APPENDIX C - LIFE CYCLE COST BASIS PARAMETERS

Values from the Ameren 10-13-2017 NPV / CPWRR Model

	Average Net Capability (Mw)	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Load Reduction Costs, $/mwh of Outage, Random Day		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Labadie 1	602	$ 6.107	$ 5.455	$ 5.342	$ 5.595	$ 8.009	$ 8.913	$ 8.915	$ 9.228	$ 9.506	$ 9.517	$ 9.888
Labadie 2	599	$ 6.190	$ 5.522	$ 5.407	$ 5.672	$ 7.595	$ 8.558	$ 8.425	$ 8.721	$ 8.981	$ 9.000	$ 9.330
Labadie 3	616	$ 5.571	$ 4.959	$ 4.886	$ 5.187	$ 7.192	$ 7.985	$ 7.757	$ 8.041	$ 8.315	$ 8.313	$ 8.635
Labadie 4	616	$ 6.160	$ 5.501	$ 5.385	$ 5.648	$ 7.712	$ 8.535	$ 8.353	$ 8.648	$ 8.911	$ 8.935	$ 9.269
Labadie Common	2,433	$ 6.005	$ 5.357	$ 5.254	$ 5.524	$ 7.625	$ 8.495	$ 8.359	$ 8.656	$ 8.924	$ 8.938	$ 9.277
Valuation of Capacity & Energy (Forward Market Curve)		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Forward Market Curve Energy Price - All Hours 7x24 ($/Mwh):		$ 25.95	$ 25.77	$ 25.87	$ 26.29	$ 29.29	$ 30.50	$ 30.65	$ 31.22	$ 31.96	$ 32.30	$ 33.50
Regulated Capacity ($/kw):		$ 8.98	$ 18.50	$ 59.99	$ 92.17	$ 96.25	$ 96.64	$ 96.24	$ 96.61	$ 97.84	$ 99.11	$ 99.89

Load Reduction Costs, $/mwh of Outage, Random Day		2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Labadie 1	602	$ 10.288	$ 10.913	$ 11.658	$ 12.615	$ 13.287	$ 13.855	$ 14.502	$ 15.387	$ 15.892	$ 16.565	$ 17.238
Labadie 2	599	$ 9.728	$ 10.320	$ 11.025	$ 11.938	$ 12.573	$ 13.112	$ 13.731	$ 14.570	$ 15.051	$ 15.690	$ 16.330
Labadie 3	616	$ 9.014	$ 9.590	$ 10.272	$ 11.165	$ 11.775	$ 12.300	$ 12.910	$ 13.732	$ 14.190	$ 14.812	$ 15.433
Labadie 4	616	$ 9.660	$ 10.254	$ 10.954	$ 11.858	$ 12.484	$ 13.022	$ 13.645	$ 14.491	$ 14.959	$ 15.595	$ 16.232
Labadie Common	2,433	$ 9.668	$ 10.265	$ 10.973	$ 11.890	$ 12.525	$ 13.067	$ 13.692	$ 14.540	$ 15.018	$ 15.660	$ 16.303
Valuation of Capacity & Energy (Forward Market Curve)		2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Forward Market Curve Energy Price - All Hours 7x24 ($/Mwh):		$ 34.74	$ 36.02	$ 37.35	$ 38.74	$ 40.17	$ 41.65	$ 43.20	$ 44.79	$ 44.24	$ 45.30	$ 46.36
Regulated Capacity ($/kw):		$ 101.77	$ 102.04	$ 102.98	$ 103.91	$ 104.84	$ 105.77	$ 106.70	$ 107.63	$ 108.56	$ 109.49	$ 110.42

Load Reduction Costs, $/mwh of Outage, Random Day		2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Labadie 1	602	$ 17.911	$ 18.584	$ 19.257	$ 19.930	$ 20.603	$ 21.276	$ 21.949	$ 22.622	$ 23.294	$ 23.967	$ 24.640
Labadie 2	599	$ 16.969	$ 17.609	$ 18.249	$ 18.888	$ 19.528	$ 20.167	$ 20.807	$ 21.447	$ 22.086	$ 22.726	$ 23.365
Labadie 3	616	$ 16.055	$ 16.677	$ 17.298	$ 17.920	$ 18.542	$ 19.163	$ 19.785	$ 20.407	$ 21.029	$ 21.650	$ 22.272
Labadie 4	616	$ 16.868	$ 17.505	$ 18.142	$ 18.778	$ 19.415	$ 20.051	$ 20.688	$ 21.325	$ 21.961	$ 22.598	$ 23.234
Labadie Common	2,433	$ 16.945	$ 17.588	$ 18.230	$ 18.873	$ 19.516	$ 20.158	$ 20.801	$ 21.443	$ 22.086	$ 22.728	$ 23.371
Valuation of Capacity & Energy (Forward Market Curve)		2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Forward Market Curve Energy Price - All Hours 7x24 ($/Mwh):		$ 47.41	$ 48.47	$ 49.53	$ 50.58	$ 51.64	$ 52.70	$ 53.75	$ 54.81	$ 55.87	$ 56.92	$ 57.98
Regulated Capacity ($/kw):		$ 111.35	$ 112.28	$ 113.22	$ 114.15	$ 115.08	$ 116.01	$ 116.94	$ 117.87	$ 118.80	$ 119.73	$ 120.66

