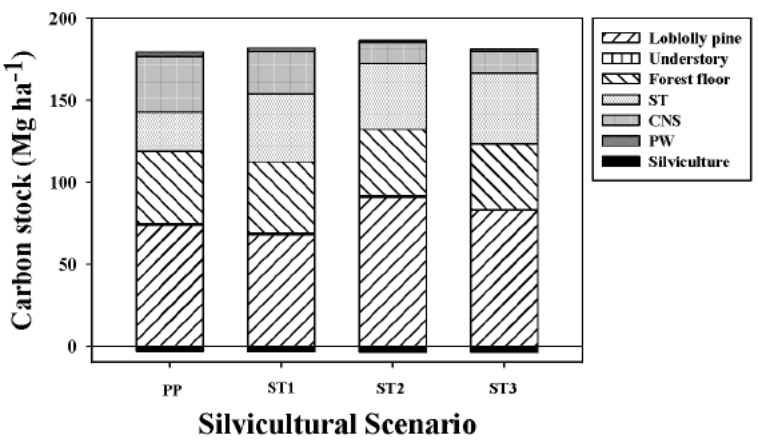


All model performance tests showed that NEP, T_C, AG_C and BG_C estimations agreed well with measured values (Table 5). For the whole-model validation of C stock estimations, MAE and RMSE ranged between 15.3 to 16.7%, and 12.8 to 14.3% of the observed C stock values, respectively. On the other hand, MAE and RMSE for the validation of the allometric equations for biomass estimation (that was carried out with sites were SI was not reported), ranged between 11.1 to 23.2%, and 8.6 to 21.4% of the observed C stock values, respectively. In all cases, BG_C estimations presented the larger differences between the observed and predicted values. The *Bias* of the validation of allometry ranged between 1.5% under-estimations for AG_C to 6.5% over-estimations for BG_C, whereas *Bias* for the whole-model validation ranged between 0.1% under-estimations for AG_C to 8.5% over-estimations for BG_C, with no clear tendency to under- or over-estimate the results. Estimated and observed values of C stock were highly correlated, with R values greater than 0.94. In the case of NEP, the model was less accurate than the C stock estimates, even though the mean was not different between the observed and predicted values. MAE and RMSE were 28.1 and 30.5 % of the observed values, respectively. The *Bias* showed a 3.7% underestimation.

3.2. Silvicultural Management Effects on C Sequestration

One-thinned or two-thinned stands with longer rotation ages (35 years) stored only 4% or 1% more C, respectively, than unthinned stands harvested at age 22 years. Under conditions used in the simulations, average net C stock, which corresponded to total C *in situ* (loblolly pine + understory + forest floor + coarse woody debris + standing dead trees) plus total C *ex situ* (C in woody products ST + CNS + PW) minus total C cost of silvicultural activities (including transport), averaged 176,179,183 and 178 MgC·ha^{-1} for PP, ST1, ST2 and ST3, respectively, for a 200 year simulation period (Figure 4). *In situ* C stock accounted for between 62% and 71% of the gross C sequestration (not including silvicultural C costs) across silvicultural regimes. The magnitude of emissions associated with silvicultural activities (including transportation) was between 1.7% and 1.8% of the gross C stock. The relative impact on C sequestration for the different woody products depended on the silvicultural regimes; ST accounted for 40%, 60%, 75% and 74% of total C *ex situ* for PP, ST1, ST2 and ST3, respectively. In contrast, CNS followed an opposite trend, accounting for 56%, 37%, 23% and 23% for the PP, ST1, ST2 and ST3 silvicultural regimes, respectively. Across different silvicultural management systems, the forest floor + dead trees + coarse woody debris (FF_D) components averaged 42 MgC·ha^{-1} (between 31% to 39% of total *in situ* C stock) and the understory averaged 1.0 MgC·ha^{-1} (less than 1% of total *in situ* C stock).

Figure 4. Average carbon stock for loblolly pine plantations for a ~200 years simulation period under different silvicultural scenarios.



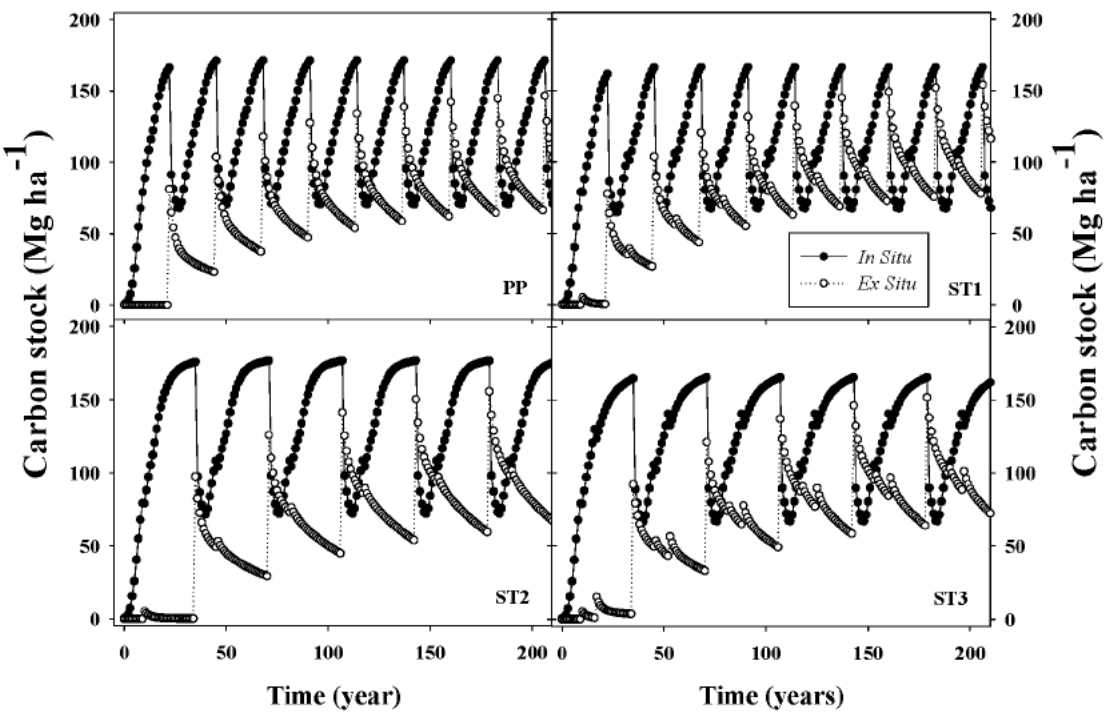
For a 22-year rotation length, removing 33% of the living trees by thinning at age 10 (ST1) had an almost null effect on average net C stock, increasing C storage by about 2.7 MgC·ha^{-1}. Even though there was a 5.8 MgC·ha^{-1} reduction in living loblolly pine C stock, there was a 9.1 MgC·ha^{-1} increment in woody products (mostly due to larger ST production). Extending the rotation age to 35 years with one thinning at age 10 (ST2) increased average net C stock by 4.3 MgC·ha^{-1} when compared with ST1. The similar C stock between both scenarios was caused mainly by the counteracting effects of larger accumulations in living loblolly pine biomass (22.4 MgC·ha^{-1} increment) and by a reduction in *ex situ* C (15.4 MgC·ha^{-1} decrease). If a second thinning was carried out at age 17 years with the extended rotation scenario (ST3), average net C stock decreased by 5.2 MgC·ha^{-1}, compared with ST2. Most of this decrease was due to lower C accumulation in living

loblolly pine (7.8 MgC·ha^{-1} reduction), which was partially counteracted by an increment in the *ex situ* C stock of 3.6 MgC·ha^{-1}.

From a total silviculture C cost perspective, fertilization accounted for 0.92 MgC·ha^{-1} (three fertilizations), representing between 28% and 30% of the total silvicultural C emissions. Harvest and transportation of woody products accounted for between 1.42 and 1.84 MgC·ha^{-1}, representing about 47 to 55 % of the total silvicultural C emissions.

In general, after ~200 years, C flux in the woody products converged to stable values, reaching quasi-equilibrium minimum and maximum values. At their respective rotation ages, *in situ* C stocks were 166, 161, 169 and 158 MgC·ha^{-1} for the PP, ST1, ST2 and ST3 scenarios, respectively (Figure 5). From that total, the C stock in living loblolly pine and the understory was 128, 126, 131 and 124 MgC·ha^{-1} for the same silvicultural regimes, respectively (data not shown). Total woody products C stock increased each rotation from 80, 77, 95 and 90 MgC·ha^{-1} during the first rotation, up to 142, 150, 153 and 150 MgC·ha^{-1} at the end of the rotation closest to the 200 year endpoint, for the PP, ST1, ST2 and ST3 scenarios, respectively (Figure 5). This result implies that in the long term, for extended rotations, C storage fluxes in woody products were similar than the amount of C stored in living loblolly pine.

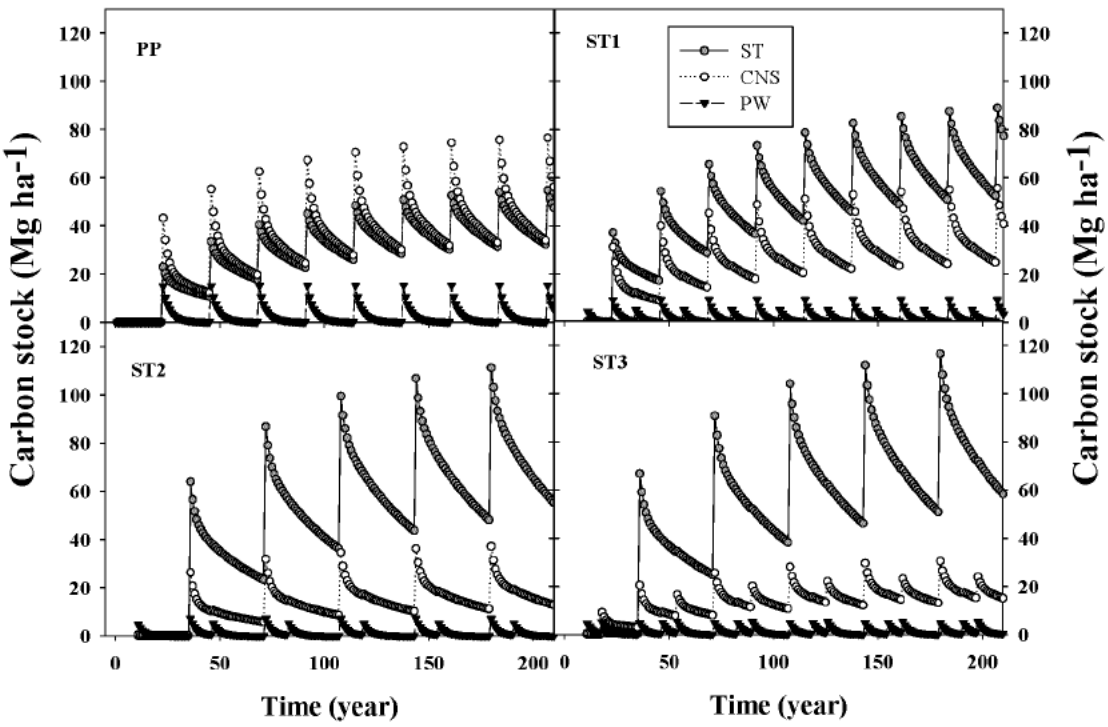
Figure 5. Annual carbon stocks for loblolly pine plantations under different silvicultural scenarios for a 200-year simulation period.



Differences in tree size (diameter and height) and number of trees remaining due to different thinning and rotation age scenarios created different woody products pools that had different life spans. While PW represented 4.2%, 3.4%, 2.3% and 2.6% of the total C extracted in products at harvest, ST accounted for 40%, 60%, 75% and 74% of that C for the PP, ST1, ST2 and ST3 scenarios, respectively. In general, C stored in products derived from PW (e.g., paper, packing material, office supplies, *etc.*) had a negligible effect on net C sequestration; between harvest events (thinning or clear

cutting) the amount of C stored in products derived from pulpwood diminished towards zero, while C stored in CNS and ST increased between harvests (Figure 6).

Figure 6. Annual carbon stocks in woody products for loblolly pine plantations under different silvicultural scenarios for a 200-year simulation period.



3.3. Sensitivity Analysis

With all other parameters held constant, site quality (or potential productivity) reflected in SI of the stand, was the major factor controlling C sequestration (Table 6). For example, on low productivity sites (e.g., base SI = 15 m), average net C stocks were about 28% lower than with the default site quality (base SI = 22 m). In contrast, for high quality sites (e.g., base SI = 30 m), C stocks across silvicultural regimes averaged about 38% greater than base SI = 22 (Table 6). When SI was set equal to 15 m, *ex situ* C stocks were largely reduced for sawtimber-oriented silvicultural regimes. *In situ* C stocks were reduced 21.6, 20, 25.6 and 24 MgC·ha^{-1}, and *ex situ* C stocks were reduced 28, 30, 26.4 and 26.8 MgC·ha^{-1}, for PP, ST1, ST2 and ST3, respectively. By comparison, for base SI = 30 m, *in situ* C stocks increased 25, 23, 30 and 28 MgC·ha^{-1}, and *ex situ* C stock augmented 44.6, 44.7, 39.3 and 40 MgC·ha^{-1}, for the PP, ST1, ST2 and ST3 management regimes, respectively. The silvicultural treatments included in our analysis, that improved SI by 3.2, 2.3 and 2.3 m, for stands with base Si of 15, 22 and 30 m, respectively, produced an increase in net C stock of 12.5, 12.4 and 12.8 MgC·ha^{-1}, respectively, across management regimes (Table 6).

Table 6. Sensitivity analysis of average net carbon stock for selected parameters under different silvicultural scenarios over a ~200 year simulation period.

Parameter	Value	PP(MgC ha^{-1} %)		ST1(MgC ha^{-1} %)		ST2 (MgC ha^{-1} %)		ST3 (MgC ha^{-1} %)	
Default value		176		179		183		178	
Site Index (m)	15	114.5	−35.1%	116.9	−34.7%	119.4	−34.8%	116.2	−34.7%
	18.2	127.2	−27.9%	129.5	−27.6%	131.9	−28.0%	128.0	−28.1%
	22	163.9	−7%	166.7	−6.9%	170.4	−7%	165.6	−7%
	30	232.9	32.1%	234.1	30.8%	238.0	29.9%	232.0	30.3%
	32.3	245.3	39.2%	246.0	37.5%	251.5	37.3%	245.3	37.8%
Planting density (trees ha^{-1})	750	159.7	−9.4%	161.6	−9.7%	164.2	−10.4%	159.2	−10.6%
	2250	187.0	6.1%	188.5	5.3%	194.5	6.1%	189.1	6.2%
Rotation length (years)	18	164.2	−6.9%	-	-	-	-	-	-
	35	183.2	3.9%	-	-	-	-	-	-
Decay rate (%)	10	190.6	8.1%	192.6	7.6%	196.1	7.0%	190.6	7.0%
	20	164.1	−6.9%	166.7	−6.8%	171.8	−6.3%	166.8	−6.3%
ST percentage in long lifespan class (%)	25	169.0	−4.1%	166.3	−7.1%	171.4	−6.5%	165.5	−7.1%
	75	183.6	4.1%	191.6	7.0%	195.1	6.5%	190.7	7.1%
CNS percentage in long lifespan class (%)	0	164.1	−6.9%	169.7	−5.2%	179.0	−2.3%	173.5	−2.6%
	50	188.5	6.9%	188.2	5.2%	187.5	2.3%	182.6	2.6%
PW percentage in medium-short lifespan class (%)	0	175.4	−0.5%	156.9	−0.5%	185.9	−0.2%	180.3	−0.3%
	67	177.2	0.5%	158.3	0.5%	186.7	0.2%	181.3	0.3%

Note: Average net carbon stock (MgC·ha^{-1}) is the average of a ~200 year simulation period and Δ% is the percentage deviation from default parameter values used (Effective site index = 24.3 m; Planting density = 1500 trees·ha^{-1}; Rotation length = 22 years; Decay rate = 15%; ST in long life class = 50%; CNS in long life class = 25%; PW in medium-short life class = 33%).

The effects of planting density were largely reflected in *in situ* rather than *ex situ* C pools. Reducing the initial planting density decreased net C stocks up to 10%, while increasing the planting density enhanced net C stocks by about 6% among silvicultural regimes. By lowering planting density from 1500 trees·ha^{-1} to 750 trees·ha^{-1}, the average net C stocks decreased 16.6,17.3,19 and 18.9 MgC·ha^{-1} for the PP, ST1, ST2 and ST3 management systems, respectively. This reduction was explained principally by a decrease in the *in situ* C stocks of 11.7, 10.5, 10.7 and 10.3 MgC·ha^{-1} for the same silvicultural regimes. The effects on *ex situ* C stocks were substantially smaller, producing gains of 2.4 MgC·ha^{-1}for the PP, but reductions of 0.1, 2.2 and 3.1 MgC·ha^{-1} for the ST1, ST2 and ST3 management systems, respectively. By increasing the initial planting density from 1500 trees·ha^{-1} to 2250 trees·ha^{-1}, average net C stocks were increased 10.7, 9.5, 11.2 and 11 MgC·ha^{-1} compared to the default initial planting density for the PP, ST1, ST2 and ST3 treatments, respectively. For the high initial planting density, *in situ* C stocks were increased 8.1, 7.2, 6.8 and 6.6 MgC·ha^{-1} for the PP, ST1, ST2 and ST3 silvicultural management systems, respectively. The C storage in woody products was reduced by 2.7, 2.4 MgC·ha^{-1} for the PP and ST1 management regimes, but was increased by 0.2 and 0.7 MgC·ha^{-1} for the ST2 and ST3 scenarios, respectively.

Shortening the rotation length to 18 years under the PP scenario (unthinned), which corresponded to the biological rotation age for that silvicultural scenario (*i.e.*, the time when mean annual increment equals periodic annual increment), reduced the average net C stock to 164.2 MgC·ha^{-1}. This

7% decrease, when compared with the default 22-year-rotation, was caused mainly by reductions in the *in situ* rather than *ex situ* C stocks (10.8 and 1.4 MgC·ha^{-1} reductions, respectively). When the rotation age was extended to 35 years, average net C stocks increased to 183.2 MgC·ha^{-1}.

When the C decay rate was reduced to 10% or increased to 20%, average net C stocks increased or decreased between 7.5 and 6.6%, respectively, across silvicultural regimes (Table 6). Assuming a decay rate of 10%, C storage in the FF_D increased to about 13.3 MgC·ha^{-1}, across silvicultural regimes, compared to a decay rate of 15%. When the decay rate was increased up to 20%, the C stocks in the FF_D were reduced to about 11.8 MgC·ha^{-1}.

Variations in average life span of ST and CNS woody products affected net C stock. On the other hand, paper product life span had a smaller effect on net C storage (Table 6). When the average life span of ST was increased by increasing the product proportion in the long-lived class (half-life 50 years, Table 2) from 50% to 75%, average net C stocks were increased 7.3, 12.6, 11.9 and 12.6 MgC·ha^{-1} for the PP, ST1, ST2 and ST3 management regimes, respectively; this represented an increment of between 4.1 and 7.1% (Table 6). On the other hand, when the ST proportion of long life span products was stepped-down to 25%, reductions in C increments of the same magnitude were observed. The impact of the CNS half-life on net C stocks was more important in the PP than the sawtimber-oriented regimes, changing average net C stocks by 12.2, 9.2, 4.3 and 4.6 MgC·ha^{-1} for the PP, ST1, ST2 and ST3 management scenarios, respectively (Table 6). When all PW products were set to have a life span of one year, average net C stocks was reduced between 0.42 and 0.86 MgC·ha^{-1}. Conversely, when the PW products life span was increased by assuming that 67% of PW products would have a life span of four years, the average net C stock was increased between 0.45 and 0.89 MgC·ha^{-1}.

3.4. Thinning Effects on Loblolly Pine C Sequestration

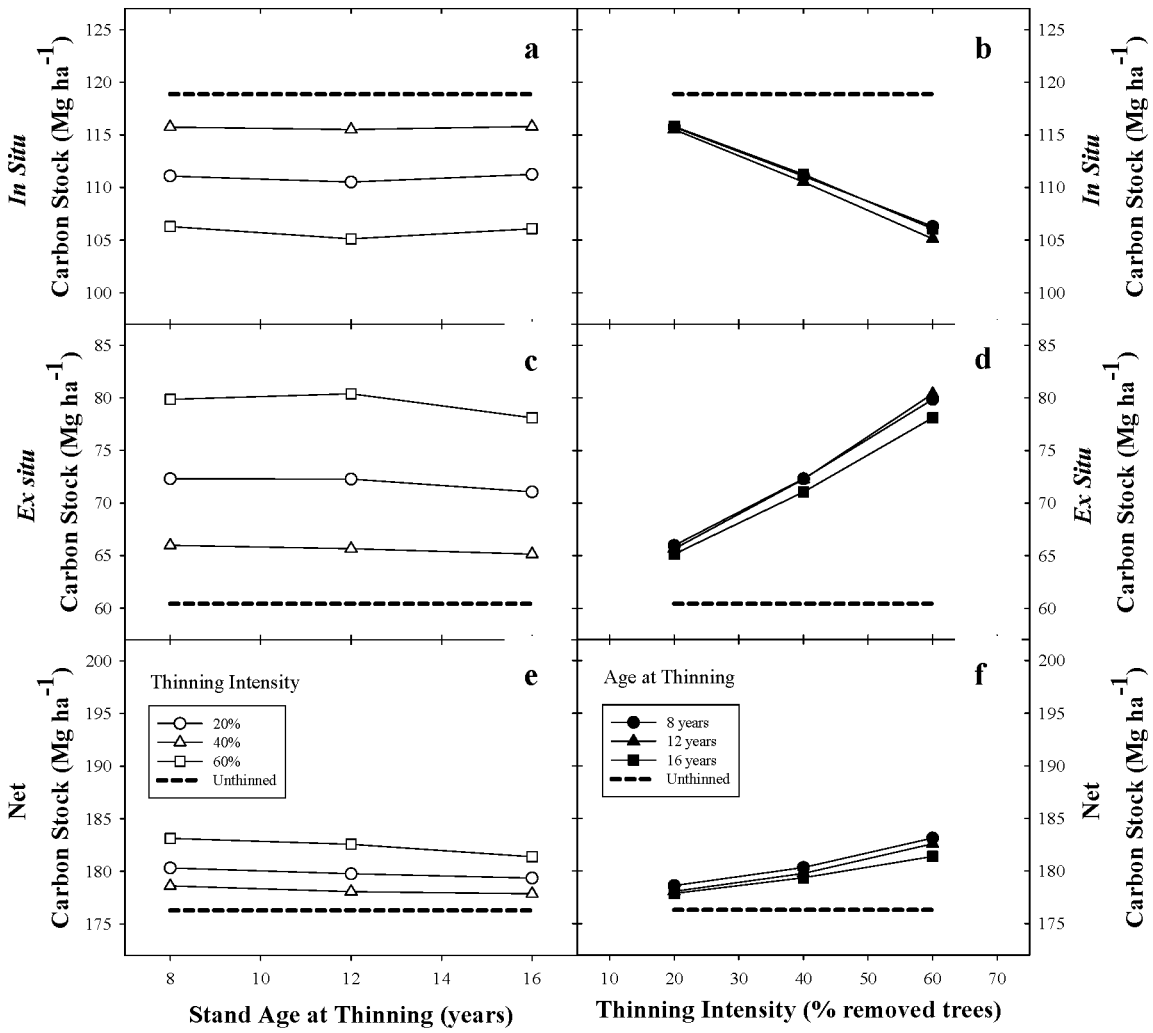
In general, for a base SI = 22 m stand with 1500 trees·ha^{-1} and managed under a 22-year rotation, thinning had a positive on net C stock. The negative effect of thinning on the *in situ* C stock was largely counteracted by increasing the *ex situ* C stock, producing an increase in average net C stock (Figure 7).

For any given thinning intensity, there was a small effect due to the age of thinning on the *in situ* C stock (Figure 7a). For example, using a thinning intensity of 20% at ages 8, 12 and 16 years reduced the *in situ* C stock by 3.1, 3.4 and 3.1 MgC·ha^{-1}, respectively (Figure 7a). Increments in thinning intensity produced a quasi-constant decline in *in situ* C stock, independent of thinning age. For instance, *in situ* C stocks were reduced 3.2, 7.9 and 13 MgC·ha^{-1}, when thinning intensities were set at 20, 40, and 60% removal of living trees, respectively (Figure 7b). *Ex situ* C storage had an opposite response to thinning; the more intensive the thinning regime, the more gain in woody products C storage. *Ex situ* C storage was slightly increased by thinning age for any given thinning intensity. For example, when thinning age was set at 8,12 and 16 years, with a thinning intensity of 20%, the *ex situ* C stock was increased by 5.6, 5.2 and 4.7 MgC·ha^{-1}, respectively; when thinning intensity was set to 60%, *ex situ* C stocks were increased 19.4, 19.9 and 17.7 MgC·ha^{-1}, respectively (Figure 7c). Increments in thinning intensity produced a quasi-constant increment in *ex situ* C stock independent of thinning age. *Ex situ* C stocks were increased 5.2, 11.5 and 19 MgC·ha^{-1}, when thinning intensities

ED_000419-0008249

were set at 20, 40 and 60% removal of living trees, respectively (Figure 7d). Due to the larger positive effects on *ex situ* C storage, rather than smaller negative effects on *in situ* C storage, net C stocks were slightly increased by thinning (Figure 7e and f).

