Example 2.3:

Using the data in Tables 2.1 and 2.2, the estimated average annual energy savings from a large tree located opposite a west facing wall of a house in the Midwest Region will be 268 kWh in cooling (electricity) savings and 3,146 kBtu (or 3,146,000 Btu, as 1 kBtu = 1,000 Btu) in heating/natural gas savings.

REDUCED ENERGY FROM REDUCED WATER TREATMENT

As mentioned earlier, it is important to recognize the off-site means by which green infrastructure practices also reduce energy use through reduced water treatment needs in communities with combined sewer systems. While the "Water" section has already accounted for the cost savings of this reduction (i.e. the "valuation" step of this direct benefit), the reduction in energy use will also provide indirect air and climate benefits from reduced emissions, which will be discussed later. Because of these indirect benefits, it is necessary to quantify the amount of energy reduced from water treatment.

To estimate the energy savings from reduced water treatment needs, it is necessary to have calculated the nega-gallons (i.e. gallons of reduced stormwater runoff) resulting from green infrastructure practices, as estimated in the "Water" section.

Table 2.3 outlines how much energy (kWh) is consumed per million gallons of water treated by six different treatment plant sizes using four different types of treatment methods. These should be referenced as default values only when calculating the energy savings from reduced treatment. Local utilities can provide more site-specific figures.

Table 2.3

	Unit Electricity Consumption | kWh/million gallons			
Treatment Plant Size million gallons/day	Trickling Filter	Activated Sludge	Advanced Wastewater Treatment	Advanced Wastewater Treatment Nitrification
1 MM gal/day	1,811	2,236	2,596	2,951
5 MM gal/day	978	1,369	1,573	1,926
10 MM gal/day	852	1,203	1,408	1,791
20 MM gal/day	750	1,114	1,303	1,676
50 MM gal/day	687	1,051	1,216	1,588
100 MM gal/day	673	1,028	1,188	1,558

Source: EPRI 2002

Example 2.4:

Referring back to Example 1.1 and relying on the default values in Table 2.3, it is possible to estimate the energy saved from reduced water treatment needs from a green roof. If water treatment needs are reduced by 71,100 gallons in an area with an advanced wastewater treatment nitrification plant with a 100 MM gal/day capacity, electricity consumption could be reduced as follows:

71,100 gal saved = 0.0711 million gal saved

0.0711 million gal * 1,558 kWh/million gal = 110.77 kWh

Thus, the 5,000 SF green roof example contributes to an annual electricity savings from reduced water treatment needs of 110.77 kWh.

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STEP 2 - VALUATION OF QUANTIFIED BENEFITS: REDUCED ENERGY USE

Having calculated the direct kWh and Btu saved in reduced building energy use, it is possible to assign a dollar value to these savings. Again, note that energy savings resulting from reduced water treatment needs have previously been accounted for and should NOT be valued here. The kilowatt hours of reduced energy from reduced water treatment should be carried directly to the "Air Quality" and "Climate Change" sections to be valued there. (In other words, the answer from Example 2.6 is not valued here, but this figure will be used later to calculate indirect emissions benefits.)

One may calculate the direct cost savings by multiplying the kilowatt hours or Btus of electricity and natural gas, respectively, by local utility rates. If local utility rates are not available, use national average retail electricity and natural gas prices.

The values below represent the U.S. average retail price for electricity for April 2010 and the 2010 forecast retail price for natural gas (US EIA 2010).

The following two equations provide a formula for calculating the value of cooling (kWh) and heating (Btu) savings respectively and rely on these national utility rate averages:

kWh reduced * $0.0959/kWh
= value of cooling or electricity savings

Btu reduced * $0.0000123/Btu
= value of heating natural gas savings

Example 2.5:

Using the cooling savings from Example 2.1 and the heating savings from Example 2.2, the following example calculates the annual direct cost savings provided by a 5,000 SF green roof:

0.2244 kWh/SF for cooling savings * 5,000 SF * $0.0959/kWh = $107.60 annual cooling or on-site electricity savings

7,231.75 Btu/ SF for heating * 5,000 SF * $0.0000123/Btu = $444.75 annual heating natural gas savings

The combined benefits from the green roof result in an average annual on-site energy savings of $552.35.

Example 2.6:

Referencing Tables 2.1 and 2.2 and the cost saving established in Example 2.5, if a house in the Midwest Region has one large tree located opposite a west-facing wall, the direct cost savings can be calculated as:

268 kWh * $0.0959 = $25.70 annual cooling or on-site electricity savings

3,146,000 Btu * $0.0000123 = $38.70 annual heating natural gas savings

The combined benefits from the large tree result in an average annual on-site energy savings of $64.40.

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3. AIR QUALITY

STEP 1 - QUANTIFICATION OF BENEFIT: REDUCED CRITERIA POLLUTANTS

This section quantifies the direct (uptake and deposition) and indirect (avoided emissions) air quality impacts of green infrastructure and provides instructions for valuing these impacts in monetary terms. The criteria pollutants addressed here are nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2) and particulate matter of aerodynamic diameter of ten micrometers or fewer (PM-10).