Figure 7. Effects of stand age at thinning (**a, c, e**) and thinning intensity (**b, d, f**) on *In Situ*, *Ex Situ* and average net C stocks for loblolly pine plantations over a ~200 year simulation period.

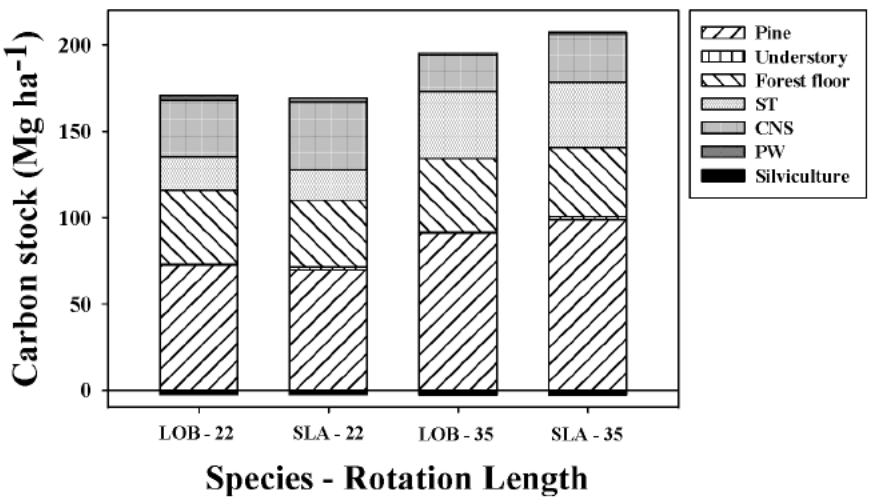


3.5. Comparison in C Sequestration between Loblolly and Slash Pine Stands

Under the default parameters used for simulations in unthinned loblolly pine stands harvested at age 22 years, loblolly and slash pine net C stocks were generally similar, albeit on an absolute basis loblolly pine accumulated 1.3 $Mg \cdot ha^{-1}$ more C than slash pine (Figure 8). This 1% difference in favor of loblolly pine was explained mainly by increases in stored C in the living tree biomass (2.8 $MgC \cdot ha^{-1}$) and FF_D (3.8 $MgC \cdot ha^{-1}$) pools. It should be noted, however, that a 4.6 $MgC \cdot ha^{-1}$ decrease in the loblolly pine woody products pool partially counteracted that gain. Understory biomass was 0.7 $MgC \cdot ha^{-1}$ larger in slash pine than in loblolly pine stands. When the rotation length was increased to 35 years without thinning, slash pine C stocks exceeded loblolly pine, averaging 11.9 $MgC \cdot ha^{-1}$ more net C stock. This difference was explained mainly through increases in net C stored in the living

tree (7.8 MgC·ha^{-1}) and *ex situ* biomass (5.3 MgC·ha^{-1}) pools. Understory C accumulation was 0.9 MgC·ha^{-1} larger in slash pine than in loblolly pine stands, and the FF_D was 2.1 MgC·ha^{-1} larger in loblolly than in slash pine stands.

Figure 8. Average carbon stock for unthinned loblolly (LOB) and slash (SLA) pine plantations for a ~200 year simulation period under two different rotation lengths (22 and 35 years).



4. Discussion

Loblolly pine plays an important role in mitigation of CO_2 emissions due to its high productivity and extensive planting throughout the southeastern U.S. Accurate determinations of C stocks and the understanding of factors controlling C dynamics in loblolly pine plantations are essential for C offset projects and the development of sustainable management systems. To validate the model predictions, we utilized 15 peer-reviewed publications that reported estimates of both above and belowground biomass accumulations in loblolly pine stands. Several other publications were also found that reported only aboveground biomass estimates ([71-75], among many others); however, we decided to validate the model using only those published studies that included both above- and below-ground estimates measured at the same time for a given site. Further, the model was tested on stands of contrasting site quality (SI ranges between 15.5 to 32 m) that ranged in age from 3 to 48 years, across different physiographic regions that cover the planting range of the species (Figure 1; Appendix 1). The strong agreement between observed and predicted values supported the robustness of the model and its usefulness for assessing the effects of forest management activities on C sequestration (*in situ, and ex situ*) for the most important commercial tree species in the southeastern US.

The dominant factor controlling C sequestration in loblolly pine plantations was site quality as it interacted with different management scenarios. Similar responses have been reported for slash pine [14], *Pinus radiata* D. Don and *Pinus pinaster* Ait. [76]. Across the silvicultural regimes evaluated there were similar changes in *in situ* C stocks, but *ex situ* C storage was largely affected by site quality changes and longer rotation lengths oriented toward sawtimber production. Specifically, our results indicated that: (i) long rotation oriented-sawtimber silvicultural regimes were not as effective for C storage on low quality sites, but they were more effective on high quality sites; and (ii) *ex situ* carbon pools were important considerations when evaluating the C offset potential of

different management systems. Over the past 50 years, the productivity of planted loblolly pine stands has tripled [9,77], implying an important effect of modern forest management systems (interaction between genetic improvement, seedling culture, and nutrient and competition management) not only on volume yield, but also on total C storage. The rate of development and implementation of technology that increases production rates will determine the contribution of future plantation C storage. The effects of site quality changes in C storage were exacerbated by the effects of *ex situ* C sequestration because increases in site quality not only increased total standing volume (or stand biomass), but also increased the proportion of trees making valuable product grades that had a long life span.

Increasing initial planting density in the range tested in this study had a positive effect on net C storage, and the effects of planting density on C storage were most apparent in the *in situ* C pool, affecting both living tree biomass and FF_D biomass accumulation. Even though raising the planting density increased the proportion of fixed C used in stem production in loblolly pine [78], this effect was not reflected in the *ex situ* C pool. As planting densities increased, there was a tendency to decrease sawtimber products yields, affecting the average *ex situ* C pools; however, the increase in forest floor, coarse woody debris and total living tree C storage largely counteracted that negative effect. Morton [79] concluded that utilizing higher planting densities maximized C sequestration and with a market value for C credits, land expectation values were maximized by utilizing higher planting densities as well.

Increasing the rotation length increased C stock in loblolly pine stands. We estimated similar net increments of 6.9 $MgC \cdot ha^{-1}$ when rotation lengths were increased from 22 to 35 years for unthinned and thinned stands. Most of this increment was accounted for in the *in situ* C storage. In contrast, when rotation lengths were shortened to 18 years, net C stock was reduced. Other reports for different conifer species [12-14] indicated similar effects of rotation length on C storage *i.e.*, extended rotations increased C sequestration in conifer forest plantations. Longer harvesting cycles represent one of the major management strategies used to increase forest C density [80]. Nevertheless, the inclusion of biomass harvest for fossil fuel offset might change our conclusions, especially when shorter rotations include provisions for a technology bump at the end of each rotation. Further research is needed in this area, and this model is a tool to address these types of questions.

In our study, under a low decomposition rate of 10%, the C stock in the FF_D increased about 13.3 $MgC \cdot ha^{-1}$; under a higher decomposition rate of 20%, C stocks in the FF_D decreased about 11.8 $MgC \cdot ha^{-1}$. As changes in soil temperature and moisture regimes can affect litter decomposition rates [81], it is probable that future environmental changes would be expected to alter litter decomposition rates in loblolly pine stands, and thereby affect the C storage capacity of the forest.

When stand C density was compared between loblolly and slash pine stands under similar levels of site quality (base SI = 20 m) and silvicultural inputs over a 22-year rotation length, living pine C stocks of loblolly and slash pine were generally similar (loblolly pine was 1% greater than slash pine). Under longer rotations (*i.e.*, 35 years), the average net C stocks of both species remained similar; however, slash pine was about 6% greater than loblolly pine. For thinned stands with similar SI as our simulations, loblolly pine at age 31 years had about 8% more standing volume than slash pine [82]. For unthinned stands at age 28 years, the differences between loblolly and slash pine standing volumes were about 1% [83]. The first study to our knowledge that compared C stocks between southern pine

species in mature stands was from Vogel *et al.* [84]. The authors reported that at age 26 years, living tree C stocks of loblolly pine were larger than slash pine when nutritional limitations were eliminated through fertilizer additions. Under nonfertilized conditions, even with sustained elimination of understory vegetation, living tree C stocks were larger for slash pine than for loblolly pine. As nutritional demands and the responses to fertilization for loblolly pine tend to be larger than slash pine [77], differences in nutrient requirements and nutrient use efficiency between the two species should be taken in account when developing sustainable and ecological forestry regimes. In our analysis, the fertilization regime included two applications, which may not be sufficient to support the demands of loblolly pine, especially under longer rotations scenarios.

For the ~200 year simulation period, thinning decreased *in situ* C stocks, but increased *ex situ* C stocks more, resulting in slight increases in net C stocks. Most of the studies that have addressed the impacts of thinning on C budgets in pine ecosystems have reported the responses only on living pine biomass [76,85-88]; few studies have reported the impacts of thinning on total *in situ* C [89-92]. All the previously cited studies concluded that there was a reduction in pine stand or total *in situ* C after thinning. The negative effects of thinning were also reported for NEP fluxes for *Pinus ponderosa* Dougl. forests [90,91]. In both studies, the authors reported a decrease in NEP for thinned stands. To our knowledge, the current study represents one of the few that incorporated the *ex situ* C pool into the analysis of thinning effects on carbon sequestration of forest plantations. Garcia-Gonzalo [93], in a similar analysis that included *ex situ* C pools for mixed coniferous stands in Finland, reported a net reduction between 25 and 33 $MgC \cdot ha^{-1}$ in trees and a net increase between 30 and 45 $MgC \cdot ha^{-1}$ in harvested timber. Even though the wood extracted in thinning was primarily pulpwood, which impacted *ex situ* C sequestration, increased growth of residual trees due to thinning promoted the production of larger tree size classes at final harvest. These long-lived products increased the *ex situ* C pool, overcompensating for the reduction in *in situ* C associated with thinning. When *ex situ* pools were considered, the possible economic benefits of thinning were not in opposition to maintaining or increasing net C stock. This, and other evidence, suggests that there is no simple inverse relationship between the amount of timber harvested from a forest and the amount of C stored [94].

It should be noted that estimates of the effects of scenarios on net C stocks are somewhat sensitive to the length of simulation. This is because *ex situ* C stocks take centuries to reach equilibrium levels (200–400 years for the scenarios we tested, data not shown). Therefore, as longer and longer simulation periods are compared, the effects of differences in *in situ* C stocks on net C stocks tend to be dampened by converging magnitudes of *ex situ* C stocks. This makes it important to carefully consider the inference space desired for a particular simulation. For relatively short-term management decisions, it may be appropriate to run simulations for only one or two rotations. For decision-making associated with C offset accounting contracts, 50–150 years may be appropriate. As mentioned previously, we chose 200-year simulations as a length of time long enough to allow development of near-equilibrium *ex situ* stock levels, but not so long that the time period moved out of the realm of realistic forest management planning.

Under the Intergovernmental Panel on Climate Change [95], reporting of C stock in wood products is not mandatory, but the enhancement of that C pool could provide important GHG emission offsets. Results from this study suggested that extending the half-life of PW products had only a marginal effect on C stock. Similar results were reported in other studies [14,56,58]. The *ex situ* C pools could

be influenced by both the final utilization of particular products, and also by substituting wood for more C intensive materials. If waste wood and forest biomass residues were used as substitutes for fossil fuels [96], or if long lasting wood products took the take the place of more C intensive materials like concrete or steel [97], then the mitigation impacts of *ex situ* C stocks could be even larger.

5. Conclusions

In this article we provide a model for quantifying C sequestration for loblolly pine plantations under varying management conditions in the southeastern U.S. Coastal Plain and Piedmont regions. The model performed accurately when it was tested against reported C measurements over a wide range of stand ages and site qualities. Using the model to evaluate the effects of silvicultural management systems on C sequestration over a 200 year simulation period, we conclude that: (i) site quality (productivity), that can be altered by silviculture and genetic improvement, represents the major factor controlling average net C stock in loblolly pine plantations; (ii) if woody products were incorporated into the accounting, thinning tends to be C positive because of the larger positive effects on *ex situ* C storage; (iii) shorter rotations (biological rotation age) were not as effective for C sequestration as extended rotations that increased average net C stock; (iv) C sequestered in woody products accounted for ~34% of the net C stock; (v) changes in decomposition rates associated with possible global climate change could affect C storage capacity of the forest; and (vi) emissions due to silvicultural and harvest activities were small compared to the magnitude of the total stand C stock.

Acknowledgements

The National Institute of Food and Agriculture funded this research through the Regional Approaches to Climate Change Coordinated Agricultural Project program. The Carbon Resources Science Center at the University of Florida also provided funding. We thank Marshall Jacobson, Plum Creek Timber Company Inc., for his advice on silvicultural prescriptions.

References

1. Nabuurs, G.J.; Masera, O.; Andrasko, K.; Benitez-Ponce, P.; Boer, R.; Dutschke, M.; Elsiddig, E.; Ford-Robertson, J.; Frumhoff, P.; Karjalainen, T.; *et al.* Forestry. In *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007*; Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2007.
2. U.S. Environmental Protection Agency (EPA). Greenhouse gas mitigation potential in U.S. In *Forestry and Agriculture*; EPA 430-R-05-006; U.S. Environmental Protection Agency: Washington, DC, USA, 2005.
3. Sundquist, E.T.; Burruss, R.C.; Faulkner, S.P.; Gleason, R.A.; Harden, J.W.; Kharaka, Y.K.; Tieszen, L.L.; Waldrop, M.P. *Carbon Sequestration to Mitigate Climate Change*; Fact Sheet 2008–3097; U.S. Geological Survey: Golden, CO, USA, 2008; p. 4.
4. Sedjo, R. Forests to offset the greenhouse effect. *J. For.* **1989**, *87*, 12-15.

5. Turner, D.P.; Koerper, G.J.; Harmon, M.E.; Lee, J.J. A carbon budget for forests of the conterminous United States. *Ecol. Appl.* **1995**, *5*, 421-436.
6. Johnsen, K.H.; Wear, D.N.; Oren, R.; Teskey, R.O.; Sanchez, F.; Will, R.E.; Butnor, J.; Markewitz, D.; Richter, D.; Rials, T.; *et al.* Carbon sequestration and southern pine forests. *J. For.* **2001**, *99*, 14-21.
7. Han, F.X.; Plodinec, M.J.; Su, Y.; Monts, D.L.; Li, Z. Terrestrial carbon pools in southeast and south-central United States. *Clim. Change* **2007**, *84*, 191-202.
8. Birdsey, R.A.; Heath, L.S. The forest carbon budget of the United States. In *USDA Forest Service Global Change Research Program Highlights: 1991–1995*; General Technical Report, NE-237; Birdsey, R., Mickler, R., Sandberg, D., Tinus, R., Zerbe, J., O'Brian, K., Eds.; USDA Forest Service: Washington, DC, USA, 1997.
9. Fox, T.R.; Jokela, E.J.; Allen, H.L. The development of pine plantation silviculture in the southern United States. *J. For.* **2007**, *105*, 337-347.
10. Cooper, C.F. Carbon storage in managed forests. *Can. J. For. Res.* **1983**, *13*, 155-166.
11. Cropper, W.P., Jr.; Ewel, K.C. A regional carbon storage simulation for large scale biomass plantations. *Ecol. Model.* **1987**, *36*, 171-180.
12. Liski, J.; Pussinen, A.; Pingoud, K.; Mäkipää, R.; Karjalainen, T. Which rotation length is favorable to carbon sequestration? *Can. J. For. Res.* **2001**, *31*, 2004-2013.
13. Harmon, M.E.; Marks, B. Effects of silvicultural practices on carbon stores in Douglas-fir—Western hemlock forests in the Pacific Northwest, USA: Results from a simulation model. *Can. J. For. Res.* **2002**, *32*, 863-877.
14. Gonzalez-Benecke, C.A.; Martin, T.A., Cropper, W.P., Jr.; Bracho, R. Forest management effects on *in situ* and *ex situ* slash pine forest carbon balance. *For. Ecol. Manag.* **2010**, *260*, 795-805.
15. Marland, G.; Marland, S. Should we store carbon in trees? *Water Air Soil Pollut.* **1992**, *64*, 181-195.
16. Harrison, W.M.; Borders, B.E. *Yield Prediction and Growth Projection for Site-Prepared Loblolly Pine Plantations in the Carolinas, Georgia, Alabama and Florida*; PMRC Technical Report 1996-1; University of Georgia: Athens, GA, USA, 1996; p. 66.
17. Logan, S.R.; Shiver, B.D.; Harrison, W.M. *Polymorphism of Southern Pine Site Index Curves Resulting from Different Cultural Treatments*; PMRC Technical Report 2002-1; Daniel B. Warnell School of Forest Resources, University of Georgia: Athens, GA, USA, 2002; p. 21.
18. Peter, G.F.; White, D.E.; de la Torre, R.; Singh, R.; Newman, D. The value of forest biotechnology: A cost modeling study with loblolly pine and kraft linerboard in the southeastern USA. *Int. J. Biotechnol.* **2007**, *9*, 415-435.
19. Naidu, S.L.; DeLucia, E.H.; Thomas, R.B. Contrasting patterns of biomass allocation in dominant and suppressed loblolly pine. *Can. J. For. Res.* **1998**, *28*, 1116-1124.
20. Jokela, E.J.; Martin, T.A. Effects of ontogeny and soil nutrient supply on production, allocation and leaf area efficiency in loblolly and slash pine stands. *Can. J. For. Res.* **2000**, *30*, 1511-1524.
21. Samuelson. L.J.; Johnsen K.; Stokes, T. Production, allocation, and stemwood growth efficiency of *Pinus taeda* L. stands in response to 6 years of intensive management. *For. Ecol. Manag.* **2004**, *192*, 59-70.

22. Baskerville, G.L. Use of logarithmic regression in the estimation of plant biomass. *Can. J. For. Res.* **1972**, *2*, 49-53.
23. Adegbidi, H.G.; Comerford, N.B.; Jokela, E.J.; Barros, N.F. Root development of young loblolly pine in Spodosols in Southwest Georgia. *Soil Sci. Soc. Am. J.* **2004**, *68*, 596-604.
24. Gonzalez-Benecke, C.A.; Jokela, E.J.; Martin, T.A. Modeling the effects of stand development, site quality, and silviculture on leaf area index, litterfall, and forest floor accumulations in loblolly and slash pine plantations. *For. Sci.* **2011**, in submission.
25. Radtke, P.J.; Amateis, R.L.; Prisley, S.P.; Copenheaver, C.A.; Chojnacky, D.C.; Pittman, J.R.; Burkhart, H.E. Modeling production and decay of coarse woody debris in loblolly pine plantations. *For. Ecol. Manag.* **2009**, *257*, 790-799.
26. Gholz, H.L.; Perry, C.S.; Cropper, W.P., Jr.; Hendry, L.C. Litterfall, decomposition and N and P immobilization in a chronosequence of slash pine (*Pinus elliottii*) plantations. *For. Sci.* **1985**, *31*, 463-478.
27. Gholz, H.L.; Krazynski, L.M.; Volk, B.G. Disappearance and compressibility of buried pine wood in a warm temperate soil environment. *Ecol. Appl.* **1991**, *1*, 85-88.
28. Binkley, D. Ten-year decomposition in a loblolly pine forest. *Can. J. For. Res.* **2002**, *32*, 2231-2235.
29. Bracho, R.; Starr, G.; Gholz, H.L.; Martin, T.A.; Cropper, W.P., Jr.; Loescher, H.W. Controls on carbon dynamics by ecosystem structure and climate for southeastern U.S. pine plantations. *Ecol. Monogr.* **2011**, in submission.
30. Martin, T.A.; Jokela, E.J. Developmental patterns and nutrition impact radiation use efficiency components in southern pine stands. *Ecol. Appl.* **2004**, *14*, 1839-1854.
31. Bentley, J.W.; Harper R.A. *Georgia Harvest and Utilization Study, 2004*; Resource Bulletin SRS-117; Southern Research Station, USDA Forest Service: Ashville, NC, USA, 2007.
32. Bentley, J.W.; Johnson, T.G. *Alabama Harvest and Utilization Study, 2008*; Resource Bulletin SRS-141; Southern Research Station, USDA Forest Service: Ashville, NC, USA, 2008.
33. Bentley, J.W.; Johnson, T.G. *Florida Harvest and Utilization Study, 2008*; Resource Bulletin SRS-162; Southern Research Station. USDA Forest Service: Ashville, NC, USA, 2009.
34. Bentley, J.W.; Johnson, T.G. *North Carolina Harvest and Utilization Study, 2007*; Resource Bulletin SRS-167; Southern Research Station, USDA Forest Service: Ashville, NC, USA, 2010.
35. Gholz, H.L.; Fisher, R.F. Organic matter production and distribution in slash pine (*Pinus elliottii*) plantations. *Ecology* **1982**, *63*, 1827-1839.
36. Harding, R.B.; Jokela, E.J. Long-term effects of forest fertilization on site organic matter and nutrients. *Soil Sci. Soc. Am. J.* **1994**, *58*, 216-221.
37. Sanchez, F.G.; Carter, E.A.; Leggett, Z.H. Loblolly pine growth and soil nutrient stocks eight years after forest slash incorporation. *For. Ecol. Manag.* **2009**, *257*, 1413-1419.
38. Johnson, D.W.; Curtis, P.S. Effects of forest management on soil C and N storage: Meta analysis. *For. Ecol. Manag.* **2001**, *140*, 227-238.
39. Clark, K.L.; Gholz, H.L.; Moncrieff, J.B.; Cropley, F.; Loescher, H.W. Environmental controls over net exchanges of carbon dioxide from contrasting Florida ecosystems. *Ecol. Appl.* **1999**, *9*, 936-947.

40. Smith, J.E.; Heath, L.S.; Skog, K.E.; Birdsey, R.A. *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States*; General Technical Report NE-343; Northeastern Research Station, USDA Forest Service: Newtown Square, PA. USA, 2006.
41. Pehl, C.E.; Tuttle, C.L.; Houser, J.N.; Moehring, D.M. Total biomass and nutrients of 25-year-old loblolly pines (*Pinus taeda* L.). *For. Ecol. Manag.* **1984**, *9*, 155-160.
42. Van Lear, D.H.; Kapeluck, P.R. Above- and below-stump biomass and nutrient content of a mature loblolly pine plantation. *Can. J. For. Res.* **1995**, *25*, 361-367.
43. Albaugh, T.J.; Allen, H.L.; Dougherty, P.M.; Johnsen, K.H. Long term growth responses of loblolly pine to optimal nutrient and water resource availability. *For. Ecol. Manag.* **2004**, *192*, 3-19.
44. Samuelson, L.J.; Butnor, J.; Maier, C.; Stokes, T.; Johnsen, K.; Kane, M. Growth and physiology of loblolly pine in response to long-term resource management: defining growth potential in the southern United States. *Can. J. For. Res.* **2008**, *38*, 721-732.
45. Albaugh, T.L.; Allen, H.L.; Dougherty, P.M.; Kress, L.W.; King, J.S. Leaf area and above- and belowground growth responses of loblolly pine to nutrient and water additions. *For. Sci.* **1998**, *44*, 317-328.
46. Maier, C.A.; Albaugh, T.J.; Allen, H.L.; Dougherty, P.M. Respiratory carbon use and carbon storage in mid-rotation loblolly pine (*Pinus taeda*) plantations: The effect of site resources on the stand carbon balance. *Glob. Chang. Biol.* **2004**, *10*, 1335-1350.
47. Hamilton, G.J.; DeLucia, E.H.; George, K.; Naidu, S.L.; Finzi, A.C.; Schlesinger, W.H. Forest carbon balance under elevated CO_2. *Oecologia* **2002**, *131*, 250-260.
48. Wells, C.G.; Jorgensen, J.R. Nutrient cycling in loblolly pine plantations. In *Forest Soils and Forest Land Management*; Bernier, B., Winget, C.H., Eds.; Presses de l'Université Laval: Québec, Canada, 1975; pp. 137-158.
49. Miller, A.T.; Allen, H.L.; Maier, C.A. Quantifying the coarse-root biomass of intensively managed loblolly pine plantations. *Can. J. For. Res.* **2006**, *36*, 12-22.
50. Coyle, D.R.; Coleman, M.D.; Aubrey, D.O. Above- and below-ground biomass accumulation, production, and distribution of sweetgum and loblolly pine grown with irrigation and fertilization. *Can. J. For. Res.* **2008**, *38*, 1335-1348.
51. Nemeth, J.C. Dry matter production in young loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm.) plantations. *Ecol. Monogr.* **1973**, *43*, 21-41.
52. Kinerson, R.S.; Ralston, C.W.; Wells, C.G. Carbon cycling in a loblolly pine plantation. *Oecologia* **1977**, *29*, 1-10.
53. Harris, W.F.; Kinerson, R.S., Jr.; Edwards, N.T. Comparison of belowground of natural deciduous forests and loblolly pine plantations. *Pedobiologia* **1977**, *17*, 369-381.
54. Oren, R.; Hsieh, C.-I.; Stoy, P.; Albertson, J.; McCarthy, H.R.; Harrell, P.; Katul, G.G. Estimating the uncertainty in annual net ecosystem carbon exchange: Spatial variation in turbulent fluxes and sampling errors in eddy-covariance measurements. *Glob. Chang. Biol.* **2006**, *12*, 883-896.
55. Spelter, H.; Alderman M. *Profile 2005: Softwood sawmills in the United States and Canada*; Research Paper FLP-RP-630; Forests Products Laboratory, USDA Forest Service: Madison, WI, USA, 2005.

56. Gundimeda, H. A framework for assessing carbon flow in Indian wood products. *Environ. Dev. Sustain.* **2001**, *3*, 229-251.
57. Birdsey, R.A. Carbon storage for major forest types and regions in the conterminous United States. In *Forest Management Opportunities. Forests and Global Change*; Sampson, R.N., Hair, D., Eds.; American Forests: Washington, DC, USA, 1996; Volume 2, pp. 1-25.
58. Harmon, M.E.; Harmon, J.M.; Ferrell, W.K.; Brooks, D. Modeling carbon stores in Oregon and Washington forest products: 1900–1992. *Clim. Chang.* **1996**, *33*, 521-550.
59. Row, C.; Phelps, R.B. Wood carbon flows and storage after timber harvest. In *Forest Management Opportunities. Forests and Global Change*; Sampson, R.N., Hair, D., Eds.; American Forests: Washington, DC, USA, 1996; Volume 2, pp. 59-90.
60. Skog, K.E.; Nicholson, G.A. Carbon cycling through wood products: The role of wood and paper products in carbon sequestration. *For. Prod. J.* **1998**, *48*, 75-83.
61. Eisenbies; M.H.; Vance, E.D.; Aust, W.M.; Seiler, J.R. Intensive utilization of harvest residues in southern pine plantations: Quantities available and implications for nutrient budgets and sustainable site productivity; General Technical Report NRS-P-31. In *Biofuels, Bioenergy, and Bioproducts from Sustainable Agricultural and Forest Crops: Proceedings of the Short Rotation Crops International Conference*; Bloomington, MN, USA, 19–20 August 2008; Zalesny, R.S., Jr., Mitchell, R., Richardson, J., Eds. Northern Research Station, U.S. Department of Agriculture, Forest Service: Newtown Square, PA, USA, 2009; pp. 90-98.
62. Clark, K.L.; Gholz, H.L.; Castro, M.S. Carbon dynamics along a chronosequence of slash pine plantations in North Florida. *Ecol. Appl.* **2004**, *14*, 1154-1171.
63. Markewitz, D. Fossil fuel carbon emissions from silviculture: Impacts on net carbon sequestration in forests. *For. Ecol. Manag.* **2006**, *236*, 153-161.
64. White, M.K., Gower, S.T., Ahl, D.E. Life-cycle inventories of roundwood production in Wisconsin—Inputs into an industrial forest carbon budget. *For. Ecol. Manag.* **2005**, 219, 13-28.
65. Gholz, H.L.; Fisher, R.F.; Pritchett, W.L. Nutrient dynamics in slash pine plantation ecosystems. *Ecology* **1985**, *66*, 647-659.
66. Fox, D. G. Judging air quality model performance. *Bull. Am. Meteorol. Soc.* **1981**, *62*, 599-609.
67. Willmott, C.J. 1982. Some comments on the evaluation of model performance. *Bull. Am. Meteorol. Soc.***1982**, *63*, 1309-1313.
68. Willmott, C.; Ackleson, S.; Davis, R.; Feddema, J.; Klink, K.; Legates, D.; O'Donnell, J.; Rowe, C. Statistics for the evaluation and comparison of models. *J. Geophys. Res.* **1985**, *90*, 8995-9005.
69. Loague K.; Green, R.E. Statistical and graphical methods for evaluating solute transport models: Overview and application. *J. Contam. Hydrol.* **1991**, *7*, 51-73.
70. Kaboyashi, K.; Salam, M.U. Comparing simulated and measured values using mean squared deviation and its components. *Agron. J.* **2000**, *92*, 345-352.
71. Switzer G.L.; Nelson, L.E. Nutrient accumulation and cycling in loblolly pine (*Pinus taeda* L.) plantation ecosystems: The first twenty years. *Soil Sci. Soc. Am. J.* **1972**, *36*, 143-147.
72. Sheppard, J.P. Relationships between Nutrient Cycling and Net Primary Productivity in Loblolly Pine Plantation Ecosystems of the East Gulf Coastal Plain. Ph.D. Dissertation. Department of Forestry, Mississippi State University: Mississippi, MS, USA, 1985; p. 191.

73. Colbert, S.R.; Jokela, E.J.; Neary, D.G. Effects of annual fertilization and sustained weed control on dry matter partitioning, leaf area, and growth efficiency of juvenile loblolly and slash pine. *For. Sci.* **1990**, *36*, 995-1014.
74. Johnson, D.W.; Lindberg, S.E. Atmospheric deposition and forest nutrient cycling. Springer-Verlag: New York, NY, USA, 1992.
75. Rubilar, R.A. Biomass and Nutrient Accumulation Comparison between Successive Loblolly Pine Rotations on the Upper Coastal Plain of Alabama. M.S. Thesis. Department of Forestry, North Carolina State University: Raleigh, NC, USA, 2003; p. 76.
76. Balboa-Murrias, M.A.; Rodriguéz-Soalleiro, R.; Merino, A.; Alvarez-González, J.G. Temporal variations and distribution of carbon stocks in aboveground biomass of radiata pine and maritime pine pure stands under different silvicultural alternatives. *For. Ecol. Manag.* **2006**, *237*, 29-38.
77. Jokela, E.J.; Martin, T.A.; Vogel, J.G. Twenty-five years of intensive forest management with southern pines: Important lessons learned. *J. For.* **2010**, *108*, 338-347.
78. Burkes E.C.; Will, R.E.; Barron-Gafford, G.A.; Teskey, R.O.; Shiveret, B. Biomass partitioning and growth efficiency of intensively managed *Pinus taeda* and *Pinus elliottii* stands of different planting densities. *For. Sci.* **2003**, *49*, 224-234.
79. Morton, J.D. The Influence of Stand Density on Rate of Carbon Sequestration in Loblolly Pine Plantations on Mined Lands in East Texas. M.S. Thesis. College of Forestry, Stephen F. Austin State University: Nacogdoches, TX, USA, 2002; p. 524.
80. Canadell, J.G.; Raupach, M.R. Managing forests for climate change mitigation. *Science* **2008**, *320*, 1456-1457.
81. Gholz, H.L.; Wedin, D.A.; Smitherman, S.M.; Harmon, M.E.; Parton, W.J. Long-term dynamics of pine and hardwood litter in contrasting environments: Toward a global model of decomposition. *Glob. Change. Biol.* **2000**, *6*, 751-765.
82. Clason, T.R.; Cao, Q.V. Comparing growth and yield between 31-year-old slash and loblolly pine plantations; General Technical Report SE-24. In *Proceedings of the Southern Silviculture Research Conference*; Atlanta, Georgia, 4–5 November, 1982; USDA Forest Service: Ashville, NC, USA, 1983; pp. 291-297.
83. Baldwin, V.C., Jr.; Feduccia, D.P.; Haywood, J.D. Post thinning growth and yield of row-thinned and selectively thinned loblolly and slash pine plantations. *Can. J. For. Res.* **1989**, *19*, 247-256.
84. Vogel, J.G.; Suau, L.; Martin, T.A.; Jokela, E.J. Long term effects of weed control and fertilization on the carbon and nitrogen pools of a slash and loblolly pine forest in north central Florida. *Can. J. For. Res.* **2011**, *41*, 552-567.
85. Madrigal, J.; Hernando, C.; Guijarro; M.; Diez, C.; Jimenez, E. Distribucion de biomasa y fijacion de carbono tras clareos mecanizados intensos en regenerado post-incendio de *Pinus pinaster* Ait. (Monte Fraguas, Guadalajara, España). *Invest. Agr. Sist. Recur. For.* **2006**, *15*, 231-242.
86. Skovsgaard J.P.; Stupak , I.; Vesterdal, L. Distribution of biomass and carbon in even-aged stands of Norway spruce (*Picea abies* (L.) Karst.): A case study on spacing and thinning effects in northern Denmark. *Scand. J. For. Res.* **2006**, *21*, 470-488.

87. Chiang, J.M.; McEwan, R.W.; Yaussy, D.A.; Brown, K.J. The effects of prescribed fire and silvicultural thinning on the aboveground carbon stocks and net primary production of overstory trees in an oak-hickory ecosystem in southern Ohio. *For. Ecol. Manag.* **2008**, *255*, 1584-1594.
88. Finkral, A.J.; Evans, A.M. The effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest. *For. Ecol. Manag.* **2008**, *255*, 2743-2750.
89. Boerner, R.E.J.; Huang, H.; Hart, S.C. Fire, thinning, and the carbon economy: Effects of fire and surrogate treatments on estimated carbon storage and sequestration rate. *For. Ecol. Manag.* **2008**, *255*, 3081-3097.
90. Campbell, J.; Alberti, G.; Martin, J.; Law, B.E. Carbon dynamics of a ponderosa pine plantation following a thinning treatment in the northern Sierra Nevada. *For. Ecol. Manag.* **2009**, *257*, 453-463.
91. Dore, S.; Kolb, T.E.; Montes-Helu, M.; Eckert, S.E.; Sullivan, B.W.; Hungate, B.A.; Kaye, J.P.; Hart, S.C.; Koch, G.W.; Finkral, A. Carbon and water fluxes from ponderosa pine forests disturbed by wildfire and thinning. *Ecol. Appl.* **2010**, *20*, 663-683.
92. Jiménez, E.; Vega, J.A.; Fernández, C.; Fonturbel, T. Is pre-commercial thinning compatible with carbon sequestration? A case study in a maritime pine stand in northwestern Spain. *Forestry* **2011**, *84*, 149-157.
93. Garcia-Gonzalo, J.; Peltola, H.; Briceño-Elizondo, E.; Kellomäki, S. Changed thinning regimes may increase carbon stock under climate change: A case study from a Finnish boreal forest. *Clim. Chang.* **2007**, *81*, 431-454.
94. Thornley, J.H.M.; Cannell, M.G.R. Managing forests for wood yield and carbon storage: A theoretical study. *Tree Physiol.* **2000**, *20*, 477-484.
95. Intergovernmental Panel on Climate Change (IPCC). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*; Prepared by the National Greenhouse Gas Inventories Programme; Eggleston H.S., Buendia L., Miwa K., Ngara T., Tanabe K., Eds. IGES: Kamiyamaguchi, Japan, 2006.
96. Galik, C.S.; Abt, R.C.; Wu, Y. Forest Biomass Supply in the Southeastern United States-Implications for Industrial Roundwood and Bioenergy Production. *J. For.* **2009**, *107*, 69-77.
97. Perez-Garcia, J.; Lippke, B.; Comnick, J.; Manriquez, C. An assessment of carbon pools, storage, and wood products market substitution using life-cycle analysis results. *Wood Fib. Sci.* **2005**, *37*, 140-148.

Appendix 1.

Summary of validation data. Stand age, location, C stock (AG_C and BG_C) and fluxes (NEP) used from the peer-reviewed literature.

Source		Stand Age	Lat	Long	Physiographic Region	AG_C	BG_C	NEP
Adegbidi *et al.* 2004	[23]	3	31.6	−81.4	LCP	9.05	2.65	-
Coyle *et al.* 2008	[98]	4	33.38	−81.67	UCP (SAH)	10.0	3.8	-
Adegbidi *et al.* 2004	[23]	4	31.92	−81.03	LCP	17.25	7.0	-
Samuelson *et al.* 2004	[21]	6	30.8	−84.65	UCP	18.6	6.15	-
Albaugh *et al.* 2004	[43]	8	34.87	−79.48	UCP (SAH)	4.7	1.6	-
Nemeth 1973	[51]	8	35.33	−76.75	UCP	51.3	12.1	-
Nemeth 1973	[51]	9	35.33	−76.75	UCP	10.45	3.05	-
Nemeth 1973	[51]	10	35.33	−76.75	UCP	11.52	4.16	-
Samuelson *et al.* 2008	[44]	11	30.8	−84.65	UCP	45.0	10.95	-
Albaugh *et al.* 1998	[45]	11	34.87	−79.48	UCP (SAH)	51.28	10.01	-
Nemeth 1973	[51]	11	35.33	−76.75	UCP	22.35	5.55	-
Nemeth 1973	[51]	11	35.33	−76.75	UCP	77.975	18.15	-
Nemeth 1973	[51]	12	35.33	−76.75	UCP	123.65	29.15	-
Maier *et al.* 2004	[46]	12	34.87	−79.48	UCP (SAH)	84.65	17.7	-
Kinerson *et al.* 1977	[52]	13	35.81	−78.7	PED	72.45	18.0	-
Kinerson *et al.* 1977	[52]	14	35.81	−78.7	PED	38.94	9.84	-
Harris *et al.* 1977	[53]	14	35.08	−79.28	PED	45.05	10.65	-
Hamilton *et al.* 2002	[47]	15	35.97	−79.08	PED	49.52	11.48	-
Kinerson *et al.* 1977	[48]	15	35.81	−78.7	PED	57.78	12.84	-
Albaugh *et al.* 2004	[43]	16	34.87	−79.48	UCP (SAH)	8.05	1.45	-
Kinerson *et al.* 1977	[52]	16	35.81	−78.7	PED	13.05	2.4	-
Wells *et al.* 1975	[48]	16	32.87	−79.98	PED	32.7	5.95	-
Miller *et al.* 2006	[49]	23	36.41	−78.05	PED	40.7	7.4	-
Pehl *et al.* 1984	[41]	25	31.7	−94.35	WGUCP	39.1	7.1	-
Van Lear and Kapeluck 1995	[42]	48	34.61	−82.08	PED	45.5	8.3	-
Oren *et al.* 2006	[54]	15	35.92	−79.08	PED	-	-	5.71
Oren *et al.* 2006	[54]	16	35.92	−79.08	PED	-	-	3.72
Oren *et al.* 2006	[54]	17	35.92	−79.08	PED	-	-	6.35
Oren *et al.* 2006	[54]	18	35.92	−79.08	PED	-	-	6.63
Oren *et al.* 2006	[54]	19	35.92	−79.08	PED	-	-	2.94
Oren *et al.* 2006	[54]	20	35.92	−79.08	PED	-	-	2.45
Oren *et al.* 2006	[54]	21	35.92	−79.08	PED	-	-	4.61

Note: AG_C is aboveground C accumulation in live loblolly pine biomass ($MgC \cdot ha^{-1}$); BG_C is belowground C accumulation in live loblolly pine biomass ($MgC \cdot ha^{-1}$); NEP is net ecosystem production ($MgC \cdot ha^{-1} \cdot year^{-1}$); Age is stand age (years); Lat is stand location latitude (decimal); Long is stand location longitude (decimal); LCP is Lower Coastal Plain; UCP is Upper Coastal Plain; SAH is Sandhills; PED is piedmont; WGUCP is West Golf Upper Coastal Plain.

© 2011 by the authors; licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/3.0/).

CURRICULUM VITA

Daniel Markewitz

Associate Professor
Warnell School of Forestry and Natural Resources
The University of Georgia
Athens, GA 30605
706-542-0133
dmarke@warnell.uga.edu

1. Academic and Professional History

a. Education

Ph.D., Department of Environment, Duke University, May, 1996.
Dissertation title: Soil acidification, soil potassium availability, and biogeochemistry of aluminum and silicon in a 34-year-old loblolly pine (*Pinus taeda* L.) ecosystem in the Calhoun Experimental Forest, South Carolina.

M.E.M., School of Forestry and Environmental Studies, Duke University, 1991.
Thesis title: Chemical patterns in snowpack, soil solution, and streamwater in a subalpine ecosystem of the Fraser Experimental Forest, Colorado.

B.S., School of Natural Resources, University of Michigan, Ann Arbor, 1986.

b. Professional Experience (University of Georgia):

Professor of Soil/site productivity. Warnell School of Forestry and Natural Resource, The University of Georgia, Athens, GA. July 2011 – present (80 % Research/20% teaching)

Associate Professor of Soil/site productivity. Warnell School of Forestry and Natural Resource, The University of Georgia, Athens, GA. July 2003 – 2010 (80 % Research/20% teaching)

Assistant Professor of Soil/site productivity. Warnell School of Forest Resource, The University of Georgia, Athens, GA. March, 1998 – June, 2003

c. Professional Experience (Other):

Postdoctoral Research Fellow. The Woods Hole Research Center, Woods Hole, MA. November 1995 – February, 1998

Graduate Research and Teaching Assistant. Department of Environment, Duke University, Durham, NC. January 1991 to October 1995

Research Assistant. Fraser Experimental Forest, U.S. Forest Service, Fraser, CO. June, 1989 to Dec. 1990

ED_000419-0008262

Environmental Scientist. Camp Dresser and Mckee, New York, NY.
May – August, 1987

Interpreter/Naturalist. Sequoia National Park, Sequoia Natural History Association.
May – Sept. 1986

Student Conservation Association Research Technician. Bureau of Land Management, Coos Bay, OR. June-July, 1985

d. Honors and Awards:

President, Soil Science Society of Georgia, 2012-2013.

Invited speaker, Special Session: Southern Forest Science in Support of a Low Carbon economy. Biennial Southern Silvicultural Research Conference, Charleston, SC, February, 2011.

Presentation Award Soil Science Society of America, S7 Division, Annual Meeting, Nov. 2010.

Invited speaker, Synthesis of Major LBA Research Results, Meeting of the Americas, American Geophysical Union, Foz do Iguassu, Brazil, August, 2010.

Invited workshop participant, Tropical Hydrology Symposium, Panama City, Panama March, 2009.

Chair, Forest, Range, and Wildlands Soils Division, Soil Science Society of America, 2008.

Presentation Award Soil Science Society of America, S7 Division, Annual Meeting, Oct. 2008.

Invited speaker, World Soil Congress, Philadelphia, PA. July 2006.

Invited speaker, 7th International Symposium on the Geochemistry of the Earth's Surface, Aix-en-Provence, France, August 2005.

Invited speaker, 31st International Geological Conference, Rio de Janeiro, Brazil. Aug. 2000.

Presentation Award Soil Science Society of America, S7 Division, Annual Meeting, Nov. 1997.

ED_000419-0008263

Awarded National Research Council Postdoctoral Fellowship, November 1995 (declined award)

Presentation Award Soil Science Society of America, S7 Division, Annual Meeting, Nov. 1994.

Academic Scholarship, Duke University Masters of Environmental Management – August 1987- May 1989

Xi Sigma Pi – Forest Resources Honor Society, University of Michigan, admitted May 1986

2. Scholarly Activities:

a. Publications

** denotes invited submission

§ denotes graduate student as lead or co-author

Books Authored:

Richter, D.D. and Markewitz, D. 2001. Understanding soil change: Soil sustainability over time scales of decades and centuries. Cambridge University Press, New York, NY. 255 pages.

Chapters in Books:

Richter, DD, MA Callaham, D Markewitz, and R Vilgalys. 2006. Understanding Ecosystem Change at the Calhoun Experimental Forest. *In* Irland, LC, AE Camp, JC Brissette, and ZR Donohew Long-term Silvicultural & Ecological Studies: Results of Science and Management, page 169-176.

Davidson, E.A., C. Neill, AV Krusche, M.V.R. Ballester, D. Markewitz, and R.O. Figueiredo. 2004. Loss of Nutrients from Terrestrial Ecosystems to Streams and the Atmosphere following Land Use Change in Amazonia. *In* DeFries, R., Asner, G., and Houghton R. (eds.), Ecosystems and Land Use Change. Geophysical Monograph Series. American Geophysical Union. Washington, D.C., p. 147-158.**,*

Nepstad, D.C., Moutinho, P.R., and Markewitz, D. 2001. The recovery of biomass, nutrient stocks, and deep-soil functions in secondary forests. P. 139-164. *In* McClain ME, RL Victoria & JE Richey (eds.), The biogeochemistry of the Amazon Basin and its role in a changing world. Oxford University Press. **, *

Richter, D.D. and Markewitz, D. 1996. Atmospheric deposition and soil resources of the southern pine forest. P. 315-336. *In* Fox, S and R.A. Mickler (eds.), Impact of air

ED_000419-0008264

pollution on southern pine forests. Ecological Studies Series, Vol. 118. Springer-Verlag, NY. **, *

Richter, D.D. and Markewitz, D. 1996. Carbon changes during the growth of loblolly pine on formerly cultivated soil: The Calhoun Experimental Forest, USA. P. 397-407. *In* Powlson, D.S., Smith, P. and Smith, J.U. (eds.), Evaluation of soil organic matter models: Using existing long-term datasets. NATO Advanced Science Series 1, Global Environmental Change Vol. 38, Springer-Verlag, Berlin. **, *

Richter, D.D., D. Markewitz, C.G. Wells, H.L. Allen, J. Dunscomb, K. Harrison, P.R. Heine, A. Stuanes, B. Urrego, and G. Bonani. 1995. Carbon cycling in an old-field pine forest: Implications for the missing carbon sink and the concept of soil. p. 233-252. *In* W. McFee and J.M. Kelly (eds.), Carbon forms and functions in forest soils. Soil Science Society of America Publishers, Madison, WI. *

Journal Articles:

Williams, T.D., R Moore, and D Markewitz. Evaluating content- and presentation-related characteristics of media coverage of environmental issues with significant public debate. Applied Environmental Education and Communication. *In press.*

Markewitz, D., R. de O. Figueiredo, C.J. de Carvalho, and E.A. Davidson. 2012. Tree growth and soil response to P fertilization in a 24-year-old tropical forest on an Oxisol. Biology and Fertility of Soil. DOI 10.1007/s00374-011-0659-9.

Worsham, L, D Markewitz, N Nibbelink, and L West. 2012. A comparison of three landscape sampling methods to estimate soil carbon content. Forest Science, DOI 10.5849/forsci.11-084.

Richter, DD, AR Bacon, ML Mobley, CJ Richardson, SS Andrews, L West, S Wills, S Billings, CA Cambardella, N Cavallaro, JE DeMeester, AJ Fransluebbers, AS Grandy, S Grunwald, J Gruver, AS Hartshorn, H Janzen, MG Kramer, JK Ladha, K Lajtha, GC Liles, D Markewitz, PJ Megonigal, AR Mermut, C Rasmussen, DA Robinson, P Smith, CA Stilles, RL Tate, A Thompson, AJ Tugel, H van Es, D Yaalon, TM Zobeck. 2011. Human-Soil Relations are Changing Rapidly: Proposals from SSSA's Cross-Divisional Soil Change Working Group. Sil Sci. Soc. Am. J. 75: 1-6. DOI: 10-2136/sssaj2011.0124.

Markewitz, D., E.C. Lamon III, MMC Bustamante, J. Chavez, R.O. Figueiredo, M. Johnson, A. Krusche, C. Neill, and JSO Silva. 2011. Discharge-calcium conentration relationships in streams of the Amazon and Cerrado of Brazil: Soil or land use controlled. Biogeochemistry 105:19-35. DOI: 10.1007/s10533-011-9574-2.

ED_000419-0008265

Neill, C, JE Chaves, T Biggs, LA Deegan, H Elsenbeer, RO Figueiredo, S Germer, MS Johnson, J Lehman, and D Markewitz. 2011. Runoff sources and land cover change in the Amazon: An end member mixing analysis from small watersheds. Biogeochemistry 105:7-18. DOI: 10.1007/x10533-011-9597-8.

Resende, J, D Markewitz, CA Klink, MM Bustamante, and EA Davidson. 2011. Phosphorus cycling in a small watershed in the Brazilian Cerrado: impacts of frequent burning. Biogeochemistry 105:105-118. DOI: 10-1007/s10533-010-9531-5.

Silva, JSO, MMC Bustamante, D Markewitz, AV Krusche, and LG Ferreira. 2011. Effects of land cover on chemical characteristics of streams in the Cerrado region of Brazil. Biogeochemistry. 105: 75-88. DOI: 10.1007/s10533-010-9557-8.

Parron, LM, MMC Bustamante, and D. Markewitz. 2011. Fluxes of nitrogen and phosphorus in a gallery forest in the cerrados of central Brazil: Effects of the topographical gradient. Biogeochemistry. 105:89-104. DOI: 10.1007/s10533-010-9537-z.

Devine, S. D. Markewitz. P. Hendrix, and D. Coleman. 2011. Soil carbon change through two meters during forest succession alongside a 30-yr agroecosystem experiment. Forest Science 57(1): 36-50.§

Joslin, AH, D Markewitz, LA Morris, F de A Oliveira, R de O Figuereido and OR Kato. 2011. Five native tree species and manioc under slash-and-mulch agroforestry in the eastern Amazon, Brazil: Plant growth and soil responses. Agroforestry Systems. 81(1): 1-14.§

Davidson, E.A., R.O. Figueiredo, D. Markewitz, and A. Aufdenkampe. 2010. Dissolved CO_2 in small catchment streams of Eastern Amazonia: A minor pathway of terrestrail carbon loss. Journal of Geophysical Research 115, G04005, doi:10.1029/2009JG001202.

Figueiredo, RO., D. Markewitz, E.A. Davidson, A.E. Schuler, O.S. Watrin, and P.S. Silva. 2010. Land-use affects on the chemical attributes of low-order streams in the eastern Amazon. Journal of Geophysical Research 115, G04004,doi:10.1029/2009JG001200.

Markewitz, D., S. Devine, E.A. Davidson, P. Brando, and D. Nepstad. 2010. Soil moisture depletion under simulated drought in the Amazon: Impacts on deep root uptake. New Phytologist, 187:592-607.

Rifai, S., D. Markewitz, and B. Borders. 2010. Twenty years of intensive fertilization and competing vegetation suppression in loblolly pine plantations: Impacts on soil C, N, and microbial biomass. Soil Biology and Biochemistry, 42:713-723. §

ED_000419-0008266

Galang, MA, D Markewitz, and LA Morris. 2010. Soil P transformations under prescribed burning and simulated heat treatment conditions. Geoderma: 155:401-408. §

Galang, MA, L Morris, D Markewitz, CR Jackson, and EA Carter. 2010. Prescribed burning effects on the hydrologic behavior of gullies in the South Carolina Piedmont. Forest Ecology and Management. 259:1959-1970. §

Worsham, L, D Markewitz, and N Nibbelink. 2010. Incorporating spatial dependence into estimates of soil carbon contents under different landcovers. Soil Science Society of America Journal. 74(2): 635-646.