Practices that provide a direct benefit of uptake and deposition include green roofs, trees and bio-infiltration.

GREEN ROOFS

Direct air quality benefits from green roofs depend on several local factors. Different plant species take up pollutants at different rates, so the type of species planted will influence the magnitude of air quality improvement. Local climate factors also influence plants' air quality effects. In cold weather climates, plant uptake will be lower during seasons when plants may be covered in snow. Climates with longer growing seasons will see greater air quality improvements, all else being equal, than those with shorter seasons.

To estimate the direct benefits of green roofs on air quality, we recommend the following range of values as an initial order of magnitude approximation of annual pounds of pollutant removed per square foot of practice installed:

Table 3.1

	Low (lbs/SF)	High (lbs/SF)
NO_2	3.00×10^{-4}	4.77×10^{-4}
O_3	5.88×10^{-4}	9.20×10^{-4}
SO_2	2.29×10^{-4}	4.06×10^{-4}
PM-10	1.14×10^{-4}	1.33×10^{-4}

Source: Currie and Bass (2008) and Yang, Qian and Gong (2008)

The following equation illustrates how to quantify the direct benefit received based on the area of the practice and the average pollutant uptake/deposition for that practice:

area of practice (SF) *
average annual pollutant uptake/deposition (lbs/SF)
= total annual air pollutant uptake/deposition (lbs)

Keep in mind that the subsequent example calculations will only walk through the quantification of reduced NO_2. Other criteria pollutants will not be illustrated, but they should be calculated when conducting a comprehensive benefit analysis.

Example 3.1:

Using the above equation, a 5,000 SF green roof could lead to an improved direct nitrogen dioxide (NO_2) uptake capacity as follows:

Lower Bound (using 3.00×10^{-4} lbs/SF/yr)
*5,000 SF * 3.00×10^{-4} lbs/SF = 1.50 lbs total annual NO_2 uptake*

Upper Bound (using 4.77×10^{-4} lbs/SF/yr)
*5,000 SF * 4.77×10^{-4} lbs/SF = 2.39 lbs total annual NO_2 uptake*

In this case, the 5,000 SF green roof would on average take up between about 1.50 and 2.39 pounds of NO_2 annually.

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TREE PLANTING

Climate zone, existing air quality and pollutant levels, and the size, age and type of tree all play a role in determining the uptake potential of tree planting.

The Forest Service *Tree Guides* estimate the level of air quality benefits from trees according to climate zone. The tables in the guides' appendices are structured based on the size of the tree (with example tree types provided) and the location of the tree with respect to a surrounding building. One can then estimate air quality benefits based on these factors (on a per tree basis) using the "Uptake and Avoided" data provided in the *Tree Guides*' appendices.

As an example, Table 3.2 shows the 40-year average air quality impacts from trees in the Midwest Climate Region.

Table 3.2
Annual Criteria Pollutant Reductions (uptake and avoided) from 1 tree, 40-year average, Midwest Region

	Small tree: **Crabapple** (22 ft tall, 21 ft spread)	Medium tree: **Red Oak** (40 ft tall, 27 ft spread)	Large tree: **Hackberry** (47 ft tall, 37 ft spread)
NO_2 Uptake and Avoided	0.39 lbs	0.63 lbs	1.11 lbs
SO_2 Uptake and Avoided	0.23 lbs	0.42 lbs	0.69 lbs
O_3 Uptake	0.15 lbs	0.2 lbs	0.28 lbs
PM-10 Uptake and Avoided	0.17 lbs	0.26 lbs	0.35 lbs

Source: McPherson, E. et al. 2006

The following equation illustrates how to reach a quantified benefit from a tree planting:

no. of trees * average annual uptake and avoided pollutant emissions (lbs/tree) = total annual air pollutant reduction (lbs)

Example 3.2:
Given the data from Table 3.2, it is possible to use the above equation to determine the annual nitrogen dioxide (NO_2) benefit of 100 medium-sized trees planted in the Midwest Region.

*100 medium trees * 0.63 lbs NO_2/tree = 63 lbs total annual NO_2 reduction*

Figures provided by the *Tree Guides* for criteria air pollutant abatement include both the direct (uptake and deposition) and indirect (avoided power plant emissions) benefits, which must be kept in mind in order to avoid double-counting these benefits in later calculations. Once a total abatement figure is reached, it is possible to move directly to calculating the monetary value of that tree practice, as outlined in the "Valuation of Quantified Benefits" section.

BIORETENTION AND INFILTRATION

Although many studies agree that vegetative infrastructure elements such as bioswales, rain gardens and other bio-infiltration techniques can provide considerable air quality benefits, there is currently a lack of scientific research measuring and quantifying the direct air pollution uptake potential of these practices. Without studies that derive specific uptake values for

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bio-infiltration practices, this guide cannot provide the steps to calculate the direct uptake benefit at this time, as further field research and data collection is needed.

Once an average value is quantified (in lbs/SF), provided sufficient research data is published, it can be substituted into the equation below:

total area of practice (SF) * average annual uptake/ deposition (lbs /SF)
= total annual pollutant uptake/deposition (lbs)

This equation could then be used to derive the total air pollutant uptake benefit for a given bioswale or rain garden and later to monetize the practice's direct uptake benefit.

Indirect Benefits

As stated above, this section quantifies not only the direct (uptake and deposition) means by which air quality is improved, but also the indirect means (avoided emissions) that provide air quality improvements.

Practices that indirectly lower emissions of air pollution include any practices that reduce energy consumption through decreased energy use in neighboring buildings or through reduced water treatment needs. These benefits are quantified in the "Energy" section, and they should be accounted for here to estimate in pounds the reduction of criteria air pollutants stemming ultimately from reduced water treatment.

The production of electricity in fossil fuel power plants entails the emission of nitrogen dioxide and sulfur dioxide. Furthermore, the burning of natural gas in homes and businesses produces additional indirect air pollutant emissions. In order to quantify this impact, multiply the estimated electricity use reduction calculated here in the "Energy" section by emissions factors provided by the US EPA. It is important to keep in mind that the net air quality benefit from trees was already calculated above, so to avoid double counting, do not recalculate the reduced pollutants from trees here.

The following equations are used to calculate the total avoided criteria pollutant emissions from reduced energy usage in terms of electricity and natural gas, respectively. Specific practice-based calculations follow from the calculations completed in the "Energy" section and do not require additional individual explanation.

Benefit from kWh of Electricity Saved

annual electricity reduction (kWh) * emissions factor (lbs/kWh)
= annual avoided pollutant emissions (lbs)

In its online eGRIDweb application, the USEPA provides the following figures for estimated annual output emissions rates of national electricity production:

- **NO_2: 1.937 lbs/MWh » 0.001937 lbs/kWh**
- **SO_2: 5.259 lbs/MWh » 0.005259 lbs/kWh**

Source: USEPA 2005

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Please note that although power plants and electricity generators emit both ozone and certain particulates into the atmosphere, data could not be found to quantify the emissions factors for those variables.

Example 3.3:
Using the example 5,000 square foot green roof again, remember the annual cooling savings determined in Example 2.1:

*5,000 SF * 0.2244 kWh/SF = 1,122 kWh in cooling savings annually*

Given the reduced electricity use of 1,122 kWh, the NO_2 emission benefits from that reduction are:

*1,122 kWh * 0.001937 lbs/kWh = 2.17 lbs avoided NO_2 emissions from cooling savings annually*

More locally-specific figures can be found in the eGRIDweb application. This tool provides emission rates by state, grid region and power plant or generating company.

Benefit from Btu of Heating Natural Gas Saved

annual heating natural gas savings (Million Btu) * emissions factor (lbs/Million Btu) = annual avoided criteria pollutant emissions (lbs)

In the same online eGRIDweb application used previously, the USEPA provides the following figures for the national annual emission factors per Btu of natural gas input:

- **NO_2: 0.721 lbs/Million Btu**
- **SO_2: 0.266 lbs/Million Btu**

Source: USEPA 2005

Please note that although the burning of natural gas emits both ozone and certain particulates into the atmosphere, data could not be found to quantify the emissions factors for those variables.

Example 3.4:
Using the example 5,000 square foot green roof again, remember the annual heating natural gas savings (Btu) determined in Example 2.2:

*7,231.75 Btu/SF * 5,000 SF = 36,158,750 Btu = 36.15875 Million Btu annually in heating natural gas savings*

Given the reduced heating natural gas use of 36.15875 Million Btu and using the US EPA emissions factors above of 0.721 lbs NO_2 / Million Btu, the NO_2 emission benefits from that reduction are:

*36.15875 Million Btu * 0.721 lbs NO_2/Million Btu = 26.07 lbs avoided NO_2 emissions from heating natural gas savings annually*

Total Benefit from Electricity and Heating Natural Gas Savings

Now that the indirect air quality benefits from electricity and natural gas savings have been quantified, the pounds of criteria pollutants calculated from both can be added together. This summation will make the later valuation calculation less complicated.

annual avoided pollutant emissions from reduced electricity (lbs) + annual avoided criteria pollutant emissions from reduced heating natural gas (lbs) = total avoided criteria pollutant emissions from electricity and heating natural gas savings annually

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Example 3.5:
Taking the answers from Examples 3.3 and 3.4, the total indirect benefit from electricity and heating natural gas savings can be quantified as:

2.17 lbs avoided NO_2 (Example 3.3) + 26.07 lbs avoided NO_2 (Example 3.4) = 28.24 lbs avoided NO_2 emissions from reduced cooling and heating energy use annually.

Now, one can quantify the total air quality benefit by adding together the total direct criteria pollutant uptake/deposition benefit and the total indirect avoided emissions benefit (from reduced energy use) for each practice.

Σ total criteria pollutant uptake/deposition benefit (lbs) + total avoided criteria pollutant emissions (lbs) = total annual criteria pollutant reduction benefit (lbs)

STEP 2 - VALUATION OF QUANTIFIED BENEFITS: REDUCED CRITERIA POLLUTANTS

In order to arrive at a value for the benefits of air quality improvements from green infrastructure, one must estimate the price or cost (per pound) of the standard air pollutants discussed in this guide.