Belk, E, D Markewitz, TC Rassmussen, EJ Maklouf Carvalho, DC Nepstad, and EA Davidson. 2007. Modelling the effects of throughfall reduction on soil water content in a Brazilian Oxisol under a moist tropical forest. Water Resources Research, vol. 43: W08432 doi:10.1029/2006WR005493. * §

Lincoln, M. Chad, Rodney E. Will, Lawrence A. Morris, Emily A. Carter, Daniel Markewitz, John R. Britt, Ben Cazell, and Vic Ford. 2007. Soil change and loblolly pine (*Pinus taeda)* seedling growth following site preparation tillage in the Upper Coastal Plain of the southeastern United States. Forest Ecology and Management, 242:558-568. *

Sartori, F, D. Markewitz, and B.E. Borders. 2007. Soil carbon storage and nitrogen and phosphorus availability in loblolly pine plantations over 4 to 16 years of herbicide and fertilizer treatments. Biogeochemistry, 84:13-30 *, §

Galang, Marco A., D. Markewitz, L.A. Morris, and P. Bussel. 2007. Land use change and gully erosion in the Piedmont region of South Carolina, USA. Journal of Soil and Water Conservation, 62(3):130-137 *, §

Markewitz, D. 2006. Fossil fuel carbon emissions from silviculture: Impacts on net carbon sequestration in forests. Forest Ecology and Management, 236:153-161. *

Markewitz, D., Julio C.F. Resende, Lucilia Parron, Mercedes Bustamante, Carlos A. Klink, Ricardo de O. Figueiredo, and EA Davidson. 2006. Dissolved rainfall inputs and streamwater outputs in an undisturbed watershed on highly weathered soils in the Brazilian cerrado. Hydrological Processes 20 (12): 2615-2639. *

Neill, C., Helmut Elsenbeer, Alex V. Krusche, Johannes Lehmann, Daniel Markewitz, and Ricardo de O. Figueiredo 2006. Hydrological and biogeochemical processes in a changing Amazon: results from small watershed studies and the large-scale biosphere-atmosphere experiment. Hydrological Processes 20 (12): 2467-2476. *

ED_000419-0008267

Markewitz, D, R.O. Figueiredo, and E.A. Davidson. 2006. CO_2 driven cation leaching after tropical forest clearing. Journal of Geochemical Explorations, 88:214-219. **, *

Richter, DD, H. Lee Allen, Jianwei Li, D Markewitz, and Jane Raikes. 2006. Bioavailability of slowly cycling soil phosphorus: major restructuring of soil P fractions over four decades in an aggrading forest. Oecologia 150 (2): 259-271. *

Will, RE, D Markewitz, RL Hendrick, DF Meason, TR Crocker, and BE Borders. 2006. Nitrogen and phosphorus dynamics for 13-year-old loblolly pine stands receiving complete competition control and annual N fertilizer. Forest Ecology and Management 227 (1-2): 155-168. *

Meason, D, D Markewitz, and RE Will. 2004. Annual fertilisation and interspecific competition control: Effects on in situ forest floor nitrogen fluxes of different aged *Pinus taeda* stands in southeast Georgia, USA. Canadian Journal of Forest Research, 34:1802-1818. *

Markewitz, D, EA Davidson, P. Moutinho, and D. Nepstad. 2004. Nutrient loss and redistribution after forest clearing on a highly weathered soil in Amazonia. Ecological Applications, 14:S177-S199.*

Keller, M.; Ane Alencar, A.; Asner, G.P.; Braswell, B.; Bustamante, M.; Davidson, E.; Feldpausch, T.; Fernandes, E.; Goulden, M.; Kabat, P.; Kruijt, B.; Luizão, F.; Miller, S.; Markewitz, D.; Nobre, A.; Nobre, C.; Priante-Filho, N.; Rocha, H.; Silva-Dias, P.; Randow, C. & Vourlitis, G.L. 2004. Ecological Research in the Large Scale Biosphere Atmosphere Experiment in Amazonia (LBA): A Discussion of Early Results. Ecological Application, 14:S3-S16. *

Echeverria, M.E., D. Markewitz, L. Morris, and R.E. Hendrick. 2004. Changes in soil organic matter fractions resulting from complete control of competition in pine plantations of the Southeastern USA. Soil Science Society of America Journal, 68:950-958. *

Borders, BD, R.E. Will, D. Markewitz, A. Clark, R. Hendrick, R.O. Teskey, and Y. Zhang. 2004. Effect of complete competition control and annual fertilization on stem growth and canopy relations for a chronosequence of loblolly pine plantations in the lower coastal plain of Georgia. Forest Ecology and Management, 192:21-37.**, *

Markewitz, D, C. Craft, and F. Sartori. 2002. Soil change and carbon storage in longleaf pine stands planted on marginal agricultural lands. Ecological Applications 12:1276-1285. *, §

ED_000419-0008268

Nepstad, D.C., P. Moutinho, M.B. Dias-Filho, E.A. Davidson, G. Cardinot, D. Markewitz, R. Figueiredo, N. Viana, J. Chambers, D. Ray, J.B. Guerreiros, P. Lefebvre, L. Sternberg, M. Moreira, L. Barros, F.Y. Ishida, I. Tohlover, E. Belk, K. Kaliff, and K. Schwalbe. 2002. The effects of partial throughfall exclusion on canopy processes, aboveground production, and biogeochemistry of an Amazon forest. Journal of Geophysical Research. 107, D20, 8085. **, *

Will, R.E., M.J. Wheeler, D. Markewitz, M.A. Jacobson, and A.M. Shirley. 2002. II. Early loblolly pine stand response to tillage on the Piedmont and Upper Coastal Plain of Georgia: Tree allometry, foliar nitrogen concentration, soil bulk density, soil moisture, and soil nitrogen status. Southern Journal of Applied Forestry. 26(4):190-196.*

Wheeler, M.J., R.E. Will, D. Markewitz, M.A. Jacobson, and A.M. Shirley. 2002. I. Early loblolly pine stand response to tillage on the Piedmont and Upper Coastal Plain of Georgia: Mortality, stand uniformity, and second and third year growth. Southern Journal of Applied Forestry. 26(4):181-189.*

Markewitz, D., E.A. Davidson, R. de O. Figueiredo, R.L. Victoria, & A.V. Krusche. 2001. Control of cation concentrations in stream waters by surface soil processes in an Amazonian watershed. Nature 410:802-805. *

Gaudinski, J.B., S.E. Trumbore, E.A. Davidson, A.C. Cook, D. Markewitz, and D.D. Richter. 2001. The age of fine-root carbon in three forests of the eastern United States measured by radiocarbon. Oecologia 129:420-429. *

Johnson, K.H., D. Wear, R. Oren, R.O. Teskey, F. Sanchez, R.E. Will, J. Butnor, D. Markewitz, D.D. Richter, T. Rials, H.L. Allen, J. Seiler, D. Ellsworth, C. Maier, G. Katul, and P.M. Dougherty. 2001. Meeting global policy commitments: Carbon sequestration and southern pine forests. J. Forestry 99:14-21. *

Markewitz, D. and D.D. Richter. 2000. Long-term soil potassium availability from a Kanhapludult to an aggrading loblolly pine ecosystem. Forest Ecology Management 130:109-129.*

Richter, D.D., D. Markewitz, P.R. Heine, V. Jin, J.A. Raikes, K. Tian, and C.G.Wells. 2000. Legacies of agriculture and forest regrowth in the nitrogen of old-field soils. Forest Ecology and Management 138:233-248. *

Richter, D.D., D. Markewitz, S.E. Trumbore, and C.G. Wells. 1999. Accumulation and turnover of radio- and organic carbon in soil of an aggrading forest. Nature 400:56-58. *

ED_000419-0008269

Markewitz, D., D.D. Richter, H. L. Allen and J.B. Urrego. 1998. Thirty years of observed forest soil acidification in the Calhoun Experimental Forest: Has acid rain made a difference? Soil Science Society of America Journal 62:1428-1439. *

Markewitz, D. and D.D. Richter. 1998. The *bio* in Al and Si geochemistry. Biogeochemistry 42:225-252. *

Stottlemyer, R., C. Troendle, and D. Markewitz. 1997. Change in snowpack, soil water, and streamwater chemistry with elevation during 1990, Fraser Experimental Forest, Colorado. Journal of Hydrology 195:114-136. *

Richter, D.D. and D. Markewitz. 1995. How deep is soil? BioScience 45:600-609. *

Richter, D.D., D. Markewitz, C.G. Wells, H.L. Allen, R. April, P.R. Heine, and B. Urrego. 1994. Soil chemical change during three decades in a loblolly pine ecosystem. Ecology 75:1463-1473. *

Proceedings:

Markewitz, D., C.R. Jackson, N. Fraser, and D. Radcliffe. 2011. Stream water dissolved organic carbon and total dissolved nitrogen: Effects of timber harvest in the Georgia Piedmont. *In* Carroll, GD (ed) Proceedings of the 2011 Georgia Water Resources Conference. April 11-13, 2011, University of Georgia Press, Athens, GA, ISBN: 0-9794100-2-9.

Markewitz, D. and Rebekah Glazer. 2009. Use of polyacrylamide (PAM) for controlling soil erosion on steep slopes in the piedmont of Georgia. Proceedings of the 2009 Georgia Water Resources Conference.

Cieszewski, CJ, RC Low, S Liu, I Elle, and D Markewitz. 2009. New functions and programs in hypermap software development for internet-based displaying of FIA data. *In* McRoberts, RE, GA Reams, PC Van Deusen, and WH McWilliams (eds) Proceedings of the 8th FIA symposium Oct. 16-19, 2006, Monterey, CA. Gen. Tech. Report WO-79 Pp. *375-392*

Galang, M.A., C.R. Jackson, L.A. Morris, D. Markewitz, and E.A. Carter. 2007. Hydrological behavior of gullies in the South Carolina Piedmont, *In* Proceedings of the 2007 Georgia Water Resources Conference, Athens, GA. *, §

Venturieri, A., R.O. Figueiredo, O.S. Watrin, and D. Markewitz. 2005. Utilização de imagens Landsat e CBERS na avaliação da mudança do uso e cobertura da terra e seus reflexos na qualidade da água em microbacia hidrográfica do município de Paragominas, Pará. *In* Anais XII Simpósio Brasileiro de Sensoriamento Remoto, Goiânia, Brasil. 16-21 Abril, INPE, p. 1127-1134.*

ED_000419-0008270

Bradshaw, J Kenneth, D Radcliffe, K Lichtenstein, M Risse, M Bakker, R Jackson and D Markewitz. 2005. Land use effects on water quality in six small Georgia watersheds. In Hatcher, J (ed.) Proceedings of the 2005 Georgia Water Resources Conference. *

Figueiredo, R.O., K.A. Sousa, D. Markewitz, and EA Davidson. 2003. Alterações nas concentrações de ortofosfato em amostras de chuva, throughfall e litter leachate armazenadas em coletores instalados em área experimental na Floresta Nacional do Tapajós.. In: VI Congresso de Ecologia da Brasil, 2003, Fortaleza. VI Congresso de Ecologia da Brasil - Anais de Trabalhos Completos. Fortaleza : Editora da Universidade Federal do Ceará, 2003. p. 676-678.

Glazer, R. and D. Markewitz. 2001. A field trial using low application rates of polyacrylamide (PAM) to reduce soil erosion from disturbed piedmont soils. Pp 736-739. *In* Proceedings of the 2001 Georgia Water Resources Conference, Athens, GA. *, §

Bulletins:

Borders, B.E., R. Will, R.L. Hendrick, D. Markewitz, T.B. Harrington, R.O. Teskey, and A. Clark. 2002. Consortium for accelerated pine production studies (CAPPS): Long-term trends in loblolly pine stand productivity and characteristics in Georgia. General Technical Report SRS-48. Asheville, NC. Pp. 591-592.

Other:

Dangerfield, CW, RL Izlar, RO Teskey, CJ Cieszewski, D Markewitz, RL Hendrick. 2004 Carbon Sequestration – A Georgia Fact Sheet. Center for Forest Business Technical Bulletin #13

Markewitz, D. 1997. Soil without life? Nature 389:435.

b. Invited presentations at professional and learned societies

Markewitz, D, L Worsham, and N Nibbelink. Estimating soil carbon contents across the landscape: a comparison of three sampling methods. Special Session: Southern Forest Science in Support of a Low Carbon economy. Biennial Southern Silvicultural Research Conference, Charleston, SC, February, 2011.

Markewitz, D et al., River corridors of the Amazon and their response to anthropogenic change: A look back and a glimpse forward. American Geophysical Union, Meeting of the Americas, Foz do Iguacu Brazil, August, 2010.

ED_000419-0008271

Markewitz, D, RO Figueiredo, EA Davidson, MAE Schuler, and OS Watrin. Land use change: Impacts on stream water chemistry in mixed-use catchments in Eastern Amazonia. Tropical Hydrology Symposium, Panama City, Panama March 16-20, 2009.

Markewitz, D. Carbon Allocation in Forested Ecosystems: Processes regulating carbon storage and turnover in forests. Southern Group of State Foresters Carbon Sequestration Workshop, Atlanta, GA Aug. 6-7, 2008.

Morris, L, D Markewitz, L Ogden, and V Ford. The past and future role of mechanical site preparation. North American Forest Soils conference, Blacksburg, VA, June 22-26, 2008.

Markewitz, D. 2007. Development of the Georgia Carbon Sequestration Registry. Grow Green Coalition and Georgia Urban Forest Council annual meeting. Athens, GA.

Markewitz, D, and D.D. Richter. 2006. Chemical signatures of land use change. World Soil Congress, Philadelphia, PA. *

Markewitz, D. 2006. Properties and processes regulating carbon storage and turnover in soils. Southern Forest Research Partnership workshop. Asheville, NC.

Markewitz, D. 2005. CO_2 driven cation leaching after tropical forest clearing. 7th International Symposium on the Geochemistry of the Earth's Surface, Aix-en-Provence, France.

Markewitz, D., R.O. Figueiredo, E.A. Davidson, A.V. Krushe, R. Victoria, J.M. Moraes, A.E. Schuler, and T. Dunne. 2002. Control of stream water cations by surface soil processes and land use effects on the exchange of nutrients between terrestrial and aquatic ecosystems in the Eastern Amazonia. Largescale Biosphere Atmosphere II Scientific Conference, Manaus, Brazil.

Richter, D.D., D. Markewitz, and K.H. Johnson. 2001. The importance of observing soil through time: The case of the Calhoun Experimental Forest. Soil Science Society of America Annual meeting, *

Markewitz, D., E.A. Davidson, P. Moutinho, D.C. Nepstad, and R. Figueiredo. 2000. Carbon cycling in a mixed land use watershed of the Eastern Amazon. 31st International Geological Conference, Rio de Janeiro, Brazil. *

c. Other creative contributions:

Website creation

Carbon Trading http://carbon.sref.info

ED_000419-0008272

Forest Assessment Tool
Forest Ecosystem Rapid Assessment Scorecard. D. Markewitz, S. Madson, T. Hinckley. 50 p manual, training DVD, and flash media scorecard.

Developed online training module for FERAS on USDA CRESS website with Dr. Ben Jackson and Ms. Morgan Nolan (http://www.forestandrange.org/)

Model development
Developed {w/L. Morris(UGA-WSFR), D. Nute, and N. Ruston (UGA-Artificial Intelligence), and J. Vose (USDA-Forest Service)} a nitrogen based forest growth model to be used by landowners to help manage long-term forest productivity.

d. Research Grants Received

(*Competitive*)

Southern Conifer Climate Change CAP. 2011-2015. $20,000,000 total program ($1.34 M to UGA) USDA-National Institute of Food and Agriculture. (Kane, Teskey, Hubbard, Markewitz, and Zhao)

High density southern pine feedstock production and carbon sequestration. 2011-2015. $886,058. USDA-National Institute of Food and Agriculture. (Markewitz, Kane, Teskey, and Zhao)

Developing Biomass Harvesting Guidelines to Improve Sustainability of Harvesting Woody Biomass fore Renewable Energy – Soil Change and Soil Quality Indicators, 2011-2013, $178,000 NCASI. (Morris and Markewitz)

Rock Creek Dispersed Recreation Study, 2010-2012, $79,000, USDA Forest Service, (Green, Nibbelink, and Markewitz)

Field based NIR and 3D electrical resistivity for quantifying spatial variability in soil processes and enhancing precision forest management. 2007-2009, $142,000. Traditional Industries Program for Pulp and Paper Processing. {D. Markewitz, L. Schimleck, P. Bettinger}

Synthesis of Nutrient Interactions in Secondary Vegetation in Amazonia. 2006-2008. $54,000 subcontract. NASA – Largescale Biosphere Atmosphere Project in Brazil. {E.A. Davidson with 7 other co-investigators)

Effect of tillage on soil physical properties and their relationship to early loblolly pine growth. 2004-2007. $280,000. Traditional Industries Program for Pulp and Paper Processing. {R. Will, D. Markewitz, and L. Morris}

ED_000419-0008273

Functional Indicators for Sustainable Forest Management: Synthesis and Experimental Evaluation. 2003-2007. $240,000. National Commission on Science for Sustainable Forestry. {D Markewitz}

Nutrient Cycling in Secondary Vegetation of Amazonia: Synthesis. 2006-2008. $300,000. NASA – Largescale Biosphere Atmosphere Project in Brazil. {E.A. Davidson with 7 other co-investigators)

Carbon Trading: A primer for landowners. 2006-2007. $50,000. National Commission on Science for Sustainable Forestry. {D Markewitz}

Initiating a Partnership Among University, Business and Non-Profit Organizations to Develop Working Forests in the Amazon. 2004. $5,000. University of Georgia. Office of the Vice President for Public Service and Outreach, International Development Education Awards (IDEAS) Program {D Markewitz and L Morris}

Dynamics of Biogeochemical Cycles in Secondary Vegetation of Amazonia. 2002-2005. $300,000. NASA – Largescale Biosphere Atmosphere Project in Brazil. {E.A. Davidson with 7 other co-investigators)

Effects of Land Use Changes on the Functioning of Soils and Watersheds of Central Brazil Savannas: impacts on nutrient and carbon cycles and trace gas exchange. 2002-2005. $241,000. NASA – Largescale Biosphere Atmosphere Project in Brazil. {R. Zepp with five other co-investigators)

Collaborative research: Drought effects on moist tropical forests: A throughfall reduction experiment in Amazonia. 2002-2007. $1,184,000. National Science Foundation. {D.C. Nepstad, E.A. Davidson, and D Markewitz}

Management of Soil Carbon Quantity and Quality in High Productivity Forest Plantations. 2000-2003. $160,000. Traditional Industries Program for Pulp and Paper. {D Markewitz, L. Morris, R. Hendrick, L.Lucia, and A. Ragaskus}.

Quantifying relations of foliar chemistry and spectral reflectance: A future plan for improving fertilization efficiency of plantation forests from space. 2000-2002. $18,444. Georgia Space Program {D. Markewitz and R.E. Will}.

The effects of rainfall exclusion on an Amazon forest. 2000-2002. $430,000 National Science Foundation Ecosystem Studies. {D.C. Nepstad with five other co-investigators)

Collaborative research on biogeochemical transfers among terrestrial and aquatic biospheres and the atmosphere in forests and pastures of eastern Amazonia. 1998-

ED_000419-0008274

2001. $280,000. NSF Program in Environmental Geochemistry and Biogeochemistry. {E.A. Davidson, D Markewitz, and T. Dunne}.

Can trees increase rates of soil nutrient supply?' 1998-2000. University of Georgia Research Foundation, $6,000.

The effects of fertilization and competition control on carbon and nutrient allocation and physiology in loblolly pine plantations. 1998-2001. $268,000. (w/R. Hendrick (PI), R.O. Teskey, R.E. Will, T. Harrington, B. Borders {UGA}). {*I did not participate in the writing of this grant but took over responsibilities for the soil component of this research*}

(*Non-competitive*)

Soil carbon dynamics in longleaf pine ecosystems at the Jones Ecological Research Center. 2008-2010. Joseph Jones Ecological Research Center, $24,706.

Life cycle analysis for woody biofuel production systems in Georgia. 2009-2010. State of Georgia. $10,350.

Carbon sequestration in managed loblolly pine forests in the Southeastern United States. 1999-2003. Cooperative agreement with USDA Forest Service $84,000. (w/R.O. Teskey (PI), R. Will, D. Daniels, L. Morris{UGA}).

An investigation of the effectiveness of silvicultural best management practices in protecting aquatic habitat in the state of Georgia. 2000-2002. $450,000. US Congressional appropriation (w/R. Jackson (PI), L. Morris, D. Greene, D. Batzer, and T. Rasmussen{UGA}).

Integrated modeling of soil C, N, and P cycles under intensive forest management: Relations to long-term soil productivity. 2000-2001. $15,000. USDA Forest Service Challenge Cost-share.

Polyacrylamide (PAM) as an effective treatment for minimizing erosion from disturbed piedmont soils. 2000-2001. $9,000. SE Erosion Control Inc., Atlanta, GA.

Polyacrylamide (PAM) as an effective treatment for minimizing erosion from disturbed piedmont soils. $19,988. Georgia Power.

The effects of competition control and fertilization on soil organic matter fractions and rates of net N-mineralization in a loblolly pine plantation. 1998-2000. $30,000. USDA Forest Service Challenge Cost-share.

ED_000419-0008275

Nutrient cycling in the Brazilian Savanna on very highly weathered soils. 1998-2000. $1,000,000. Mellon Foundation Grant to The Woods Hole Research Center with subcontract to UGA. (E.A. Davidson)

(Industry cooperative)

Consortium for Accelerated Pine Productivity Studies. ~$100,000 annual budget. UGA-Warnell School of Forest Resources. (serve as co-PI)

(Formula funding)

The sustainability of soil productivity in intensively managed forest plantations. 1998-20011. $70,000 USDA McIntire-Stennis.

3. Resident Instruction and Continuing Education:

a. Undergraduate Courses Taught:

Forest Ecology (FORS 3020/3020L)

Year	Term	Credit hours	Enrollment	Paticipation
2000	Fall	4	24	100%
2001	Fall	4	15	90%
2002	Fall	4	28	90%
2003	Fall	4	22	100%
2006	Spr	4	35	90%
2007	Spr	4	23	80%

Ecology of Natural Resources (FANR 3200/3200L)

Year	Term	Credit hours	Enrollment	Paticipation
2007	Fall	4	40	50%
2008	Spr	4	43	50%
2008	Fall	4	37	50%
2009	Spr	4	48	80%
2010	Spr	4	60	50%
2011	Spr	4	58	50%
2012	Spr	4	64	50%

Sustainable systems in Brazil (AESC 3150)

Year	Term	Credit hours	Enrollment	Paticipation
2003	Sum	3	10	50%
2005	Sum	3-6	10	50%
2008	Sum	6	7	30%

Special problems (FORS 5920)

Year	Term	Credit hours	Enrollment	Paticipation
2003	Spr	5	1	100%

ED_000419-0008276

Understanding your Carbon Footprint (FYOS 1001)

Year	Term	Credit hours	Enrollment	Paticipation
2011	Fall	1	14	100%
2012	Fall	1	13	100%

b. Graduate Courses Taught:

Biogoechemistry: Analysis of Global Change

Year	Term	Credit hours	Enrollment	Paticipation
2010	Spring	4	12	50%
2012	Spring	4	18	50%

Science of Sustainability (FORS 7870)

Year	Term	Credit hours	Enrollment	Paticipation
2006	Spr	2	7	100%
2008	Spr	2	7	100%
2011	Spr	2	4	100%

Special problems (FORS 7983)

Year	Term	Credit hours	Enrollment	Paticipation
2000	Spr	1	1	100%
2000	Sum	3	1	100%

Directed research (FORS 8983)

Year	Term	Credit hours	Enrollment	Paticipation
2001	Spring	3	1	100%

c. Supervision of Student Research:

Theses Directed:

(*Completed*)

Raina Sheridan (MNR) 2011
J. Claire Ike (MS) 2010
Scott Devine (MS) 2009
Marco Galang (PhD) 2008
Sami Rifai (MS) 2008
Luke Worsham (MS) 2008
Aaron Joslin (MS), 2007
Brian Adams (MS), 2007
Fabio Sartori (PhD) 2004
Elizabeth Belk (MS), 2002
Rebekah Lillian Glazer (MS), 2001
Joshua Paul Price (MS), 2001

ED_000419-0008277

(*Current*)
Aaron Joslin (PhD)
Ji Qi (PhD)
Christian Hoadley (MS, with Dr. Morris)
Anchal Bangar (MS, with Dr. Morris)

d. Postdoctoral Scholars Advised or Hosted

Dr. Gary Rachel, School of Forest Resources, University of Georgia, advised Oct 2005 to June 2006.

Dr. Stephanie Madson, Institute of Ecology, University of Georgia, advised August 2003 to August 2005

Dr. Ricardo de O. Figueiredo, Instituto de Pesquisa Ambiental da Amazônia. Hosted visiting scientist February 5 –22, 2002, September 2006, Jan 2008 to Jan 2009.

Professor Okazaki Masanori, Tokyo University of Agriculture and Technology. Hosted visiting scientist for tour of Calhoun Experimental Forest, South Carolina. (March 24 and 25, 1999).

e. Membership in Professional Societies:

Ecological Society of America
International Union of Soil Scientists
Society of American Foresters
Soil Science Society of America
Soil Science Society of Georgia
American Geophysical Union

ED_000419-0008278

Can Thinning of Managed Plantations for Bioenergy Feedstock be Treated as Carbon Neutral?