The following numbers represent US Forest Service recommendations for valuation of criteria air pollutants:

- **NO_2 = $3.34/lb**
- **SO_2 = $2.06/lb**
- **O_3 = $3.34/lb**
- **PM-10 = $2.84/lb**

Source: McPherson et al. (2006), Wang and Santini (1995)

The equation below allows for valuation of air quality benefits derived from using green infrastructure practices:

total annual criteria pollutant reduction benefit (lbs) * price of criteria pollutant ($/lb) = total value of pollutant reduction ($)

Example 3.6:
Recall that Example 3.1 found that a hypothetical 5,000 SF green roof yields an annual nitrogen dioxide (NO_2) uptake benefit between 1.50 and 2.39 pounds of NO_2 reduction, or an average of 1.95 pounds. Furthermore, Example 3.5 found the same roof yields 28.24 pounds of indirect NO_2 reduction. Notice that these figures are the same resource unit and can be summed as follows:

$\sum$ 1.95 lbs NO_2 + 28.24 lbs NO_2 = 30.19 lbs NO_2

Given the above valuation equation and a price per pound of NO_2 of $3.34/lb, the following calculation determines the monetary value of the on-site uptake and off-site emissions benefits, as follows:

*30.19 lbs NO_2 * $3.34/lb NO_2 = $100.83*

Thus, the green roof would lead to a monetary benefit from on-site and off-site NO_2 benefits of about $100.83 annually.

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The Role of Permeable Pavement in Improving Air Quality

In addition to green roofs, trees, and bioretention and infiltration practices, permeable pavement can also improve air quality and reduce atmospheric CO_2. Permeable pavement reduces the amount of water treatment needed by allowing stormwater to infiltrate on site, in turn reducing air pollution and CO_2 emissions from power plants. It also decreases ground level ozone formation and helps to lower pavement surface temperatures by reducing the amount of heat absorbed. This helps to cool the air and decrease the amount of energy needed for cooling. It also mitigates the urban heat island effect.

A recent study comparing pervious concrete to traditional pavement found that "...while the pervious concrete becomes hotter than the surrounding air temperature during the daytime much less heat is transferred and stored in the underlying soil than the traditional pavement. Even though the pervious concrete became warmer than the traditional [concrete], at night the pervious concrete was equal to or cooler than the [traditional concrete] pavement. This indicates less heat storage potential and a greater rate of cooling in the pervious concrete versus the traditional system" (Kevern, J.T. et al. 2009b).

While research has demonstrated the ability of permeable pavement to improve air quality and reduce atmospheric CO_2, not enough data exists to walk through a valuation of these benefits at this time.

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4. CLIMATE CHANGE

STEP 1 - QUANTIFICATION OF BENEFIT: REDUCED ATMOSPHERIC CO_2

This section provides instructions on how to quantify and value direct (sequestration) and indirect (avoided emissions) climate benefits. While recognizing that there are other types of greenhouse gases that contribute to climate change, the focus in this section is specifically on the climate benefits of reducing atmospheric CO_2, as this is the greenhouse gas most directly affected by green infrastructure. A similar framework can be used to value the climate impacts of those other gases, particularly when they are put in terms of CO_2-equivalents. Outlining those additional steps, however, is outside the scope of this guide.

Green infrastructure practices specifically addressed in this section for their direct benefit of carbon sequestration include green roofs, trees and bio-infiltration. The authors acknowledge that there are additional climate benefits from other practices, such as permeable pavement, which cannot be explicitly quantified at this time due to the infancy of the research surrounding this benefit within those practices. Finally, it is important to note that sequestration benefits only last as long as the plants or trees are alive and that they vary with the age of the vegetation.

The following equation is used to quantify the amount of carbon sequestered for a given area and green infrastructure practice, keeping in mind that the pounds of carbon sequestered per unit area depend on several local factors, including the specific practice, the types of species planted and the local climate:

total area of practice (SF) *
average annual amt. of carbon sequestered (lbs C /SF)
= annual amount of carbon sequestered (lbs C)

It is important to note that a common point of confusion when quantifying carbon sequestration benefits is how many pounds of CO_2 are avoided from a certain amount of stored carbon. Due to the molecular structures involved, the pounds of carbon stored in plants do not equal the pounds of carbon dioxide that are removed from the atmosphere (because an atom of carbon has a smaller atomic mass than a carbon dioxide molecule). Employ the following conversion factor ($^{44}/_{12}$ or 3.67) to arrive at the equivalent CO_2 impacts of a specific carbon sequestering practice.

GREEN ROOFS

Research synthesized in a Michigan State University report offers average carbon sequestration values provided by extensive green roofs' aboveground biomass (Getter et al. 2009). Using the data from that report, it is possible to arrive at an estimated range of carbon sequestration per square foot for similarly implemented extensive green roofs. Because one of the two studies lacks belowground sequestration figures, this guide does not take belowground biomass into account when determining the recommended range. (See below.) As such, the given range may provide an underestimate of the practice's full sequestration potential. Further field research and data collection are needed in order to more precisely determine the full carbon sequestration potential of green roofs.

The recommended range of grams of carbon sequestered per square meter from aboveground biomass, as determined by

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the averages of the two Michigan State University studies (which include data from extensive green roofs surveyed in both Michigan and Maryland), is as follows:

162 g C/m² to 168 g C/m² (Getter et al. 2009)

Converting to lbs C/SF from metric units[2], the range can be defined: 0.0332 lbs C/SF to 0.0344 lbs C/SF

Example 4.1:

A hypothetical 5,000 SF extensive green roof provides an estimated carbon sequestration capacity as follows:

Lower Bound (using 0.0332 lbs C/SF)
0.0332 lbs C/SF * 5,000 SF = 166 lbs of carbon per year

Upper Bound (using 0.0344 lbs C/SF)
0.0344 lbs C/SF * 5,000 SF = 172 lbs of carbon per year

In this case, the hypothetical 5,000 SF extensive green roof would sequester between about 166 and 172 pounds of carbon annually, or an average of 169 pounds of carbon per year.

TREE PLANTING

Local conditions—such as climate zone, existing air conditions and season—as well as size, age and species type all play a role in determining the carbon sequestration potential of a tree.

The referenced Forest Service *Tree Guides* provide an estimate of the level of CO_2-related benefits from trees according to climate zone. Once the climate zone is determined, the tables in the tree guides' appendices are structured on the basis of size of tree (with example tree types provided) as well as the location of the tree with respect to a surrounding building. Climate benefits can then be estimated based on these factors (on a per tree basis) using the "Net CO_2" data provided in the tree guides' appendices. These benefits vary by region and according to energy sources.

As an example, Table 4.1 shows the 40-year average CO_2 benefits from trees in the Midwest Climate Region.

Table 4.1: Annual Net CO_2 (lbs) Benefits from 1 tree, 40-year average, Midwest Region

Net CO_2 (lbs)	Residential Yard Opposite West-Facing Wall	Residential Yard Opposite South-Facing Wall	Residential Yard Opposite East-Facing Wall	Public Tree on a Street or in a Park
Small tree: Crabapple (22 ft tall, 21 ft spread)	390	226	335	336
Medium tree: Red Oak (40 ft tall, 27 ft spread)	594	212	487	444
Large tree: Hackberry (47 ft tall, 37 ft spread)	911	665	806	734

Source: McPherson, E. et al. 2006

[2] Converting g C /m² into lbs. C/SF, we multiply the metric units by a conversion factor 0.00220462262 lbs/g to arrive at lbs C/m², then we multiply by a conversion factor of 0.09290304 m² /SF to arrive at the desired lbs C/SF

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Example 4.2:
Given the data in Table 4.1, it is possible to determine the benefits of planting 100 medium trees in a public space. In this case, the number of trees planted is used instead of the amount of vegetated area in the equation to arrive at the final figure:

number of medium trees planted * total CO_2 abated (lbs /tree) = total annual climate benefit (direct and indirect) (lbs CO_2)

100 medium trees * 444 lbs total CO_2/tree = 44,400 lbs of total annual CO_2 abatement

Please note that these "total CO_2" figures include both direct (sequestration) and indirect (avoided power plant emissions) benefits for trees, to avoid double-counting these benefits in later calculations. Once an abatement figure is reached, it is possible to calculate the monetary value of the green infrastructure practice following the steps outlined in the "Valuation of Quantified Benefits: Reduced Atmospheric CO_2" section. Notice also that the above figure is already in "pounds of CO_2,"thus no conversion from carbon to CO_2 will be necessary.

BIORETENTION AND INFILTRATION

Although many studies agree that vegetative infrastructure such as bioswales, rain gardens, and other bio-infiltration techniques can provide a considerable amount of carbon sequestration benefit, there is a current lack of scientific research measuring and quantifying the sequestration potential of those practices. Without studies that demonstrate average values for the carbon sequestration potential per square foot of certain bio-infiltration practices, this guide cannot provide the steps to estimate the direct benefit.

Once an average value is quantified (in lbs/SF), it can be used in the equation below:

total area of practice (SF) * average annual amt. of carbon sequestered (lbs C /SF) = annual amt. of carbon sequestered (lbs C)

Once it is possible to determine the total amount of carbon sequestration for a given bioretention or infiltration practice, the resulting pounds can be used to monetize the practice's direct sequestration benefit.

Indirect Benefits

As previously stated, this section quantifies the direct (sequestration) means by which CO_2 is reduced. It also quantifies the indirect means (avoided emissions) that provide climate change improvements.

Practices that provide an indirect benefit of avoided emissions include any practice that reduces energy consumption through reduced energy use in a neighboring building or through reduced water treatment needs. The "Energy" section quantifies these benefits, and they should now be accounted for to estimate the reduced pounds of criteria pollutants.

This section outlines a process for calculating the total avoided CO_2 emissions from reduced energy usage. Specific practice-based calculations follow from the calculations completed in the "Energy" section.