Research Notes for a Manuscript in Preparation

Daniel Markewitz[1], Bruce Borders[1], Ray Souter[2], Melissa Shockey[1], and Michael Clutter[1]

[1]Warnell School of Forestry and Natural Resources, The University of Georgia

[2]Southern Research Station USDA Forest Service

Thinning: What and Why?

- Thinning is a long-used silvicultural technique that removes a portion of standing trees to manipulate stand structure and individual tree growth.
- Thinning salvages trees that will be lost due to mortality and concentrates future growth on fewer trees.
- Stand thinning can also provide forest health (i.e., pest resistance) and aesthetic (i.e., open structure) benefits.
- Thinned trees can be sold as pulpwood or bioenergy
- The extent of thinning is defined by the percent removal of the cross sectional area of trees (i.e., the basal area)
  - Light thinning 30% removal of basal area
  - Moderate thinning 50% removal of basal area

Hypotheses:

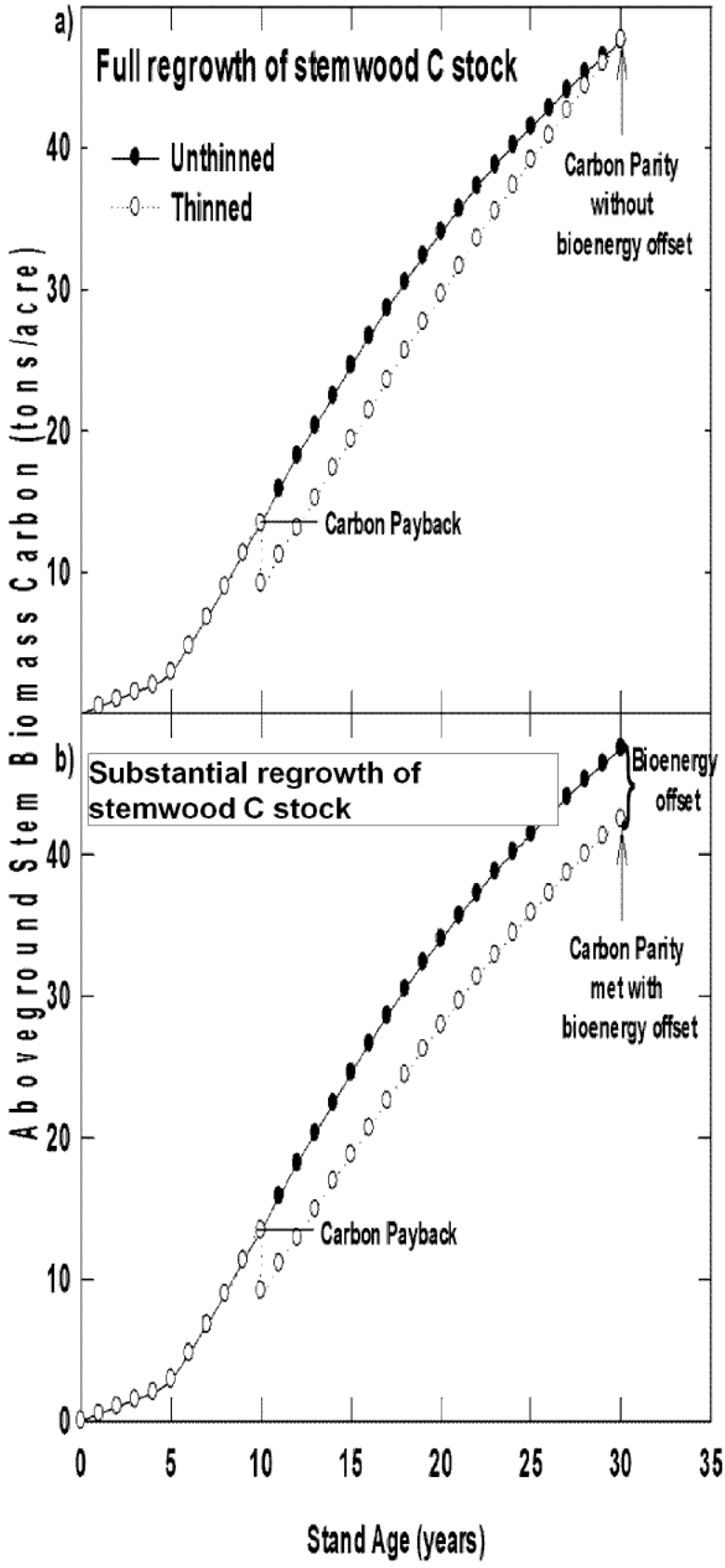
- Thinnings used for bioenergy production are carbon neutral either due to:
  - equal standing stocks of carbon at final harvest in thinned and unthinned stands
  - a substantial recovery of standing stocks in thinned stands combined with carbon offset from bioenergy that exceeds the difference in standing stocks

Hypothetical Model showing
a) equal standing stock of C at 30
yr rotation and
b)equality with standing stock of
C and bioenergy offset.

Carbon Payback: The time when the stand regains C stock that existed prior to thinning.

Carbon Parity: The time when the stand regains C stock equal to an unthinned reference.

Bioenergy offset: C emissions as CO_2 that produce energy and displace emissions from fossil fuels



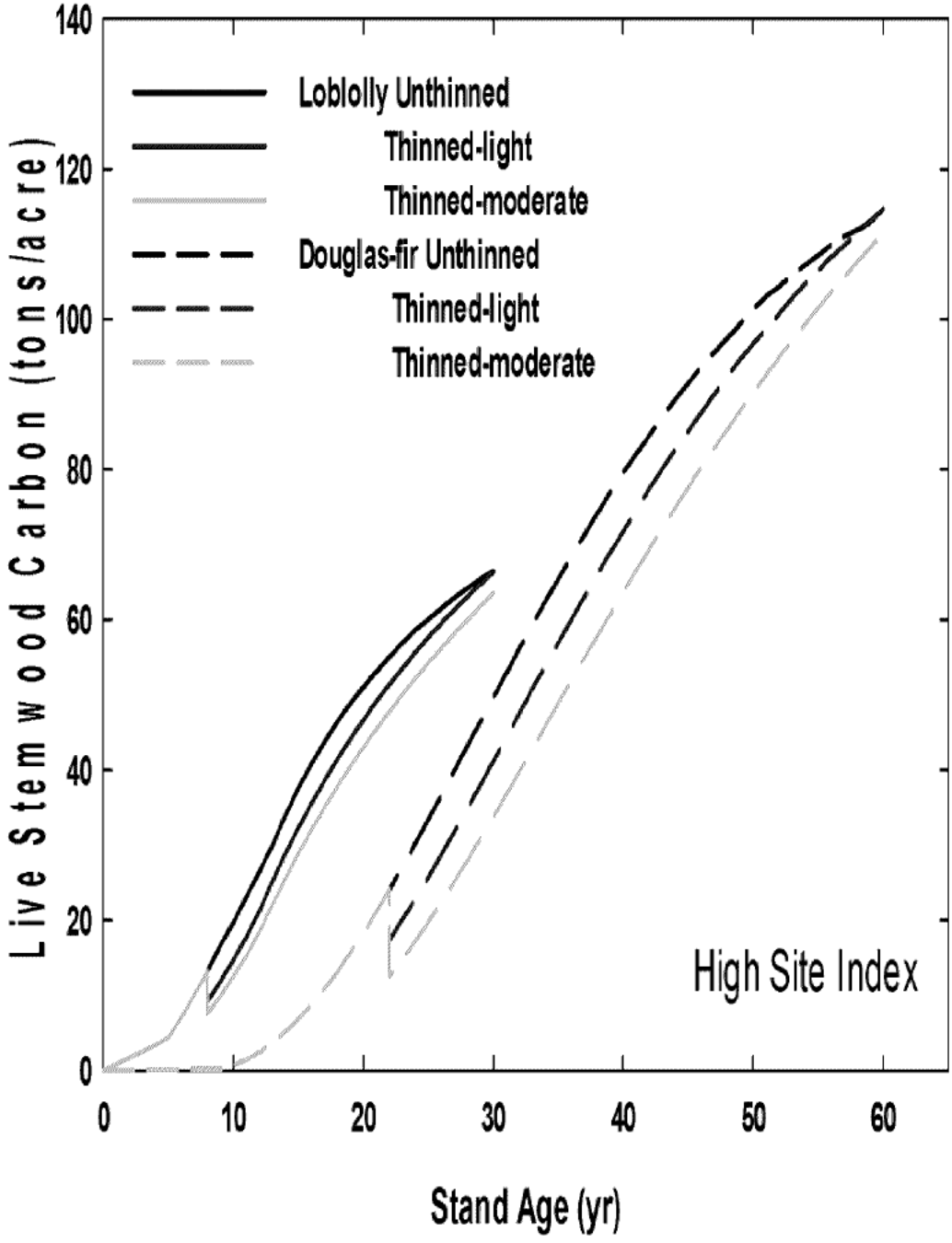
Glossary of other terms:

- Site Index: Defines the productivity of a site, based on the height of trees achieved by a certain age; taller is more productive.
- Planting Density: The number of trees planted per acre; common range 300-900.
- Thinning: Partial removal of standing trees.
- Silvicultural Amendments: Fertilizers and herbicides.
- Displacement Efficiency: How many tons of wood is required to replace 1 ton of coal (or other fossil fuel).

Empirically Based Growth and Yield Model Output

Loblolly Pine (30-yr) and Douglas-fir (60-yr)

Range of site productivities, planting densities, and thinning intensities



Total Carbon Accumulation

Examples for Medium Site and High Density

		No Thin	Light Thin	Moderate Thin
		----------Tons-C ac^{-1}----------		
Loblolly	Standing C	47.6	42.5	40.0
Unamended	Thinned C	0	4.3	5.9
	Total C	47.6	46.8	45.9
Loblolly	Standing C	49.6	49.7	47.1
Amended	Thinned C	0	4.3	5.9
	Total C	49.6	54.0	53.0

Percent Reduction in Atmospheric CO_2

Examples for Medium Site and High Density

Stand	Displacement Efficiency	Light Thin	Moderate Thin
Loblolly	100	98	97
Unamended	80	97	94
	50	94	90
	20	91	87
Loblolly	100	109	107
Amended	80	107	104
	50	105	101
	20	102	97
Douglas-fir	100	104	104

Wood-in-Use

Examples for Medium Site and High Density

Units are % of Fiber or Solid Wood at Final Harvest or tons-C ac^{-1}

Stand		**No Thin**	**Light Thin**	**Moderate Thin**
Loblolly	Fiber/Solid (%)	19/81	12/88	10/90
Unamended	Wood-in-use C (tons-C ac^{-1})	50.6	49.3	47
Loblolly	Fiber/Solid (%)	17/83	8/92	7/93
Amended	Wood-in-use C (tons-C ac^{-1})	47.4	47.5	45
Douglas-fir	Fiber/Solid (%)	30/70	26/74	24/76
	Wood-	63.8	61.9	58.7

Summary

- In ~25% of cases, by rotation age, C standing stocks in thinned and unthinned stands were equal.
- In 70% of cases total C (standing + thinned) in thinned stands exceeded that in unthinned
- Biomass displacement of fossil fuel at 20% efficiency (i.e., 5 tons wood:1 ton fossil fuel) achieves carbon parity of 85% or better. Better efficiency=closer parity.
- Thinned stands represent a carbon neutral or near-neutral outcome in our modeling results.

Can Thinning of Managed Plantations for Bioenergy Feedstock be Treated as Carbon Neutral?

Daniel Markewitz[1,*], Bruce Borders[1], Melissa Shockey[1], Ray Souter[2], and Michael Clutter[1]

[1]Warnell School of Forestry and Natural Resources

The University of Georgia, Athens, GA 30602

[2]Southern Research Station

USDA Forest Service, Athens, GA 30602

NOT FOR CITATION

ED_000419-0008289

Abstract

This study focuses on the carbon balance of woody feedstock used for bioenergy sourced from intermediate age stand management activities; in other words forest thinnings. It was hypothesized that thinnings used for bioenergy production are carbon neutral either due to equal standing stocks of carbon at final harvest in thinned and unthinned stands or due to carbon offset from bioenergy exceeding the change in standing stocks such that the net balance to the atmosphere is zero. Growth and yield models for even aged plantation management of loblolly pine and Douglas-fir were used to simulate a matrix of projections that include variation in site index, stand density, and intensity of a single thinning. For loblolly pine, silvicultural inputs of fertilization and vegetation control after thinning were also considered. The C standing stock, bioenergy offset, and carbon storage as wood-in-use were evaluated for each combination. The effect of replacement efficiency from biomass to bioenergy on offsets was also considered over a range of 100 to 20%. The total standing stock of stemwood C in thinned loblolly pine stands equaled or exceeded that of unthinned stands in all cases of light thinnings with silvicultural amendments at rotation. The opposite was true for unamended loblolly pine or medium intensity thinnings. In Douglas-fir only the high site, high density, light thinning treatment had greater standing stock C at rotation. If the stemwood removed at thinning is summed with the standing stemwood C at rotation age the total C accumulation of thinned stands exceeds that in the unthinned in 70% of cases (i.e., 25 of 36 simulations) by 0.3 or 7.3 ton-C acre^{-1}. The replacement efficiency of the thinned biomass to bioenergy effects the value of offsets such that at 20% replacement efficiency thinned stands achieve 83% or better atmospheric CO_2 reduction relative to the unthinned condition while at 50% replacement efficiency more than half the stand conditions achieve carbon neutrality or better. As expected, thinning increased the proportion of

ED_000419-0008290

stemwood in solid wood products at rotation by 2 to 18%, which decreases the C stock difference as standing stock relative to that C retained as wood-in-use. This growth simulation suggests that at worst stands with single, intermediate age thinnings for bioenergy production will accumulate 85% of the C in unthinned stands. At best thinning and silvicultural management can enhance overall stand C accumulation and reduce atmospheric CO_2.

ED_000419-0008291

The United States Environmental Protection Agency is currently regulating CO_2 emissions and is considering how to treat biomass energy relative to such emissions (i.e., biogenic CO_2). Given the current regulatory framework for CO_2, power producing entities are being required to reduce emissions of CO_2 from fossil fuel sources. One opportunity for reducing fossil fuel CO_2 is using woody biomass, a number of power producing facilities already co-fire wood with coal. EPA recognizes that CO_2 emissions released from fossil fuel burning will increase the CO_2 concentration of the atmosphere while that from biogenic sources has the potential to do less harm relative to atmospheric CO_2 concentrations (EPA, 2011).

The net balance of biogenic CO_2 emissions, that is the difference between removal of CO_2 from the atmosphere for plant growth and emission of CO_2 to the atmosphere for bioenergy production, has been investigated under a range of biomass feedstock production systems (Marland and Schlamadinger, 1997; Wang et al., 2012). Research has focused on whether emissions of CO_2 to the atmosphere from burning plant biomass should be treated as carbon neutral as there is an expectation that new, re-growing plant biomass, which replaces the biomass that was consumed, will re-accumulate and remove the released CO_2 from the atmosphere. As such, the net increase of CO_2 in the atmosphere could be zero.

The original EPA biogenic CO_2 accounting framework suggested that woody feedstocks for bioenergy might be treated as carbon neutral and could potentially receive a categorical exclusion from further quantification (EPA, 2011). An external review of this framework, however, requested a better quantitative accounting of complexities in the forest carbon budget, feedstock supply chain, and bioenergy production process (SAB, 2012). Over time, the idea behind carbon neutrality (i.e., net zero carbon emission) has grown to include definitions of carbon payback and carbon parity (Jonker et al., 2013; Mitchell et al., 2012). Carbon payback

ED_000419-0008292

(C_{pb} in years) is defined as the period between initial harvest and the point in time where the carbon in the forest from regrowth ($C_{f(t)}$) plus the avoided fossil fuel emissions from the harvested feedstock (C_e) equals the forest carbon existing before initial harvest ($C_{f(0)}$).

$$C_{pb}: C_{f(t)} + C_e - C_{f(0)} = 0$$

The carbon parity point (C_{pp}) is similar but includes the additional carbon that continues to accumulate in a reference non-harvested forest ($\sum_0^t C_{nh}$). As such, the parity point is the time between initial harvest and the point in time when the carbon in the forest from regrowth ($C_{f(t)}$) plus the avoided fossil fuel emissions (C_e) from the harvested feedstock equals the forest carbon existing in the forest stand before initial harvest ($C_{f(0)}$) plus new carbon that has accumulated in the non-harvested reference during this period ($\sum_0^t C_{nh}$).

$$C_{pp}: C_{f(t)} + C_e - C_{f(0)} - \sum_0^t C_{nh} = 0$$

There have been many studies that have investigated the CO_2 balance of forest growth for wood and bioenergy utilization (CORRIM, 2004; Gonzalez-Benecke et al., 2010; Markewitz, 2006; Schlamadinger et al., 1995). For example, a recent study of wood pellet production in the southeast US (Jonker et al., 2013) found carbon payback times of up to 27 years at the stand level and carbon parity point between 2 to 106 years. The variation in parity point results from assumptions made in model calculations such as fossil fuel utilization in transportation and energy efficiency of co-firing power plants.

This current study differs from the above work by focusing on the specific question of CO_2 balance of woody feedstock for bioenergy sourced from intermediate age stand management activities; in other words forest thinnings. Thinning is used to salvage volume that will be lost due to mortality during normal stand development as well as to increase and concentrate future

ED_000419-0008293

growth on more valuable trees (Olsson et al., 1997). Stand thinning can also provide forest health (i.e., pest resistance) and aesthetic (i.e., open structure) benefits. Much of the past research on the effects of thinning on aboveground tree biomass has focused on traditional individual-tree or stand level volume growth and yield (Pienaar, 1979) as opposed to specifically on stand level total C.

Recent work of Clark et al. (2011a), however, simulated a plot-level analysis of on-site carbon stores under different fuel reduction thinning operations in different forest types of the Pacific Northwest. This simulation compared carbon pools in thinned and unthinned scenarios that included the total forest carbon, biomass for energy, and lumber and paper products. This analysis started with older existing forest conditions and measured the net change in carbon stores due to the thinning treatments as opposed to starting with a bare ground at initiation. They found that carbon pool estimates for thinned stands remained lower for 50 years than unthinned stands even after accounting for carbon transferred to wood products and avoided emissions from fossil fuels for energy production.

Another assessment of the carbon consequences of thinning from an ongoing study in a hardwood stand in Pennsylvania included four different treatments: control (no thinning), thin from below, thin from middle, and thin from above (Hoover and Stout, 2007). These thinning treatments mostly relate to the size of the trees being removed from small (thin from below) to larger (thin from above). This study indicated that the choice of thinning method can alter the future carbon storage by the stand. Plots thinned from below had the highest carbon sequestration rate. The carbon sequestration rate of the thinned from below plots was not statistically different from the unthinned control plots. In another study in upland hardwoods of the southern Appalachians (Keyser and Zarnoch, 2012) light, low intensity thinnings had a

ED_000419-0008294

neutral to slightly positive effect on net aboveground total carbon stocks over 30 years when compared to unthinned stands of similar age and initial basal area. In general the gains in thinned verses unthinned stands were minor but were hypothesized to result from an increased growth rate in thinned stands coupled with increased mortality in unthinned stands. An earlier study from Keyser (2010) looked at the effect of thinning and site quality on aboveground tree carbon stocks in yellow-poplar forests also in the southern Appalachians. This experimental study lacked a control treatment so a control was simulated during the analysis. The thinning method used in this study was the operational thin from below with different thinning intensities defined by the residual basal area. Residual basal area describes the remaining cross sectional area of tree stems left per acre after thinning. Results of this study indicated that the residual basal area after a thinning had a three decade effect on carbon storage with greater carbon storage occurring at greater residual basal areas (i.e., lighter thinnings).

The current research builds on these previous results but focuses specifically on managed loblolly pine plantations in the Southeast US and managed Douglas-fir plantations in the Pacific Northwest. These plantation acres differ by often being of younger age and lower total C standing stocks than stands modeled by Clark et al. (2011b) in the PNW. These plantations also differ from the southern Appalachian hardwoods in being managed more actively and again possessing a younger age structure. These managed forest plantations are regularly thinned with age of thinning depending on the fertility of the specific site, the density of initial planting, silvicultural inputs such as herbicide or fertilizers, and the rate of growth of the trees. Thinning in loblolly pine may range from 9-15 years while for Douglas-fir 25-35 years is possible. Multiple thinnings over a single rotation is also possible. Currently, in the PNW the level of

ED_000419-0008295

commercial thinning is low due to a range of technological and financial reasons but this is subject to change in the future (Briggs, 2007; Talbert and Marshall, 2005).

Trees harvested during first thinnings are typically sold as pulp (e.g., to make paper) but might be sold for bioenergy production. The remaining trees in the stand will continue to grow, and may in fact, accelerate their growth given that that they have more space as well as water and nutrients to grow (Pienaar, 1979). Eventually (i.e., age 30 or 60 yr) the remaining trees, which are now of larger size, will be harvested and utilized as saw timber (i.e., converted to lumber or solid wood products), pulp wood, or bioenergy.

Under the current management of plantation stands that includes thinning, it is hypothesized that thinnings used for bioenergy production are carbon neutral. In the first case, it is hypothesized that carbon payback is short and carbon parity is achieved such that at final harvest by age 30 or 60 thinned and unthinned stands will possess the same amount of standing stock carbon (Figure 1a). The alternative hypothesis is that thinned stands will possess a smaller standing stock of carbon but that by accounting for the carbon offset from bioenergy the net balance will still be zero with a net benefit to the atmosphere (Fig. 1 b). A final hypothesis is that thinned stands will have less standing stock of carbon and carbon offset from bioenergy will be insufficient to balance this deficit but the increased production of solid wood products that result from thinning will sequester more C in use such that there will still be a net benefit to the atmosphere. Of course, the alternative is that these processes are insufficient to offset emissions due to thinning and thinned stands will reduce the amount of CO_2 in the atmosphere less than the unthinned stands.

In this study, existing growth and yield models for managed plantation stands are used to simulate response to thinning while manipulating initial tree planting density, site index, and

ED_000419-0008296

thinning intensity to test the above hypotheses. Net biogenic CO_2 emissions are estimated based on tree growth, bioenergy offsets, and product distribution as pulp or saw timber.

Methods:

Growth and Yield Models

Loblolly pine (*Pinus taeda L.*) growth and yield models are strongly grounded in decades of empirical research trials for even aged plantations (Eisenbies, 2006). This detailed knowledge and the associated data have been used to develop and refine mathematical models that faithfully reproduce well understood stand dynamics for managed loblolly pine (Burkhart and Tomé, 2012; Weiskittel et al., 2011). Specific loblolly pine models used for this study were developed by Harrison and Borders (1996) and Borders et al. (2004b). Incorporation of thinning into these models is based on early work of O'Connor (1935) that was updated by Pienaar (1979) and subsequently by Harrison and Borders (1996). Growth responses to vegetation control and fertilization follow original suggestions of Pienaar and Rheney (1995) that were subsequently calibrated and updated (Borders et al., 2004a; Harrison and Borders, 1996).

For simulations of Douglas-fir (*Psuedotsuga menziesii*) , growth and yield models are similarly based on empirical field trials as described by Talbert and Marshall (2005). Permission was granted to utilize a Douglas-fir growth and yield model, developed from the long-term data of the Stand Management Cooperative at the University of Washington. This model was melded to the architecture of TREES (Total Resource Estimation and Evaluation System) a simulation program being developed at the USDA Forest Service, Center for Bottomland Hardwoods Research. TREES is a forest stand simulator developed for evaluating silvicultural prescriptions including thinnings. Initial stand conditions simulated reflect those that have been observed in

ED_000419-0008297

previous Douglas-fir studies (Flewelling et al., 2001; Harrington et al., 2003) and reflect observed responses to thinning (Emmingham and Green, 1984; Emmingham et al., 2007; Marshall and Curtis, 2002; Worthington and Staebler, 1961).

Both growth and yield simulation systems are utilized to evaluate a range of stand conditions that are typical for the regions being both operationally feasible and financially attractive. For both species three site qualities (low, medium, and high) defined by site index (i.e., dominant tree height at a specific stand age) are assessed. For loblolly pine site indices are 55, 70, and 85 ft at age 25 yr and for Douglas-fir indices are 50, 70, and 90 ft at age 30 yr. For Douglas-fir these are comparable to ~40, 57, and 75 ft at age 25. Site index drives stand productivity, which may be a critical driver in assessing the C balance response to thinning. In addition, two stand densities (low and high) are evaluated for each species. Density is critical because it influences the timing and intensity of resource competition among trees and thus affects the age when thinning may be most appropriate (Harrington et al., 2009). For loblolly pine that have a shorter rotation age (i.e., 30 yr) densities are based on initial planting densities of 545 and 726 trees per acre. For Douglas-fir with a longer rotation (i.e., 60 yr) the low density is targeted to be 420 trees per acre at age 25, derived from a 10 x 10 ft (3 x 3 m) planting spacing. The higher density is based on a 8 x 8 ft (2.4 x 2.4 m) planting spacing that equates to 650 trees per acre at age 25 (Harrington et al., 2003).

These six initial stand conditions (three sites indices and two densities) are each examined for the unthinned case, a single light intensity thinning, and a single moderate intensity thinning. For loblolly pine, thinnings are imposed when stands achieve a basal area of 120 ft^2 ac^{-1}. For Douglas-fir, thinnings are imposed at the earliest age that would support a viable commercial thinning operation (i.e., when the stand has 3000 ft^3 ac^{-1} of standing stemwood

ED_000419-0008298

volume). For both species a light thinning is defined as removing ~30% of the basal area, while the moderate thinning removes ~50% of the basal area.