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Benefit from kWh of Electricity Saved

The first step toward calculating the total avoided CO_2 emissions is to quantify the amount of electricity (in kWh) saved for a given area and green infrastructure practice. GI practices will reduce energy consumption on site as well as off site at water treatment facilities. These energy reductions depend on several local factors, including the specific practice, the types of species planted and local climate. The total annual electricity-saved calculation from the "Energy" section can be substituted into the equation below to calculate the total pounds of avoided CO_2:

total annual electricity saved (kWh) * lbs CO_2 /kWh = lbs annual avoided CO_2 emissions from practice's electricity savings

Because the amount of CO_2 emissions from power plants varies depending on the electricity source (e.g. coal, nuclear, wind, etc), use Table 4.2 to specify the appropriate figure for "**lbs CO_2 /kWh**" (in the above equation) given the specific region under consideration.

Example 4.3:

Using the example 5,000 SF green roof again, remember the annual building electricity savings determined in Example 2.1 and the water treatment electricity savings determined in Example 2.4:

total electricity savings from a 5,000 SF green roof = 1,122 kWh in building electricity savings + 110.77 kWh in water treatment electricity savings = 1,232.77 kWh annually

Using the U.S. average of 1.33 lbs CO_2/kWh from Table 4.2, the reduced electricity savings would provide the following indirect climate benefit:

1,232.77 kWh * 1.33 lbs CO_2/kWh = 1,639.58 lbs avoided CO_2 emissions from reduced electricity annually

Table 4.2
Year 2005 eGRID Subregion Emissions, CO_2 Greenhouse Gas

eGRID Subregion Acronym	eGRID Subregion Name	CO_2 Output Emission Rate (lb CO_2/KWh)
AKGD	ASCC Alaska Grid	1.23236
AKMS	ASCC Miscellaneous	0.49886
AZNM	WECC Southwest	1.31105
CAMX	WECC California	0.72412
ERCT	ERCOT All	1.32435
FRCC	FRCC All	1.31857
HIMS	HICC Miscellaneous	1.51492
HIOA	HICC Oahu	1.81198
MORE	MRO East	1.83472
MROW	MRO West	1.82184
NEWE	NPCC New England	0.92768
NEWPP	WECC Northwest	0.90224
NYCW	NPCC NYC/Westchester	0.81545
NYLI	NPCC Long Island	1.5368
NYUP	NPCC Upstate NY	0.7208
RFCE	RFC East	1.13907
RFCM	RFC Michigan	1.56328
RFCW	RFC West	1.53782
RMPA	WECC Rockies	1.88308
SPNO	SPP North	1.96094
SPSO	SPP South	1.65814
SRMV	SERC Mississippi Valley	1.01974
SRMW	SERC Midwest	1.83051
SRSO	SERC South	1.48954
SRTV	SERC Tennessee Valley	1.51044
SRVC	SERC Virginia/Carolina	1.13488
U.S.		1.32935

Source: USEPA 2008c

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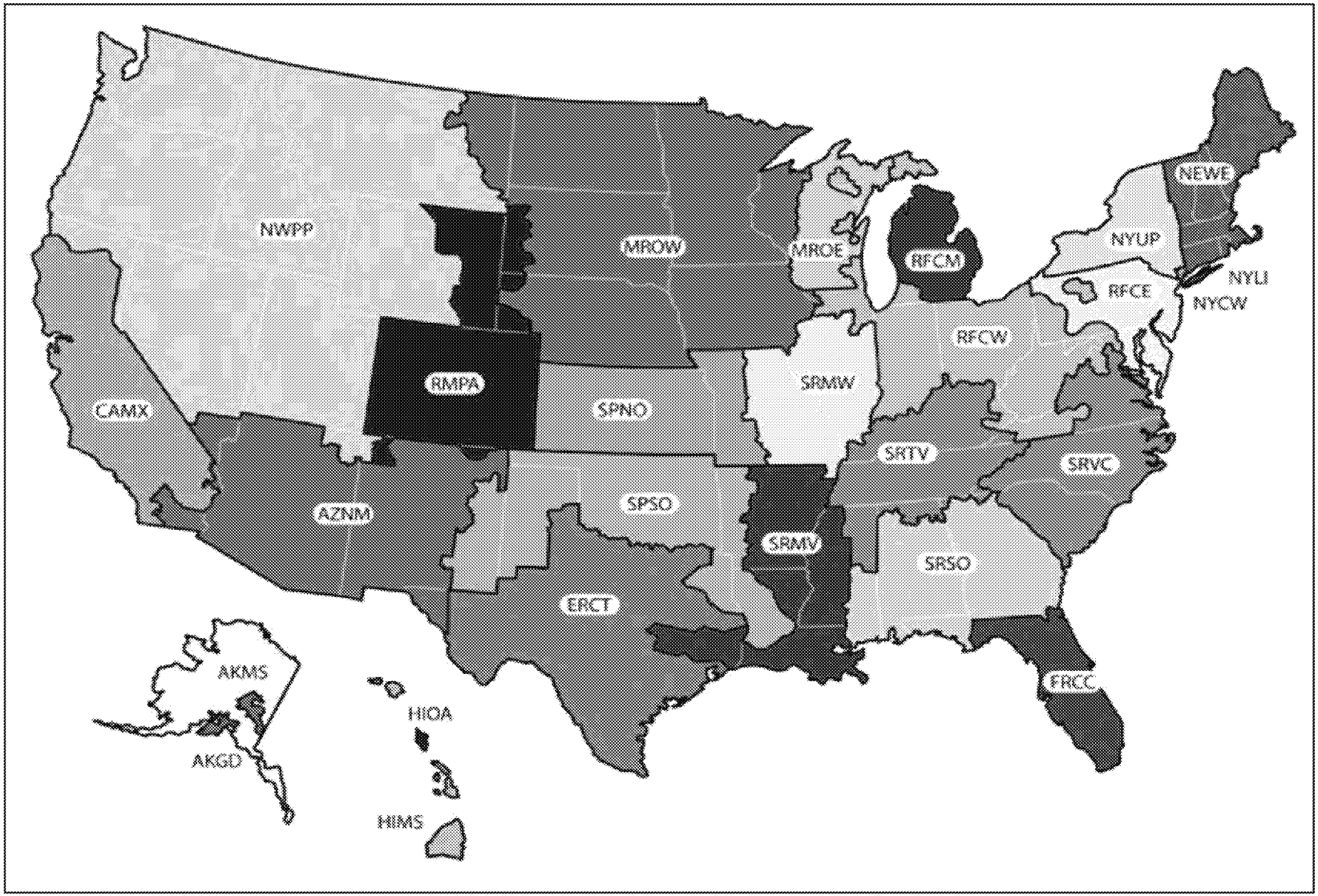
Year 2005 eGRID Subregion Emissions, CO_2 Greenhouse Gas