For loblolly pine an additional treatment considered is silvicultural amendments of fertilization and competition control after thinning. This treatment is imposed for loblolly pine since these activities are common in the region and there is sufficient empirical data to constrain the simulated growth response (Sword Sayer et al., 2004). Fertilization and competition control are imposed on the growth trajectories of the light and moderately thinned stands while the unthinned control is adjusted with a fertilization treatment as there is no logical basis for a competition control response. For Douglas-fir, due to the longer rotation age of these stands, a multiple thinning regime is also considered. In all cases, these models report outputs relative to merchantable roundwood and these results are utilized for the analysis.

Bioenergy Offsets

Woody biomass that is harvested for energy does not have the same energy density as fossil fuels and thus is typically treated with a conversion efficiency factor (Dwivedi et al., 2012). In other words, it may take more than 1 bone dry metric ton (BDT) of wood to produce the same amount of energy as 1 ton of coal; an replacement efficiency factor of <1.0. For example, wood may not be bone dry during combustion so efficiencies may be lower. Mitchell et al., (2012) suggest a range of efficiencies between 0.2 to 0.8 and the same range is used here to assess how efficiencies may influence the final carbon balance. Note that in the EPA framework some inefficiency was estimated as wood lost during transport but this component of inefficiency is not separated out in the current analysis and is presumed to be part of the overall efficiency of conversion.

ED_000419-0008299

Wood in Products

Thinning often results in larger trees at final harvest and thus a greater percentage of the harvested wood is converted to saw timber as opposed to pulp or chips. This difference matters for the removal of CO_2 from the atmosphere since C is retained in solid wood products (i.e., wood-in-use). Typically this wood-in-use is slowly decayed back to the atmosphere with an estimated half-life (Masera et al., 2003). Half-life values for wood in use range from 15-100 years with the longest values being for wood used in home construction (CORRIM, 2004). A similar range is utilized here.

Results

Growth and Yield Thinning Response

In the absence of thinning the growth and yield models for both species demonstrate greater stemwood growth on sites of higher site index as well as increased total stemwood carbon with greater initial planting density (Figure 2, 3, and 4). For loblolly pine, the minimum (low density, low SI, no amendments) and maximum (high density, high SI, amendments) accumulations of stemwood C at rotation ranged from 29.7 to 66.5 tons acre^{-1}. In the absence of amendments, after thinning the total standing stock of stemwood C was lower in the light and moderate thinned stands at the 30 yr rotation age than in the unthinned condition. In contrast, with amendments, the light thinned stands had greater standing stocks of C in all cases while the moderate thinnings (i.e., lower residual basal area) still had lower stemwood C with deficits ranging from 1.2 to 3.3 tons-C ac^{-1}. In the case of Douglas-fir, even in the absence of amendments the high site index, high density, light thin (HSHDLT) condition had equal C

ED_000419-0008300

standing stock at rotation to the HSHDNT (high site, high density, no thin). In all other cases for Douglas-fir, the C standing stock with thinning lagged the unthinned condition by 2.6 to 12.1 tons-C ac^{-1}.

If the stemwood removed at thinning is summed with the standing stemwood C to estimate the total CO_2 fixed at rotation age, total C accumulation in the unamended condition for loblolly pine is often still slightly lower for thinning treatments relative to unthinned with exceptions for three low site index scenarios (LSLDLT, LSHDLT, and LSHDMT) that were greater by 0.1 to 0.8 tons-C ac^{-1} (Table 1). Deficits in total C were similarly relatively small (0.3 to 2.4 tons-C ac^{-1}). In the case of loblolly with amendments total C accumulations in thinned stands always exceeded those in the unthinned condition with an excess ranging from 2.5 to 5.2 tons-C ac^{-1} (Table 1). For Douglas-fir, total C accumulation (i.e., standing C stock + thinned C) at rotation in thinned stands almost always exceeded the unthinned except with exceptions for LSLDMT and LSHDMT that lagged by 0.1 and 0.3 tons-C ac^{-1}, respectively (Table 2). In the other cases the thinned scenarios exceeded the unthinned by 0.7 to 7.4 tons-C ac^{-1} (Table 2).

Bioenergy Offsets

The above results account for the C accumulated in the growing biomass. From a bioenergy perspective, however, there is interest in how substituting wood energy for fossil fuel energy will impact the balance of CO_2 in the atmosphere. If wood energy had an equal energy density to coal and replacement efficiency was 100% results would be the same as above. If, however, replacement efficiency is <100% than the total reduction of CO_2 in the atmosphere (CO_2 fixed in biomass + bioenergy offsets of fossil fuel carbon) would similarly decline (Figure 3). Under the conditions investigated the lowest atmospheric CO_2 reduction in thinned stands

ED_000419-0008301

relative to the unthinned is 80% at the 20% replacement efficiency (Table 3). The lowest rates occur with low site index and moderate thinnings. In the amended loblolly pine cases or under high site for Douglas-fir relative atmospheric CO_2 reduction is actually improved (i.e., >100%) in all cases with a replacement efficiency of >50% (Table 3).

Wood-in-use

Thinning coniferous plantations is well-known to affect the diameter distribution of trees by final harvest, which influences the distribution of stemwood that is utilized for pulp or solid wood products. For example, in loblolly pine at LSLD without thinning, at final harvest 30% of stemwood goes to fiber and 70% to solid wood (Table 4). Under the same conditions with moderate thinning only 16% goes to fiber and 84% to solid wood. These differences in product classes may not be as great at higher site index and are also influenced by planting density (Table 4). Given this effect on stemwood products the difference in C stocks stored as wood-in-use is less between unthinned and thinned stands than the difference in total standing stocks of C at rotation (Figure 6). In the particular case of unamended loblolly pine LSHD, in the absence of thinning such a large proportion of stemwood goes to fiber that thinning actually produces more C as wood-in-use (Table 4).

Discussion

There has been much enthusiasm about a growing bioenergy market in the USA and thus much debate about the sustainability of such activities (Janowiak and Webster, 2010) and their net benefit to atmospheric CO_2 concentrations ((Jonker et al., 2013; Mitchell et al., 2012). These debates are not new (Schlamadinger et al., 1995) and have also previously incorporated the use

ED_000419-0008302

of forests as carbon offsets in the absence of bioenergy production (Gonzalez-Benecke et al., 2010). Currently, a question of interest to the US EPA regulatory framework on biogenic CO_2 is whether emissions from biomass can be treated as carbon neutral (EPA, 2011). There has, however, been a recognition that not all forest management will have a net benefit to the atmosphere in the short-term as exemplified by the simple case of converting large stature old-growth forests to young plantations for bioenergy production (Harmon et al., 1990).

The forests addressed in this work, however, are already younger, managed plantations specifically grown for wood production. A long used strategy in these silvicultural systems is thinning. Thinning of these stands is largely driven by a desire for pest resistance and an improvement in products produced (i.e., larger diameter trees have higher value). The question addressed is can wood recovered during thinning of these managed stands be treated as carbon neutral if utilized for bioenergy production.

Results from this study are based on growth and yield models specific to these plantation regions and thus reflect the empirically observed growth dynamics and growth responses to thinning. In Douglas-fir, early hypotheses included the presumption that thinning may not reduce total growth due to a removal of trees that would die anyhow, or those which are suppressed and are unable to grow to much effect, and that level of growing stock would not affect accumulation (Worthington and Staebler, 1961). Also, there is an expectation that the release of trees from competition provides an enhancement in growth to residual trees in the stand (Pienaar, 1979). Experiences have shown there are important factors controlling this response, however, such as site index, which can reflect nutrient limitations that restrict the overall growth increment (Albaugh et al., 1998). This is well reflected in the unamended vs amended loblolly pine simulations. Furthermore, density affects the observed response. Low

ED_000419-0008303

density unthinned stands may simply not approach a point of resource limitation or self-thinning and thus thinning would not provide a beneficial response. On the other hand, high density unthinned stands may begin to stagnate in growth relatively early and self-thin and can provide stand dynamics where thinning is beneficial or, at least, neutral relative to total standing C accumulation. Finally, as observed here, the extent of thinning can affect the C accumulation potential as wood volume production does eventually decrease with decreasing growing stock (Marshall and Curtis, 2002). As such, there are clearly some site index by density by thinning combinations (e.g., high site index, high density, light thinning) that increase total C uptake and storage but not all thinning will enhance C accumulation.

As suggested in the conceptual model (Figure 1a) if the standing stock of C in the thinned stands catch up to the unthinned stands (i.e., carbon parity) by the final harvest age (i.e., 30 or 60 yrs) then all carbon removed and utilized for bioenergy would be a net benefit to the atmosphere in displacing fossil fuel carbon. This result is observed in 8 of the 18 scenarios with light thinning (i.e., loblolly amended, high site index Douglas-fir) when grown to simulated harvest ages. If these stands were harvested earlier (i.e., 25 or 50 yrs) then parity would not be achieved (Figure 2, 3, and 4). In the other cases of light thinning or under medium thinning results suggest that although carbon payback is achieved quickly, that is the standing stock of carbon 2-10 years after thinning is equal to the standing stock at the time of thinning, the standing stock at the end of the rotation in these stands never equals that of the unthinned stands (Figure 2, 3, and 4). These carbon differences range from to 0.3 to 12 tons-C acre^{-1} (Standing C in Table 1). Given greater productivity with higher site index some of the larger differences are actually a smaller percent difference in the standing stock. For example, in unamended loblolly pine MSHDMT

ED_000419-0008304

standing stock C is 7.6 ton-C ac^{-1} or 16 % below MSHDNT while HSHDMT is 8.1 ton-C ac^{-1} or 12 % below HSHDNT.

In the cases where there is only a partial recovery of standing stocks, an assessment of bioenergy offsets (Figure 1b) is required to assess carbon benefits to the atmosphere. Bioenergy offsets can only account for the absolute difference in the standing stocks if the amount of C in thinnings exceeds or equals this difference. This is rarely true in the loblolly unamended scenarios but virtually always true in the loblolly amended and Douglas-fir scenarios. In the first case of unamended loblolly pine, decreasing efficiency of bioenergy replacement relative to fossil fuels will reduce the extent of carbon parity of the thinned stands, although in all cases this exceeds 83%. In the other cases, the replacement efficiency will determine if the stands are C deficits, C neutral, or C enhanced (Table 4).

The final component of this analysis incorporates the effect of thinning on tree diameter distributions and thus on roundwood product classes either as fiber or solid wood products. Since thinning improves the amount of C in the solid wood product class and this material decays back to the atmosphere more slowly than bioenergy or fiber more C is retained over multiple rotations (Figure 6 and Table 4). This benefit of thinning reduces the differences in unthinned and thinned treatments relative to the C removed from the atmosphere over multiple rotations.

This analysis is similar to others in its C accounting (Gonzalez-Benecke et al., 2010; Marland and Schlamadinger, 1997), although has treated a few components as net zero based on these previous studies (i.e., soil and root carbon). The growth and yield response of the current model is consistent with previous tree level studies (Pienaar, 1979, 1995) as the models were based on similar experimental data. Furthermore, these analysis are consistent with Hoover and

ED_000419-0008305

Stout (2007) as well as Keyser and Zarnoch (2012) in finding that lighter intensity thinnings improve the recovery of standing stocks of carbon by rotation age. Unlike Clark et al. (2011b), however, the young age of these plantation stands and the rapid rate of growth allows recovery of C standing stocks in many cases within the rotation.

Are thinnings used for bioenergy carbon neutral? The answer is it depends. At the stand level thinnings appear beneficial for high productivity, high density stands that are lightly thinned. At the energy production level the critical factor appears to be the conversion efficiency. If efficiencies are as low as 20% then thinned stands might only account for 80% of atmospheric CO_2 reduction observed in unthinned stands. EPA treats this as a biogenic accounting factor (BAF), which would suggest, for example, that each ton of CO_2 equivalents from bioenergy would displace only 0.8 tons of fossil fuel CO_2 emissions. If, however, conversion efficiencies achieve 50% or better, in all cases thinnings are carbon neutral. In other words, if two bone dry tons of woods is always sufficient to produce as much energy as one ton of coal the atmosphere will benefit from burning C from thinnings. Of course, if conversion efficiencies are better than the balance is closer to ton per ton and carbon neutrality will be more readily achieved.

ED_000419-0008306

References

Albaugh, T., Allen, H.L., Dougherty, P.M., Kress, L., King, J.S., 1998. Leaf area and above- and belowground responses of loblolly pine to nutrient and water additions For Sci 44, 317-327.

Borders, B., Will, R., Markewitz, D., Clark, A., Hendrick, R., Teskey, R., Zhang, Y., 2004a. Effect of complete competition control and annual fertilization on stem growth and canopy relations for a chronosequence of loblolly pine plantations in the lower coastal plain of Georgia. Forest Ecol Manag 192, 21-37.

Borders, B.E., Will, R.E., Markewitz, D., Clark, A., Hendrick, R.L., Teskey, R.O., Zhang, Y., 2004b. Effect of complete competition control and annual fertilization on stem growth and canopy relations for a chronosequence of loblolly pine plantations in the lower coastal plain of Georgia. Forest Ecol Manag 192, 21-37.

Briggs, D., 2007. Management practices on Pacific Northwest west-side industrial forest lands, 1991-2005: with projections to 2010., Working Paper 6 ed.

Burkhart, H.E., Tomé, M., 2012. Modeling forest trees and stands. Springer.

Clark, J., Sessions, J., Krankina, O., Maness, T., 2011a. Impacts of thinning on carbon stores in the PNW: A plot level analysis. Oregon State University, p. 61.

Clark, J., Sessions, J., Krankina, O., Maness, T., 2011b. Impacts of thinning on carbon stores in the PNW: A plot level analysis. Oregon State University, Oregon.

CORRIM, 2004. CORRIM: Phase I Final Report Module A: Forest Resources - Pacific Northwest and Southeast, in: Bowyer, J., Lippke, B., Briggs, D., Perez-Garcia, J., Wilson, J. (Eds.), Phase I Research Report on the Research Plan to Develop Environmental-Performance Measures for Renewable Building Materials with Alternatives for Improved Performance. Consortium for Research on Renewable Industrial Materials, pp. 1-79.

ED_000419-0008307

Dwivedi, P., Bailis, R., Stainback, A., Carter, D.R., 2012. Impact of payments for carbon sequestered in wood products and avoided carbon emissions on the profitability of NIPF landowners in the US South. Ecological Economics 78, 63-69.

Eisenbies, M.H., 2006. Long-term timber productivity research on intensively managed pine forests of the South. Long-term silvicultural and ecological studies: Results for science and management 5, 139-153.

Emmingham, W.H., Green, D., 1984. Thinning systems for western Oregon Douglas-fir stands: what is best for you? [Corvallis, Or.]: Oregon State University, Extension Service.

Emmingham, W.M., Fletcher, R., Fitzgerald, S., Bennet, M., 2007. Comparing tree and stand volume growth response to low and crown thinning in young natural Douglas-fir stands. Western Journal of Applied Forestry 22, 124-133.

EPA, 2011. Accounting Framework for Biogenic CO2 Emissions from Stationary Sources., in: Programs, O.o.A. (Ed.), Washington DC, p. 140.

Flewelling, J.W., Collier, R., Gonyea, B., Marshall, D., Turnblom, E., 2001. Height-age curves for planted stands of Douglas fir, with adjustments for density. College of Forest Resources, University of Washington.

Gonzalez-Benecke, C.A., Martin, T.A., Cropper Jr, W.P., Bracho, R., 2010. Forest management effects on in situ and ex situ slash pine forest carbon balance. Forest Ecol Manag 260, 795-805.

Harmon, M.E., Ferrell, W.K., Franklin, J.F., 1990. Effects of carbon storage on conversion of old-growth forests to young forests. Science 247, 699-702.

ED_000419-0008308

Harrington, C.A., Piatek, K.B., DeBell, D.S., 2003. Site Preparation Effects on 20 Year Survival and Growth of Douglas-Fir (Pseudotsuga menziesii) and on Selected Soil Properties. Western Journal of Applied Forestry 18, 44-51.

Harrington, T.B., Harrington, C.A., DeBell, D.S., 2009. Effects of planting spacing and site quality on 25-year growth and mortality relationships of Douglas-fir (< i> Pseudotsuga menziesii var.< i> menziesii). Forest Ecol Manag 258, 18-25.

Harrison, W.M., Borders, B.E., 1996. Yield prediction and growth projection for site-prepared loblolly pine plantations in the Carolinas, Georgia, Alabama and Florida., PMRC Research Paper. The University of Georgia, Athens, p. 59.

Hoover, C., Stout, S., 2007. The carbon consequences of thinning techniques: stand structure makes a difference. . Journal of Forestry 105.

Janowiak, M.K., Webster, C.R., 2010. Promoting Ecological Sustainability in Woody Biomass Harvesting. Journal of Forestry 108, 16-23.

Jonker, J.G.G., Junginger, M., Faaij, A., 2013. Carbon payback period and carbon offset parity point of wood pellet production in the South-eastern United States. GCB Bioenergy, n/a-n/a.

Keyser, T.L., 2010. Thinning and site quality influence aboveground tree carbon stocks in yellow-poplar forests of the southern Appalachians. Canadian Journal of Forest Research 40, 659-667.

Keyser, T.L., Zarnoch, S.J., 2012. Thinning, age, and site quality influence live tree carbon stocks in upland hardwood forests of the southern Appalachians. For Sci 58, 407-418.

Markewitz, D., 2006. Fossil fuel carbon emissions from silviculture: Impacts on net carbon sequestration in forests. Forest Ecol Manag 236.

ED_000419-0008309

Marland, G., Schlamadinger, B., 1997. Forests for carbon sequestration or fossil fuel substitution? A sensitivity analysis. Biomass and Bioenergy 13, 389-397.

Marshall, D.D., Curtis, R.O., 2002. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 15-Hoskins: 1963-1998. United States Department of Agriculture, Forest Service.

Masera, O., Garza-Caligaris, J.F., Kanninen, M., Karjalainen, T., Liski, J., Nabuurs, G.J., Pussinen, A., de Jong, B.H.J., 2003. Modelling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V.2 approach. Ecological Modelling 164, 177-199.

Mitchell, S.R., Harmon, M.E., O'Connell, K.E.B., 2012. Carbon debt and carbon sequestration parity in forest bioenergy production. GCB Bioenergy 4, 818-827.

O'Connor, A.J., 1935. Forest research with special reference to planting densities and thinning., British Empire Forestry Conference, South Africa, p. 30.

Olsson, U., Binkley, D., Smith, F.W., 1997. Nitrogen supply, nitrogen use, and production in an age sequence of lodgepole pine. For Sci 44, 454-457.

Pienaar, L., Rheney, J., 1995. Modeling stand level growth and yield response to silvicultural treatments. For Sci 41, 629-638.

Pienaar, L.V., 1979. An Approximation of Basal Area Growth after Thinning Based on Growth in Unthinned Plantations. For Sci 25, 223-232.

Pienaar, L.V., 1995. Results and analysis of a slash pine spacing and thinning study in the Southeast Coastal Plain., Plantation Management Research Cooperative Technical Report. University of Georgia, Athens, GA.

ED_000419-0008310

SAB, 2012. SAB Review of EPA's Accounting Framework for Biogenic CO2 Emissions from Stationary Sources, in: Swackhamer, D.L., Khanna, M. (Eds.).

Schlamadinger, B., Spitzer, J., Kohlmaier, G.H., Lüdeke, M., 1995. Carbon balance of bioenergy from logging residues. Biomass and Bioenergy 8, 221-234.

Sword Sayer, M.A., Goelz, J.C.G., Chambers, J.L., Tang, Z., Dean, T.J., Haywood, J.D., Leduc, D.J., 2004. Long-term trends in loblolly pine productivity and stand characteristics in response to thinning and fertilization in the West Gulf region. Forest Ecol Manag 192, 71-96.

Talbert, C., Marshall, D., 2005. Plantation productivity in the Douglas-fir region under intensive silvicultural practices: results from research and operations. Journal of Forestry 103, 65-70.

Wang, M., Han, J., Dunn, J.B., Cai, H., Elgowainy, A., 2012. Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. Environmental Research Letters 7, 045905.

Weiskittel, A.R., Hann, D.W., Kershaw Jr, J.A., Vanclay, J.K., 2011. Forest growth and yield modeling. John Wiley & Sons.

Worthington, N.P., Staebler, G.R., 1961. Commercial thinning of Douglas-fir in the Pacific Northwest. US Department of Agriculture.

ED_000419-0008311

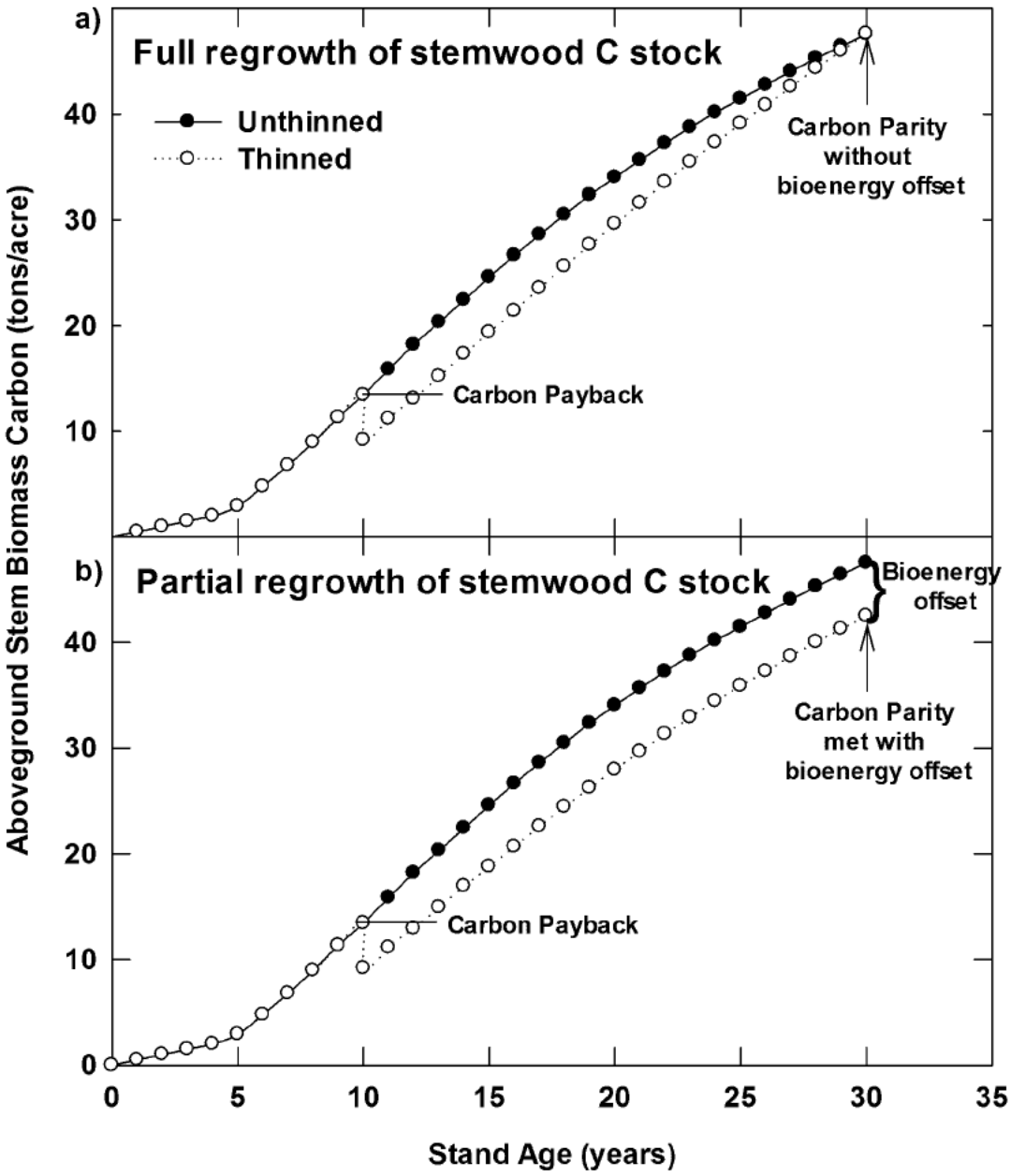


Figure 1: Conceptual model for effect of thinning on carbon. Carbon payback requires that the standing stock of C in the thinned stand is equals that at the time of thinning. Carbon parity requires that the standing stock of carbon in the thinned stand equals that in a non-thinned reference stand sometime in the future. a) Hypothetical model of thinned stand fully recovering standing stocks of carbon by rotation age. b) Hypothetical model of thinned stand partial recovering standing stock of C but achieving carbon parity through bioenergy offsets.