Source: USEPA 2008c

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Benefit from Btu of Natural Gas Saved

Using the calculation of reduced natural gas from the "Energy" section, the total amount of avoided CO_2 emissions for the given area and green infrastructure practice can be estimated using the following equation:

total heating natural gas saved (Million Btu) * lbs CO_2 /Million Btu = lbs of avoided CO_2 emissions annually from heating natural gas savings

Note that the previous equation relies on the CO_2 emissions factor of 116.89 lbs CO_2/Million Btu of natural gas[3] (i.e. the number of pounds of CO_2 released per million Btu) (US EPA 2009).

Example 4.4:

Using the example 5,000 SF green roof again, remember the annual heating natural gas savings (Btu) determined in Example 2.2:

7,231.75 Btu/SF * 5,000 SF = 36,158,750 Btu = 36.15875 Million Btu annually in heating natural gas savings

Using the CO_2 emissions factor above of 116.89 lbs CO_2/Million Btu, the reduced natural gas savings would provide the following indirect climate benefit:

36.15875 Million Btu * 116.89 lbs CO_2/Million Btu = 4,226.6 lbs avoided CO_2 emissions from reduced natural gas annually

[3] Converting the USEPA Code of Federal Regulations standard of 53.02 kg CO_2 / Million Btu into lbs CO_2 /Million Btu, multiply the metric units by a conversion factor of 2.20462262185 lbs/kg to arrive at the desired lbs CO_2/ Million Btu.

Total Benefit from Electricity and Heating Natural Savings

Now that the indirect benefits from electricity and natural gas savings have been quantified, the pounds of CO_2 from both calculations can be added together. This summation will make the later valuation calculation less complicated.

lbs avoided CO_2 emissions from electricity savings + lbs avoided CO_2 emissions from heating natural gas savings = total lbs avoided CO_2 emissions from electricity and heating natural gas savings annually

Example 4.5:

Recall that Example 4.3 calculated the annual avoided CO_2 from electricity of the 5,000 SF green roof and that the annual avoided CO_2 from natural gas savings was calculated in Example 4.4. Notice that these figures are the same resource unit and can be summed as follows:

1,639.58 lbs CO_2 + 4,226.6 lbs CO_2 = 5,866.18 lbs avoided CO_2 emissions from reduced building cooling and heating and reduced water treatment energy use annually

Now, the total benefit can be quantified by adding together the total carbon sequestered and the total CO_2 emissions avoided (from reduced energy use) for each practice. To do so, any carbon sequestration benefit (lbs C) must be converted, as previously mentioned, to its CO_2 equivalent.

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To convert pounds of carbon sequestered into pounds of carbon dioxide equivalent:

total lbs carbon sequestered (lbs C) * 3.67 lbs CO_2/lb C = total annual equivalent sequestration benefit (lbs CO_2)

Then, the user can combine the direct (sequestration) and indirect (off-site avoided emissions) benefits into a figure for the total climate benefit, as follows:

Σ total equivalent sequestration benefit (lbs CO_2) + total avoided CO_2 emissions (lbs CO_2) = total annual climate benefit (lbs CO_2)

An example of this calculation will follow; please refer to Example 4.6.