ED_000419-0008312

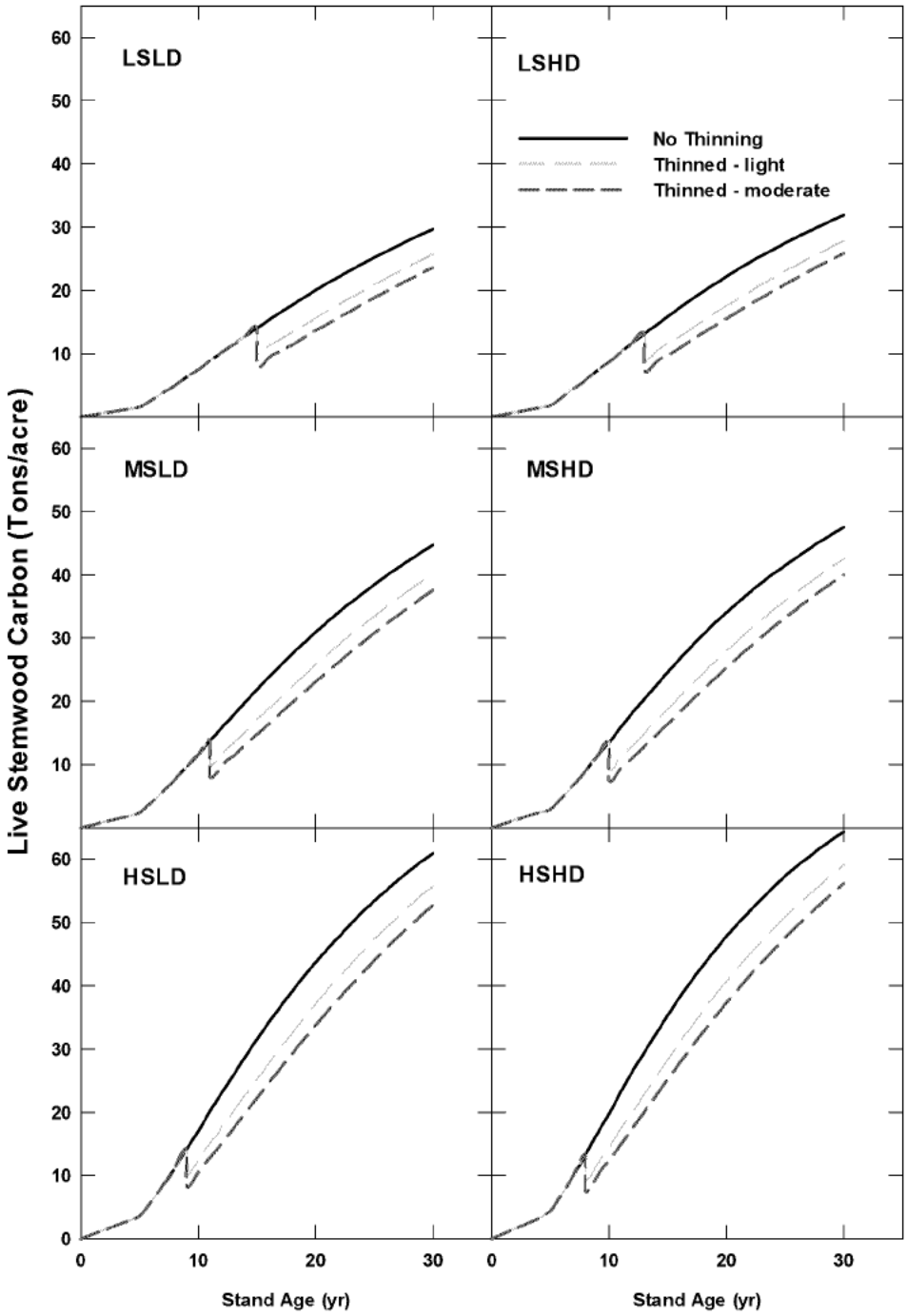


Figure 2: Live stemwood carbon in unamended loblolly pine stands with and without thinning treatments. Tree densities are low (LD; 545 trees/ac) and high (HD; 726 trees/ac). Site index is low (LS; 55 feet@25 yrs), medium (MS; 70 ft @25 yr), and high (HS; 85 ft @ 25yr). Thinning treatments are initiated at a basal area of 120 ft^2 $acre^{-1}$ and are thus imposed at different ages depending on SI. Thinnings are light (~30 of basal area) and moderate (~50 of basal area). No silviculture inputs are applied after thinning.

ED_000419-0008313

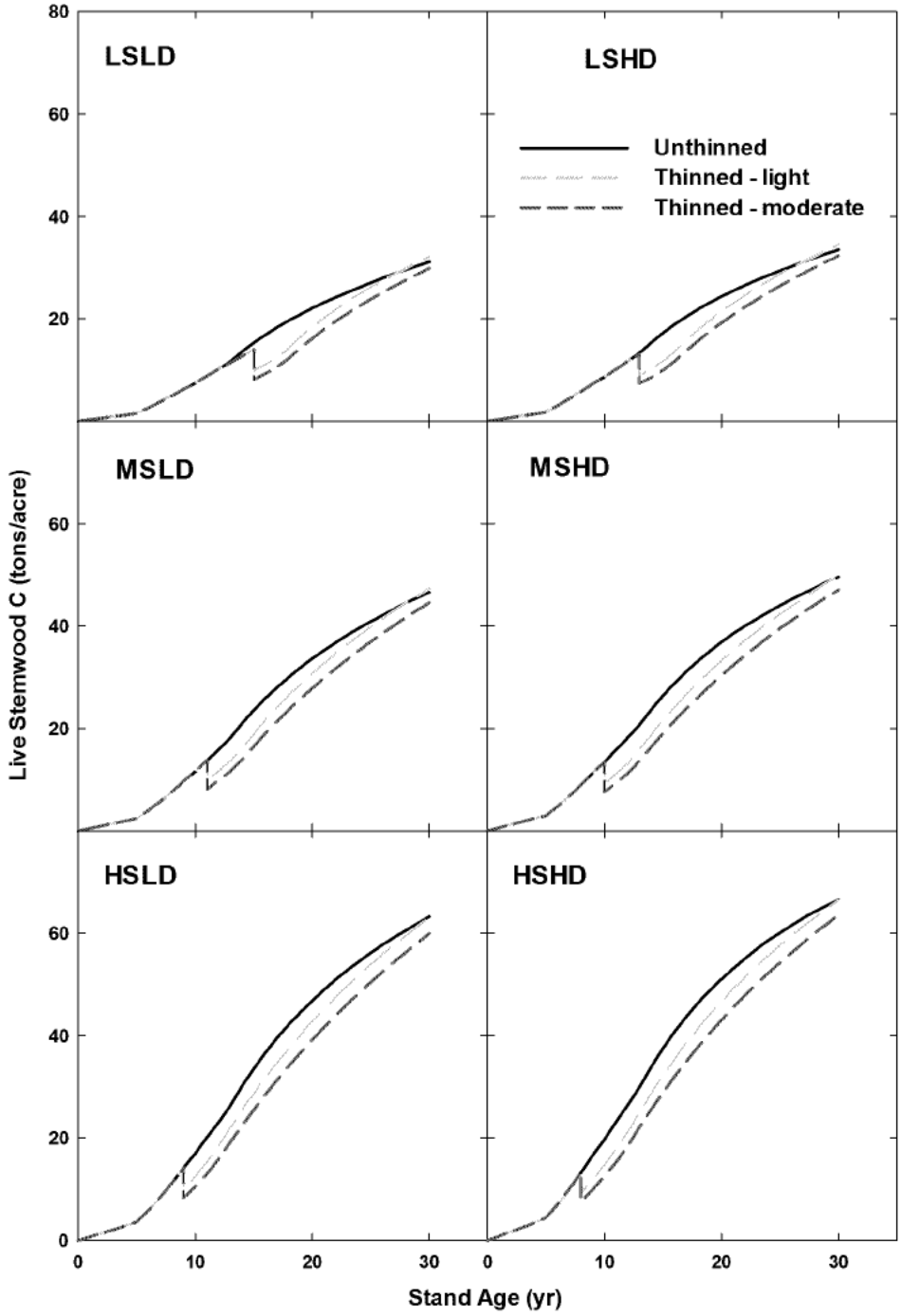


Figure 3: Live stemwood carbon in amended loblolly pine stands with and without thinning treatments. Tree densities are low (LD; 545 trees/ac) and high (HD; 726 trees/ac). Site index is low (LS; 55 feet@25 yrs), medium (MS; 70 ft @25 yr), and high (HS; 85 ft @ 25yr). Thinning treatments are initiated at a basal area of 120 ft^2 $acre^{-1}$ and are thus imposed at different ages depending on SI. Thinnings are low (~30 of basal area) and medium (~50 of basal area). Silviculture inputs (In) of fertilization and competition control are applied after thinning.

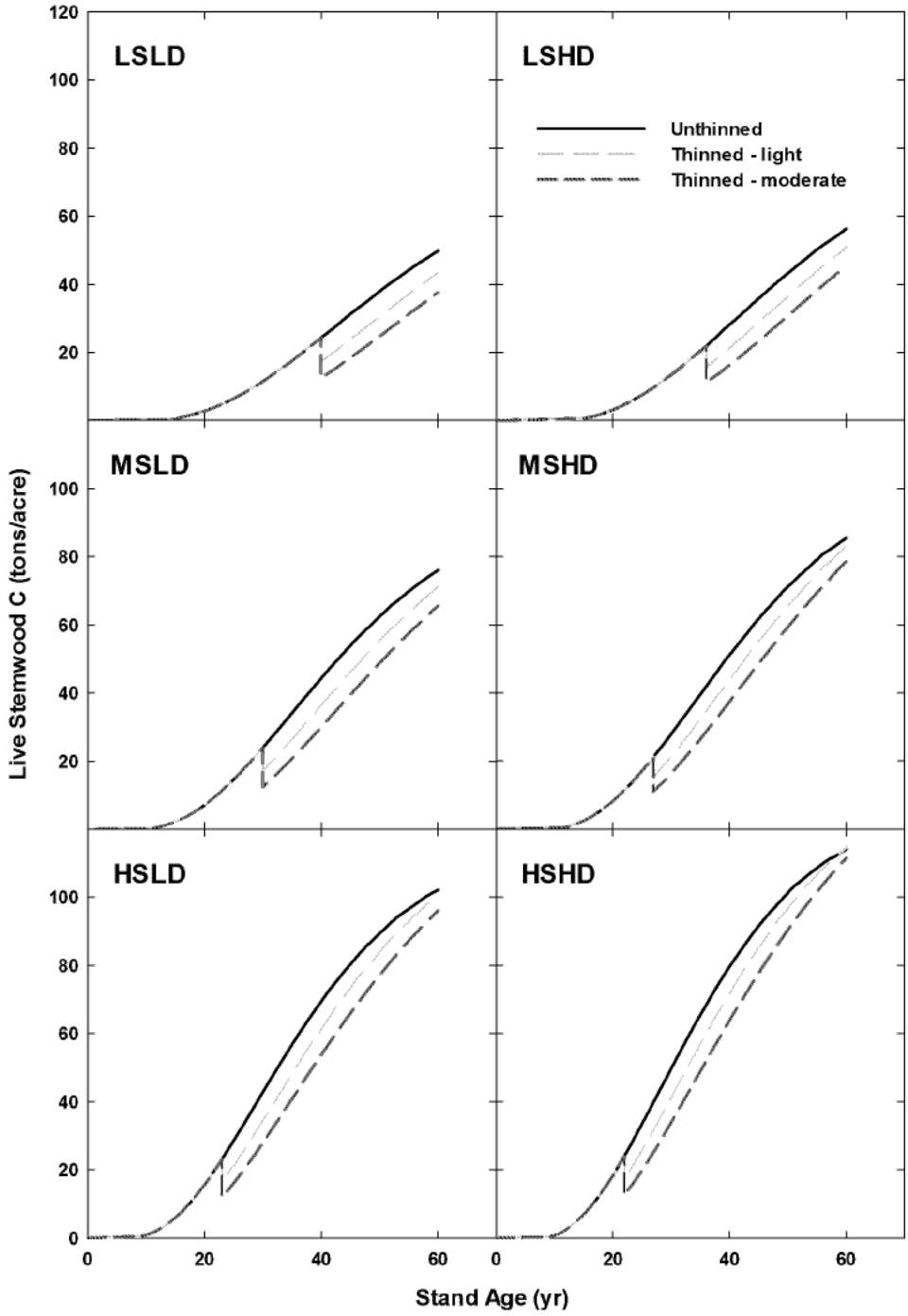


Figure 4: Live stemwood carbon in Douglas-fir stands with and without thinning treatments. Tree densities are low (LD; 420 trees/ac) and high (HD; 650 trees/ac). Site index is low (LS; 50 feet@30 yrs), medium (MS; 70 ft @30 yr), and high (HS; 90 ft @ 30yr). Thinning treatments are initiated at the earliest age for a viable commercial thinning and are thus imposed at different ages depending on SI. Thinnings are low (~30 of basal area) and medium (~50 of basal area). No silviculture inputs are applied after thinning.

ED_000419-0008315

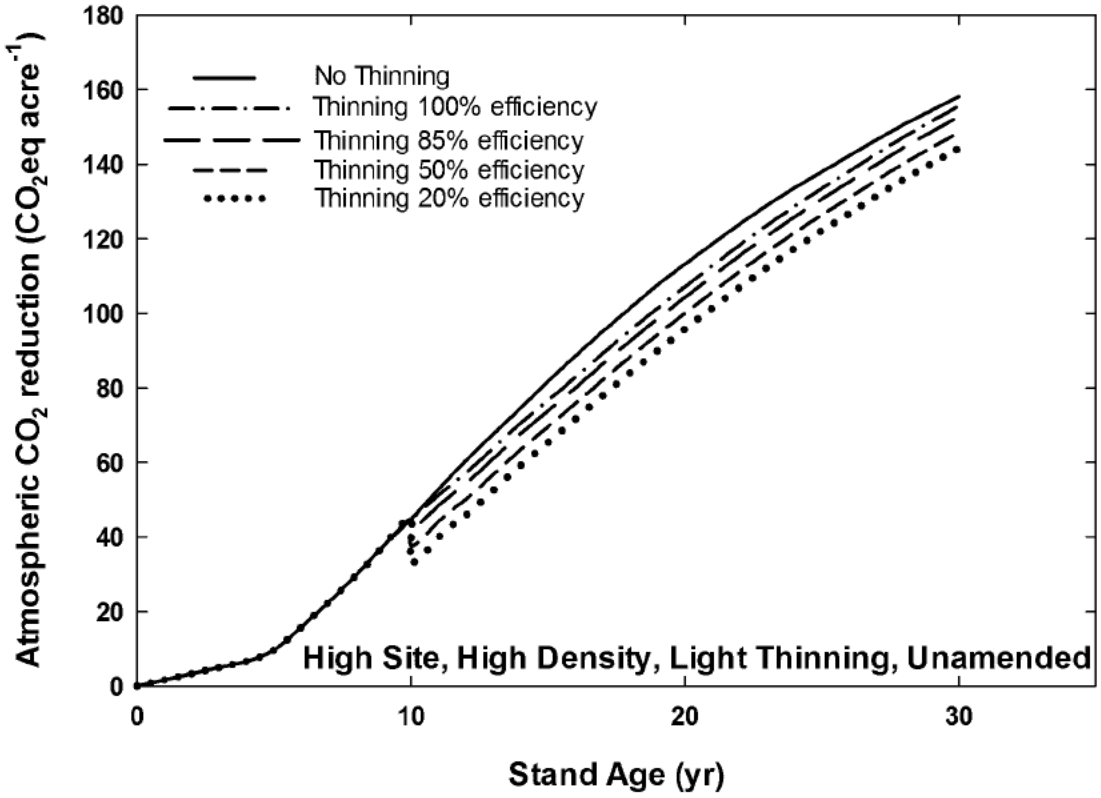


Figure 5: Example of reduction in CO_2 in the atmosphere relative to loblolly pine tree growth and carbon offsets due to bioenergy substitution for fossil fuels. The extent of the carbon offset is affected by the conversion efficiency of the biomass to bioenergy.

ED_000419-0008316

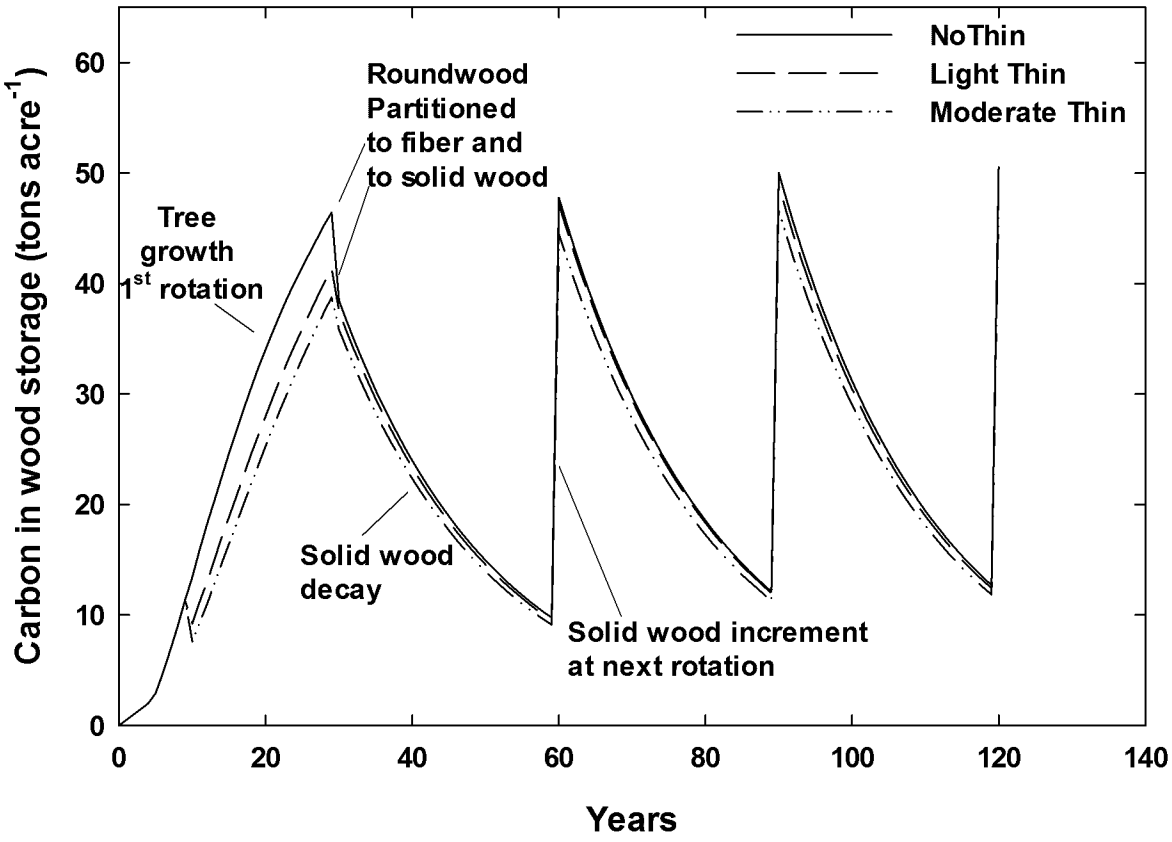


Figure 6: Simulating the effect of wood-in-use on C storage. Year 0-30 are stemwood growth in the 1st rotation under unamended unthinned and thinned loblolly pine stands. After partitioning grown stemwood into fiber and solid wood products the solid wood is decayed with a half-life of 15 years. In the 2nd and 3rd rotations the increment of solid wood products is added and subsequently decayed with any remaining wood-in-use from earlier rotations.

ED_000419-0008317

Table 1: Carbon harvested at thinning and standing stocks of carbon in aboveground stemwood at age 30 in loblolly pine stands. Units are tons-C/acre.

Stand Type	Stand Density		Site Index: Low			Site Index: Med			Site Index: High		
			Thinning Intensity			Thinning Intensity			Thinning Intensity		
			@15 yrs			@11yrs			@9 yrs		
			0	Lite	Mod	0	Lite	Mod	0	Lite	Mod
Loblolly Unamended	Low	Standing C	29.7	25.7	23.6	44.7	40.2	37.6	61	55.8	52.8
		Thinned C	0	4.1	5.8	0	3.9	5.6	0	4.1	5.8
		Total C	29.7	29.8	29.4	44.7	44.1	43.2	61	59.9	58.6
			@13 yrs			@10 yrs			@8 yrs		
	High	Standing C	31.1	27.8	25.9	47.6	42.5	40.0	64.3	59.1	56.2
		Thinned C	0	4.1	5.7	0	4.3	5.9	0	4.1	5.7
		Total C	31.1	31.9	31.6	47.6	46.8	45.9	64.3	63.2	61.9
			@15 yrs			@11yrs			@9 yrs		
			0	Lite	Mod	0	Lite	Mod	0	Lite	Mod
Loblolly Amended[4]	Low	Standing C	31.1	32.2	29.9	46.6	47.3	44.6	63.2	63.1	59.9
		Thinned C	0	4.1	5.8	0	3.9	5.6	0	4.1	5.8
		Total C	31.1	36.3	35.7	46.6	51.2	50.2	63.2	67.2	65.7
			@13 yrs			@10 yrs			@8 yrs		
	High	Standing C	33.5	34.5	32.3	49.6	49.7	47.1	66.5	66.4	63.6
		Thinned C	0	4.1	5.7	0	4.3	5.9	0	4.1	5.7
		Total C	33.5	38.6	38.0	49.6	54.0	53.0	66.5	70.5	69.3

[1] Tree densities are 545 (low) and 726 (high) trees/ac.
[2] Site Indices are 55 (low), 70 (med), and 85(high) ft at 25yrs.
[3] Thinning treatments are ~30 (low) and ~50 (high) % of basal area. Thinnings are initiated at 120 ft^2 $acre^{-1}$ of basal area and are imposed at different ages depending on site and silviculture.
[4] Amendments of fertilization and competition control are simulated after thinning in all stands including unthinned controls.

ED_000419-0008318

Table 2: Carbon harvested at thinning and standing stocks of carbon in aboveground stemwood at age 60 in Douglas-fir stands. No silvicultural amendments are applied after thinning. Units are tons-C/acre.

Stand Type	Stand[1] Density		Site Index[2] Low			Site Index[2] Med			Site Index[2] High		
			Thinning Intensity[3]			Thinning Intensity			Thinning Intensity		
			@40 yrs			@30yrs			@23 yrs		
			0	Lite	Mod	0	Lite	Mod	0	Lite	Mod
Douglas-fir Unamended	Low	Standing C	49.7	43.4	37.6	76.1	71.2	65.6	102.1	100.4	96.1
		Thinned C	0	7.0	11.8	0	6.9	11.5	0	6.6	11.2
		Total C	49.7	50.4	49.4	76.1	78.1	77.1	102.1	107.0	107.3
			@36 yrs			@27 yrs			@22 yrs		
	High	Standing C	56.3	50.9	45.5	85.5	83.0	78.6	114.1	114.7	111.5
		Thinned C	0	6.3	10.7	0	6.1	10.2	0	6.8	11.6
		Total C	56.3	57.2	56.2	85.5	89.1	88.8	114.1	121.5	123.1

[1] Tree densities for are 420 (low) and 650 (high) trees/ac.
[2] Site Index 50 (low), 70 (Med), and 90 (High) ft at 30yrs.
[3] Thinning treatments are ~30 (low) and ~50 (high) % of basal area. Thinning is imposed at the earliest age for a viable commercial thinning. Thinnings are imposed at different ages depending on site and density.

ED_000419-0008319

Table 3: Percent reduction in atmospheric CO_2 in thinned coniferous stands relative to an unthinned control stand. CO_2 reductions include C stored in live stem biomass and that carbon offset from utilizing thinned stems for bioenergy production.

Stand Type	Tree[1] Density	Displacement Efficiency	Site Index[2] Low		Med		High	
			Thinning Intensity[3]					
			Lite	Mod	Lite	Mod	Lite	Mod
Loblolly Unamended	Low	100	101	99	99	97	98	96
		80	98	95	97	94	97	94
		50	94	89	90	90	95	91
		20	89	83	87	87	93	89
	High	100	100	99	98	97	98	96
		80	98	95	97	94	97	94
		50	94	90	94	90	95	92
		20	90	85	91	87	93	89
Loblolly Amended[4]	Low	100	117	115	110	108	106	104
		80	114	111	108	105	105	102
		50	110	105	106	102	103	99
		20	106	106	103	98	101	97
	High	100	115	114	109	107	106	104
		80	113	110	107	104	105	102
		50	109	105	105	101	103	100
		20	106	100	102	97	101	97
Douglas-fir Unamended	Low	100	101	99	103	101	105	105
		80	98	95	101	98	104	103
		50	94	87	98	94	102	100
		20	90	80	95	89	100	96
	High	100	102	100	104	104	106	108
		80	99	96	103	101	105	106
		50	96	90	101	98	104	103
		20	93	85	99	94	102	100

[1] Tree densities for loblolly pine are 545 (low) and 726 (high) trees/ac; for Douglas-fir 420 and 650 trees/ac, respectively.

[2] Site Index for loblolly pine is 55 (low), 70 (med), and 85(hight) ft at 25yrs; for Douglas-fir 50, 70, and 90 ft at 30yrs, respectively.

[3] Thinning treatments for both loblolly pine and Douglas-fir are ~30 (low) and ~50 (high) % of basal area. For loblolly pine thinnings are initiated at 120 ft^2 $acre^{-1}$ of basal area; in Douglas-fir at the earliest age for a viable commercial thinning. Thinnings are imposed at different ages depending on site and silviculture.

[4] Amendments of fertilization and competition control are simulated after thinning in all stands including unthinned control.

ED_000419-0008320

Table 4: Product class distribution at final harvest and carbon stored as wood-in-use after 120 yrs (four rotations of loblolly pine and two rotations of Douglas-fir). Wood-in-use is decayed with a half-life of 15 yrs. Units are percent for Fiber/Solid or tons-C/acre.

Stand Type	Stand Density[1]		Site Index[2]								
			Low			Med			High		
	Trees/ac		Thinning Intensity[3]			Thinning Intensity			Thinning Intensity		
			0	Lite	Mod	0	Lite	Mod	0	Lite	Mod
Loblolly Unamended	Low	Fiber/Solid	30/70	22/78	16/84	14/86	10/90	8/92	6/94	6/94	5/95
		Wood C	27.3	26.3	26.1	50.4	47.6	45.6	75.0	69.1	65.8
	High	Fiber/Solid	39/61	27/63	21/79	19/81	12/88	10/90	7/93	7/93	6/94
		Wood C	25.5	26.7	28.8	50.6	49.3	47.0	78.3	72.2	69.7
Loblolly Amended[4]	Low	Fiber/Solid	27/73	12/88	09/91	13/87	6/94	6/94	6/94	5/95	4/96
		Wood C	29.8	30.7	28.6	53.4	54.3	51.1	77.8	77.6	73.7
	High	Fiber/Solid	36/64	16/84	13/87	17/83	8/92	7/93	7/93	5/95	4/96
		Wood C	32.0	32.0	30.9	47.4	47.5	45	63.5	63.4	60.8
Douglas-fir Unamended	Low	Fiber/Solid	29/71	24/76	20/80	26/74	19/81	16/84	22/78	17/83	14/86
		Wood C	37.5	32.5	28.1	59.9	56.1	51.6	84.5	83.2	79.6
	High	Fiber/Solid	34/66	31/69	28/72	30/70	26/74	24/76	29/71	24/76	22/78
		Wood C	39.3	35.5	31.7	63.8	61.9	58.7	94.5	95.0	92.3

[1] Tree densities for loblolly pine are 545 (low) and 726 (high) trees/ac; for Douglas-fir 420 and 650 trees/ac, respectively.
[2] Site Index for loblolly pine is 55 (low), 70 (med), and 85(hight) ft at 25yrs; for Douglas-fir 50, 70, and 90 ft at 30yrs, respectively.

ED_000419-0008321

[3] Thinning treatments for both loblolly pine and Douglas-fir are ~30 (low) and ~50 (high) % of basal area. For loblolly pine thinnings are initiated at 120 ft^2 $acre^{-1}$ of basal area; in Douglas-fir at the earliest age for a viable commercial thinning. Thinnings are imposed at different ages depending on site and silviculture.
[4] Amendments of fertilization and competition control are simulated after thinning in all stands including unthinned control.

ED_000419-0008322

From: Ohrel, Sara
To: Baker, Justin; Cole, Jefferson
Sent: 8/6/2014 9:47:33 AM
Subject: RE: App G-- deliberative
Attachments: Appendix_G_Process_Atts_8 5 14_so.docx

Thanks Justin. This looks really good. My responses and questions below in green.
Once the remaining questions below are resolved, I think this one is good to go for reference check and editing.

From: Baker, Justin [mailto:justinbaker@rti.org]
Sent: Tuesday, August 05, 2014 10:16 PM
To: Ohrel, Sara; Cole, Jefferson
Subject: FW: App G-- deliberative

__this email and all attachments are deliberative__

Sara and Jeff,

Here is a revised version of App G that Katie has worked on. There are some remaining issues/comments for you to look at, as indicated by the list below. Let me know if you have any other questions.

Justin

From: Hanks, Katie P.
Sent: Tuesday, August 05, 2014 1:50 PM
To: Baker, Justin
Subject: App G

I placed a redline revised version of App G here:

Ex. 6 - Personal Privacy

The status of the spreadsheet outstanding issue list is below.

Ex. 5 - Deliberative

Please let me know if I need to do anything else on this or the black liquor addendum.

Katie Hanks

RTI International
3040 Cornwallis Road
Research Triangle Park, NC 27709
(919) 316-3732
(919) 541-7155 (fax)

From: Ohrel, Sara
To: Clouse, Matt
Sent: 8/4/2014 2:07:55 PM
Subject: RE: Biomass accounting framework - deliberative
Attachments: Framework_Report_all comments_7 27_draft final.docx

Hi Matt,
Nice to hear from you. Happy to help. Attached is the most recent version of the revised framework. Please do not cite or distribute, as it is deliberative and we are currently editing it.
Please let me know if you have any questions,
Sara

From: Clouse, Matt
Sent: Monday, August 04, 2014 1:35 PM
To: Ohrel, Sara
Subject: FW: Biomass accounting framework

Hi Sara,

I'm following up on Reid's suggestion to review the latest version of the draft biomass accounting framework. Chris suggested that I check with you for an electronic copy.

Reid's suggestion came up in a discussion of biomass in the 111d state goal calculations. He thought it may be helpful for me to be familiar with it.

Thanks,
Matt

Matt Clouse
Director, Renewable Energy Policy and Programs
Climate Protection Partnerships Division
U.S. Environmental Protection Agency
phone: (202) 343-9004

From: Sherry, Christopher
Sent: Monday, August 04, 2014 1:28 PM
To: Clouse, Matt
Subject: RE: Biomass accounting framework

Matt,

Here is the 2011 report submitted to the Scientific Advisory Board, but significant revisions have been made to it since, and the updated framework has yet to be released. Sara Ohrel in the Climate Economics Branch of CCD would be the one to talk with regarding the updated framework that is in progress.

Info about the SAB review is at **Ex. 6 - Personal Privacy: internal share drive link**
Ex. 6 - Personal Privacy: internal share drive link

Chris

From: Clouse, Matt
Sent: Monday, August 04, 2014 1:19 PM

To: Sherry, Christopher
Subject: Biomass accounting framework

Hi Chris,

Reid suggested I ask you about getting a copy of the biomass accounting framework. The suggestion came up in a discussion of biomass in the 111d state goal calculations. He thought it may be helpful for me to be familiar with it.

Matt

Matt Clouse
Director, Renewable Energy Policy and Programs
Climate Protection Partnerships Division
U.S. Environmental Protection Agency
phone: (202) 343-9004

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org); Cole, Jefferson
Sent:	8/4/2014 10:59:45 AM
Subject:	updated tasks list
Attachments:	Oustanding Items 8 4 14.xlsx

Hi all,
Justin and I chatted and here is the current tasks list and assignments.
Thanks!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org); Cole, Jefferson
Sent:	7/30/2014 4:59:29 PM
Subject:	AF2 - deliberative
Attachments:	Framework_Report_all comments_7 27_changessavedwcomments_soedits_cleanwcoms.docx; Framework_Report_all comments_7 27_draft final.docx

Two drafts of main doc, just to make sure we all have them:
- completely clean draft I shared with Janet and Joe Monday
- with comments version, no tracked changes version just prior to cleaning

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Cole, Jefferson; Justin Baker (justinbaker@rti.org)
Sent: 7/30/2014 3:30:53 PM
Subject: next steps list - deliberative
Attachments: Oustanding Items 2014 07 30_so.xlsx

Hi guys,
Here is our follow up list for the AF2 package (tab 1 on apps, tab 2 on main doc). Not too much, and I am hoping we can knock a lot of it out before the end of next week.

As we just discussed quickly on the phone, Justin will delegate certain elements to his team (i.e., editing team, reference check - Please have your editing team use the clean version of the main doc for editing/ref check). Jeff and I can tackle other elements on the list, working with Robert and Katie directly if/as needed, and then reconvene with Justin on what else is needed to be done upon his return next week.

Thanks all!
Sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Cole, Jefferson
Sent: 7/29/2014 8:41:57 AM
Subject: follow up for b thru j - deliberative
Attachments: Appendix_B_Temporal Scale_5 1_Final_RTI_jc.docx; Appendix_C_Spatial Scale_5 1_oaqps_otaq_jc_so.docx; Appendix_D_Feedstock Categories_5 1_oaqps jc2_so_cleanwcomments.docx; Appendix_G_Process_Atts_oaqps_mkw_tb_so_RTI7-16-14_so_cleanv2so.docx; Appendix_H_RefPt LandscapeAtts OAQPS SP tb so_RTI.docx; Appendix_I_Ref Pt CaseStudies OAQPS SP tb so RTI.docx; Appendix_J_Anticipated Baselines Background_5_1_oaqps_RTI_PSG.docx

Hi Jeff is the first half. I am only including ones that seem to need follow. We will not be editing this versions directly – rather, just finding what needs follow up and make further edits to clean version. Thanks!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Knapp, Kristien
Sent: 7/28/2014 3:40:16 PM
Subject: 3 of 3
Attachments: Appendix_H_RefPt LandscapeAtts 7 27df.docx; Appendix_I_Ref Pt CaseStudies 7 27df.docx; Appendix_J_Anticipated Baselines Background_7 27df.docx; Appendix_K_Anticipated Baseline Construction Methods_7 27.docx; Appendix_L_Anticipated Baseline Case Studies_7 27df.docx; Appendix_M_Summary of Illustrative Forest and Ag Case Studies_7 27df.docx; Appendix_N_Waste Derived Feedstocks_7 27df.docx

Last but not least - attached you will find:

- Appendix H: Illustrative Biogenic Landscape Attributes Using a Retrospective Reference Point Baseline
- Appendix I: Illustrative Forestry and Agriculture Case Studies using a Retrospective Reference Point Baseline
- Appendix J: Anticipated Baselines: Background and Key Modeling Considerations
- Appendix K: Future Anticipated Baseline Construction: Methodology and Results
- Appendix L: Illustrative Forestry and Agriculture Case Studies using a Future Anticipated Baseline
- Appendix M: Summary of Illustrative Forestry and Agriculture Results

THANK YOU!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Knapp, Kristien
Sent: 7/28/2014 3:39:13 PM
Subject: 2 of 3
Attachments: Appendix_B_Temporal Scale_5 1_Final_RTI_jc (clean)2.docx; Appendix_C_Spatial Scale_7 27df.docx; Appendix_D_Feedstock Categories_7 27df.docx; Appendix_E_Discussion of Leakage Literature_7 27df.docx; Appendix_F_General Algebraic Representation_7.26df.docx; Appendix_G_Process_Atts_7.26_final.docx

Attached you will find:

- Appendix B: Temporal Scale
- Appendix C: Spatial Scale
- Appendix D: Feedstock Categorization and Definitions
- Appendix E: Discussion of Leakage Literature
- Appendix F: General Algebraic Representation of the Biogenic Assessment Factor Equations
- Appendix G: Biogenic Process Attributes

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Ohrel, Sara
To: Schrock, Bill
Sent: 7/28/2014 9:11:58 AM
Subject: FW: slides for Monday biomass briefing with Janet - deliberative
Attachments: Biomass Assessment Framework Briefing for Janet 7-28-14v2.pptx

Hi Bill,
I received your vmail. Here is the updated slides for today – (b)(5) deliberative
Please feel free to share this with others on your team before today's discussion.
Happy to discuss if needed,
Sara

From: Ohrel, Sara
Sent: Friday, July 25, 2014 4:01 PM
To: Doster, Brian; Williams, Melina; Scott Jordan (Jordan.Scott@epa.gov); Hoffman, Howard; Lie, Sharyn; Camobreco, Vincent; Santiago, Juan; Kornylak, Vera S.; Culligan, Kevin; Koerber, Mike; Mangino, Joseph; Levy, Aaron; Montanez, Jessica; Stenhouse, Jeb; Deck, Leland
Cc: Suzanne Kocchi; Allen Fawcett; Bill Irving; Cole, Jefferson
Subject: RE: slides for Monday biomass briefing with Janet - deliberative

Hello everyone,

Attached is the final version we will use Monday (one update from OGC on slide 10 per Melina's email this am).

Thanks again and have a great weekend,
Sara

From: Ohrel, Sara
Sent: Thursday, July 24, 2014 3:59 PM
To: Doster, Brian; Williams, Melina; Scott Jordan (Jordan.Scott@epa.gov); Hoffman, Howard; Lie, Sharyn; Camobreco, Vincent; Santiago, Juan; Kornylak, Vera S.; Culligan, Kevin; Koerber, Mike; Mangino, Joseph; Levy, Aaron; Montanez, Jessica; Stenhouse, Jeb; Deck, Leland
Cc: Suzanne Kocchi; Allen Fawcett; Bill Irving; Cole, Jefferson
Subject: RE: slides for Monday biomass briefing with Janet - deliberative

Thank you all for your comments and edits. I incorporated them as well as those received from within OAP. Attached you will find the version we will use for the briefing Monday.
Thank you all again,
Sara

From: Ohrel, Sara
Sent: Wednesday, July 23, 2014 9:51 AM
To: Doster, Brian; Williams, Melina; Scott Jordan (Jordan.Scott@epa.gov); Hoffman, Howard; Lie, Sharyn; Camobreco, Vincent; Santiago, Juan; Kornylak, Vera S.; Culligan, Kevin; Koerber, Mike; Mangino, Joseph; Levy, Aaron; Montanez, Jessica; Stenhouse, Jeb; Deck, Leland
Cc: Suzanne Kocchi; Allen Fawcett; Bill Irving; Cole, Jefferson
Subject: slides for Monday biomass briefing with Janet - deliberative
Importance: High

Hello everyone,

In preparation for our meeting with Janet on biogenic emissions on Monday, we are sending you our draft slides. We need to finish edits and send the PPT to the OAR IO tomorrow, so please send us your suggested edits no later than close of business today.

Thank you,
Sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

-- this email and its contents are deliberative--do not distribute or cite --

From: Cole, Jefferson
To: Ohrel, Sara
Sent: 7/27/2014 12:59:07 PM
Subject: Apps I, K, L, N with corrected footnotes
Attachments: Appendix I Ref Pt CaseStudies OAQPS SP tb so RTI_clean (ftnte).docx; Appendix_K_Anticipated Baseline Construction Methods_5 1_oaqps_RTI_clean (ftnte).docx; Appendix_L_Anticipated Baseline Case Studies_5 1_oaqps_RTI_gl_7_23_14_clean (ftnte).docx; Appendix_N_Waste Derived Feedstocks_5_1_oaqps coburn jc_RTI_clean (ftnte).docx

Sara,

Per your request, here are the appendices from JB with the footnotes corrected. Appendix J, also sent earlier today, was already set to July.

If there is anything else you need today, let me know. I'll be out for most of the afternoon, but could have time later this evening.

Jeff

From:	Cole, Jefferson
To:	Ohrel, Sara
CC:	Baker, Justin
Sent:	7/27/2014 12:10:40 PM
Subject:	RE: Appendix D (feedstocks) *Deliberative*
Attachments:	Appendix_D_Feedstock Categories_5 1_oaqps jc2 (clean).docx; Appendix_D_Feedstock Categories_5 1_oaqps jc2.docx

Sara and Justin,

I made a small edit to the feedstock categories appendix (footer and font color), and attached the tracked changes and clean versions for use on Monday.

Thanks,

Jeff

From: Cole, Jefferson
Sent: Thursday, July 24, 2014 4:54 PM
To: Justin Baker
Cc: Ohrel, Sara; Greg Latta; Dr. Robert Beach
Subject: Fwd: Appendix D (feedstocks) *Deliberative*

Justin and team,

FYI, here's the latest version of Appendix D - Feedstock Categories.

Jeff

Begin forwarded message:

From: "Cole, Jefferson" <Cole.Jefferson@epa.gov>
Date: July 23, 2014 at 11:46:28 AM EDT
To: "Ohrel, Sara" <Ohrel.Sara@epa.gov>
Subject: Appendix D (feedstocks) *Deliberative*

This email is deliberative

Sara,

I have not had much luck in my searches so far for **Ex. 5 - Deliberative** Please advise on how you would like to proceed.

I've attached a version of Appendix D that has all of the edits we've discussed, as well as my response to the comments we received (which were just from OAQPS).

Thanks,

Jeff

Jefferson Cole
Economist
Climate Change Division
U.S. EPA
Desk: 202.343.9671
Mobile: 202.701.8795
cole.jefferson@epa.gov

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org); Cole, Jefferson
CC:	Robert H. Beach (rbeach@rti.org); Greg Latta
Sent:	7/27/2014 4:00:14 PM
Subject:	2 of 2 - DELIBERATIVE I-N and response
Attachments:	Appendix_I_Ref Pt CaseStudies 7 27df.docx; Appendix_J_Anticipated Baselines Background_7 27df.docx; Appendix_K_Anticipated Baseline Construction Methods_7 27.docx; Appendix_L_Anticipated Baseline Case Studies_7 27df.docx; Appendix_M_Summary of Illustrative Forest and Ag Case Studies_7 27df.docx; Appendix_N_Waste Derived Feedstocks_7 27df.docx; SAB_Response_Document_7 27df.docx

THANKS!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org); Cole, Jefferson
CC:	Robert H. Beach (rbeach@rti.org); Greg Latta
Sent:	7/27/2014 3:58:31 PM
Subject:	DELIBERATIVE 1 of 2; A-H
Attachments:	Appendix_A_IPCC_Emissions Inventory_7 27df.docx; Appendix_B_Temporal Scale_5 1_Final_RTI_jc (clean)2.docx; Appendix_C_Spatial Scale_7 27df.docx; Appendix_D_Feedstock Categories_7 27df.docx; Appendix_E_Discussion of Leakage Literature_7 27df.docx; Appendix_F_General Algebraic Representation_7.26df.docx; Appendix_G_Process_Atts_7.26_final.docx; Appendix_H_RefPt LandscapeAtts 7 27df.docx

THANK YOU all, especially Justin and Jeff, for helping getting these ready for delivery tomorrow. We will have a few odds and ends to clean up next week, but really made a great effort to get things looking really good!!!!

I am sending all current drafts (most will differ slightly to drafts just sent around as I went through them all and updated TOCs, footers on ones not updated to July, and other small edits and uncleaned up tracked changes); here is A-H

Thanks again!!!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org); Cole, Jefferson
CC:	Robert H. Beach (rbeach@rti.org); Greg Latta
Sent:	7/27/2014 1:38:41 PM
Subject:	DELIBERATIVE
Attachments:	Framework_Report_all comments_7 27_changessavedwcomments_soedits_cleanwcoms.docx; Framework_Report_all comments_7 27_draft final.docx

Hi all,
Attached is the current draft of the AF2 main report, as well as a commented version for our following on a few things next week. This is deliberative and not final. Please do not share or cite (RTI, you can share with others on your team involved on this, like Katie and Annah).
Thank you all,
Sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Cole, Jefferson
To: Ohrel, Sara
Sent: 7/27/2014 3:48:46 PM
Subject: Re: concept characterization *Deliberative*

Thanks, Sara.

I think this looks good. Let's include it in the Monday version. Agreed on the other items you brought up in the email before last.

Best,

Jeff

On Jul 27, 2014, at 3:10 PM, "Ohrel, Sara" <Ohrel.Sara@epa.gov> wrote:

How does this sound? New or edited language in red;

Ex. 5 - Deliberative

From: Ohrel, Sara
Sent: Sunday, July 27, 2014 2:30 PM
To: Cole, Jefferson
Subject: RE: concept characterization *Deliberative*

Hi Jeff,
Looking at this now and have a few comments (which I will incorporate into App D):

Ex. 5 - Deliberative

can in the time we have for tomorrow and we can discuss next week.
Thanks!

From: Fawcett, Allen
Sent: Tuesday, July 22, 2014 4:28 PM
To: Cole, Jefferson; Ohrel, Sara
Subject: RE: concept characterization *Deliberative*

Thanks Jeff, this looks good, though I don't have a citation handy for you to use.

From: Cole, Jefferson
Sent: Tuesday, July 22, 2014 4:14 PM
To: Fawcett, Allen; Ohrel, Sara
Subject: RE: concept characterization *Deliberative*

This email is deliberative

Hello Allen,

Ex. 5 - Deliberative

My question for you: is there is a citation that we could include alongside this new text that supports our consideration? If you do not have one handy, Sara and I should otherwise be able to find one.

Thanks,

Jeff

Appendix D: Section 3.1.3

Ex. 5 - Deliberative

From: Fawcett, Allen
Sent: Thursday, July 17, 2014 9:58 AM
To: Ohrel, Sara
Cc: Cole, Jefferson
Subject: RE: concept characterization

Here are my thoughts. Let me know if this is helpful.

Thanks,
Allen

Ex. 5 - Deliberative

Ex. 5 - Deliberative

From: Ohrel, Sara
Sent: Wednesday, July 16, 2014 5:51 PM
To: Fawcett, Allen
Subject: concept characterization

Hi Allen,
Can you check this to see if I have the general concept correct? If not, please set me straight.

Ex. 5 - Deliberative

Thanks.
And thanks again for all the support and patience today. It is deeply appreciated.

Sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Baker, Justin
To: Ohrel, Sara
CC: Cole, Jefferson
Sent: 7/27/2014 9:00:10 AM
Subject: RE: App K-- deliberative
Attachments: Appendix_K_Anticipated Baseline Construction Methods_5 1_oaqps_RTI_clean....docx

this email and all attachments are deliberative

Here is a clean version of App K to accompany the version with comments/track changes sent earlier in the week.

Justin

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Sunday, July 27, 2014 8:51 AM
To: Baker, Justin
Cc: Cole, Jefferson
Subject: Re: App N-- deliberative

Great, thanks for app N Justin!
OK, I will look for the excel now.

From: Baker, Justin
Sent: Sunday, July 27, 2014 8:48 AM
To: Ohrel, Sara
Cc: Cole, Jefferson
Subject: App N-- deliberative

Attached are edited and clean versions of App N (Waste)

Sara—I do not have the file that you and Greg used to build the FABA tables for App M—if there is such a spreadsheet. It's possible these were cut and pasted from somewhere. If you do have the file, can you please send that to me? I asked Greg for it as well. I checked my records but can't find a spreadsheet with these final tables.

Ex. 5 - Deliberative

Thanks,
Justin

From: Baker, Justin
Sent: Friday, July 25, 2014 4:42 PM
To: 'Ohrel, Sara'
Cc: Cole, Jefferson
Subject: RE: non-co2 - deliberative

Here is the section with a few minor edits. I think we need to Ex. 5 - Deliberative

Ex. 5 - Deliberative

Otherwise, it looks good!

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Friday, July 25, 2014 4:21 PM
To: Baker, Justin
Cc: Cole, Jefferson
Subject: non-co2 - deliberative

Hi Justin,
Can you please review Ex. 5 - Deliberative
Ex. 5 - Deliberative

Thanks!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From:	Ohrel, Sara
To:	Justin Baker (justinbaker@rti.org); Hanks, Katie P.
CC:	Cole, Jefferson
Sent:	7/26/2014 11:04:24 AM
Subject:	app G - deliberative
Attachments:	Appendix_G_Process_Atts_7.26_final.docx; Appendix_G_Process_Atts_oaqps_mkw_tb_so_RTI7-16-14_so.docx; Appendix_G_Process_Atts_oaqps_mkw_tb_so_RTI7-16-14_so_cleanv2so.docx

Hello everyone,
Thank you for your hard work on App G Process Attributes. It is a hard nut to crack but looks loads better. I am attaching 3 draft for record-keeping and for revisiting after Monday:
- my tracked changed atop of Katie's and Melina's
- a cleaner version that retains comments and has a few more edits
- Monday's (final) version.

Thanks!

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--

From: Hanks, Katie P.
To: Ohrel, Sara
CC: Baker, Justin
Sent: 7/25/2014 3:12:26 PM
Subject: RE: Biomass "conversion" description

Yes. Black liquor combustion results in heat and/or electricity generation. Black liquor is a form of biomass.

Katie Hanks
RTI International
3040 Cornwallis Road
Research Triangle Park, NC 27709
(919) 316-3732
(919) 541-7155 (fax)

From: Ohrel, Sara [mailto:Ohrel.Sara@epa.gov]
Sent: Friday, July 25, 2014 2:48 PM
To: Hanks, Katie P.
Cc: Baker, Justin
Subject: RE: Biomass "conversion" description

Thanks Katie. Would black liquor combustion also fall under 'biomass conversion'?

From: Hanks, Katie P. [mailto:kphanks@rti.org]
Sent: Friday, July 25, 2014 2:47 PM
To: Ohrel, Sara
Cc: Baker, Justin
Subject: Biomass "conversion" description

Below is a general description of "biomass conversion:"

Biomass conversion technologies convert biomass into energy directly, in the form of heat or electricity, or may convert it to another form, such as liquid biofuel or combustible biogas. Examples of biomass conversion processes include biomass-fired or co-fired boilers, biomass gasification or pyrolysis systems, ethanol fermentation processes, and anaerobic digesters.

Katie Hanks
RTI International
3040 Cornwallis Road
Research Triangle Park, NC 27709
(919) 316-3732
(919) 541-7155 (fax)

From: Baker, Justin
To: Ohrel, Sara; Cole, Jefferson; Latta, Greg (greg.latta@oregonstate.edu)
Sent: 7/25/2014 4:26:13 PM
Subject: App K -- Deliberative
Attachments: Appendix_K_Anticipated Baseline Construction Methods_5 1_oaqps_RTI.docx

this email and all attachments are deliberative

All,

Here is App K, where I've made a minor change to reflect **Ex. 5 - Deliberative**
Ex. 5 - Deliberative

Justin

From:	Ohrel, Sara
To:	Cole, Jefferson; Justin Baker (justinbaker@rti.org)
Sent:	7/25/2014 1:43:04 PM
Subject:	deliberative - draft af2
Attachments:	Framework_Report_all comments_7 25_v4.docx

Hi all,
Attached in all its glory is the revised AF2, with its 2000+ edits and comments – not for your review or actions at this point, but 1) to make sure I am not the only person with a copy and 2) in case you are interested. I will next accepted changes and then run through to clean it up. There are a few small things that I may need help on today (like updating graphics or other things) but I don't know them off the top of my head currently but I will know after I run through a cleaner version.
sara

Sara Bushey Ohrel
Climate Economics Branch
Climate Change Division
U.S. Environmental Protection Agency
Phone: (202) 343-9712
Cell: (202) 341-6748

--this email and its content are deliberative--do not distribute or cite--