STEP 2 - VALUATION OF QUANTIFIED BENEFITS: REDUCED ATMOSPHERIC CO_2

With the total pounds of CO_2 reduced, the following equation estimates the monetary value:

total climate benefit (lbs CO_2) * price of CO_2 ($/lb) = total annual value of climate benefit ($)

Example 4.6:

Following from Example 4.1, which quantified the direct and indirect climate benefits of a hypothetical 5,000 SF green roof, it was found that the green roof sequestered between 166 and 172 pounds of carbon per year. (An average of 169 pounds of carbon is used below.) In Example 4.5, this green roof had the indirect benefit of avoiding 5,866.18 lbs of CO_2 emissions from reduced energy use. One can calculate the monetary value of the total climate benefit as follows:

169.0 lbs C * 3.67 lbs CO_2/lb C = 620.23 lbs CO_2 in total annual sequestration benefit

5,866.18 lbs CO_2 in total annual indirect emissions benefit (Example 4.5)

Σ 620.23 lbs CO_2 + 5866.18 lbs CO_2 = 6486.41 lbs CO_2 in total annual climate benefits

This total climate benefit can be valued by multiplying by a price for carbon. In the following parts (4.6.a. and 4.6.b.), the guide walks through calculations of a lower and upper bound for valuing these carbon benefits.

Example 4.6.a:

Lower Bound: EU ETS Carbon Price of $0.00756 / lb CO_2

*6,486.41 lbs CO_2 * $0.00756 / lb CO_2 =*
$49.04 monetary value of the total annual climate benefits

This lower-bound calculation shows that the hypothetical green roof could provide about $49.04 in annual climate change benefits.

Example 4.6.b:

Upper Bound: Stern's Value of $0.0386/lb CO_2

*6,486.41 lbs CO_2 * $0.0386/lb CO_2 =*
$250.38 monetary value of the total annual climate benefits

This upper-bound calculation shows that the hypothetical green roof could provide about $250.38 in annual climate change benefits.

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Pricing Carbon

To complete the valuation of the direct and indirect climate benefits for a given practice, a monetary price for carbon must be determined. In other words, it is necessary to assign a value to the **$/ lb of CO_2** figure found in the final equation.

Assigning a price for carbon is not an exact science, and a degree of uncertainty still exists about the "best" or true price of carbon. It is generally accepted within the scientific community, however, that one can arrive at a working price estimate for the purpose of economic valuation of climate change.

Existing literature concerning the price of carbon dioxide and other greenhouse gas emissions offers a wide range of values for the market price of carbon. The latest report by the Intergovernmental Panel on Climate Change (IPCC) surveyed 100 peer reviewed studies and found an average estimated price per metric tonne[1] (Mg) of $12 (or $0.00544/lb) in a wide range that tops out at $95/Mg (or $0.0431/lb) (IPCC 2007).

The European Union's Emissions Trading System (EU ETS) is an example of a fully functioning carbon cap and trade market. A current average price within this market is about 12€, which according to today's conversion rate is about $16.86[2] per metric tonne of carbon (Chevallier, J. 2010). However, it is important to note this is only a partial market given that it is not globalized and its prices are dependent upon specific regulatory parameters. In contrast, a widely read and cited report on the economic impact of climate change values carbon emissions at $85/Mg (or $0.0386/lb) (Stern 2006). However, this value is strictly academic since it has not been tested in the market.

The IPCC and other experts note that current carbon prices are very likely underestimated in the marketplace, given the exclusion of many unquantifiable risks associated with climate change (for example, future damages from more intense rain events) (IPCC 2007, Clarkson & Deyes 2002). Given the range of potential value for a unit of carbon in the market, the guide provides a low- and high-end valuation example that can be applied to the climate benefit calculations in this section.

[1] Mg=metric tonne or megagram; Conversion: 1 Mg = 2204.62262 lbs.

[2] currency conversion based on a rate of 1 EUR = 1.389 USD from Google Finance, 11/1/2010, 7:00PM

Example 4.7:

Following from the earlier tree example in Example 4.2, the 100 medium trees planted in a public space abated a net amount of 44,400 pounds of CO_2 annually.

Remember that because the *Tree Guide* value includes the net benefit from CO_2 abatement—the direct and indirect benefits—the indirect energy benefit for a given tree practice does not need to be recalculated here. (Otherwise, that calculation would double count the indirect energy benefit.) Instead, just multiply the total amount of CO_2 abatement (44,400 lbs in this case) by a given carbon price.

In the following (4.7.a. and 4.7.b.), the guide walks through calculations of a lower and upper bound for valuing these carbon benefits.

Example 4.7.a:

Lower Bound: EU ETS Carbon Price of $0.00756 / lb CO_2

44,400 lbs CO_2 * $0.00756 /lb CO_2 =
$335.66 in total annual climate benefits

This lower-bound calculation shows that 100 medium trees planted in a public space could provide about $335.66 in annual climate change benefits.

Example 4.7.b:

Upper Bound: Stern's Value of $0.0386/lb CO_2

44,400 lbs CO_2 * $0.0386/lb CO_2 =
$1,713.84 in total annual climate benefits

This upper-bound calculation shows that 100 medium trees planted in a public space could provide about $1,713.84 in annual climate change benefits.

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