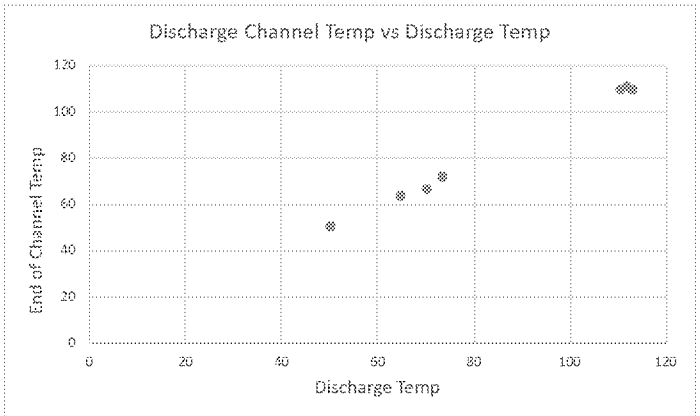
1. Value of Capacity, Value of Energy, and Load Reduction Costs are based on economic forecasts for energy prices (LMP) and fuel costs and other variable O&M costs at Labadie.

Basis Dispatch Profile, % Hours

Percent Hours for Summer Peak	10%
Percent Hours for Summer Avg	35%
Percent Hours for Winter/Ann Avg	55%

APPENDIX D – DISCHARGE CHANNEL TEMPERATURE REDUCTION

Date	River Flow at Labadie Upstream of Facility Intake (cfs)	Background River Temperature (°F)	Facility Discharge Flow (cfs)	Facility Discharge Temperature (°F)	Temperature (°F) at End of Discharge Channel	Channel / Discharge
July 31 – August 1, 2003	43,219	83.7	2,033	110.6	109.7	0.992
25-Aug-03	35,478	83.4	1,988	113.05	109.6	0.969
14-Jan-04	41,391	36.3	1,586	70.24	66.5	0.947
14-Jan-16	164,021	36.1	1,839	50.2	50.5	1.006
28-Jan-16	110,656	34.8	1,895	64.8	63.6	0.981
1-Apr-16	80,281	53.2	1,569	73.5	72	0.980
25-Jul-17	68731	86.5	2162	111.86	111.02	0.992



Average	84.893	83.274	**0.981**	**<<< Temp at end of channel is aproximately 2% less than discharge temp**
Min	50.2	50.5	0.947	
Max	113.05	111.02	1.006	
Std Dev	26.245	25.919	0.019	
CV	0.309	0.311	0.019	
Average Summer	111.84	110.11	**0.985**	**<<< Temp at end of channel is aproximately 1.5% less than discharge temp during summer conditions**

BURNS McDONNELL

CREATE AMAZING.

Burns & McDonnell World Headquarters
9400 Ward Parkway
Kansas City, MO 64114
O 816-333-9400
F 816-333-3690
www.burnsmcd.com

Appendix 10 C. Burns Engineering Services, Inc. - Assessment of Alternative Cooling Technologies for Potential Retrofitting at the Labadie Energy Center

ED_005618_00000108-00006

Assessment of Alternative Cooling Technologies for Potential Retrofitting At The Labadie Energy Center

By
J.M. Burns, P.E.

March 19, 2018

Burns Engineering Services, Inc.
PO Box 272
Topsfield, MA 01983
Tel: (978) 887-1172
Fax: (978) 887-1169
Email: burnsengr@aol.com

I. Purpose and Opinion Summary

Burns Engineering Services Inc. was engaged to independently review and opine on engineering aspects of a best available technology economically achievable (BAT) under Section 304 of the Clean Water Act (CWA) for thermal discharges from the Labadie Energy Center (Labadie) operated by Ameren Missouri (Ameren). Our evaluation was based on our extensive cooling technology and power plant retrofitting experience, prior direct experience with Labadie, and our review of multiple Labadie-specific reports prepared by others, including a recent report prepared by Burns & McDonnell (B&M) – *Ameren Labadie Energy Center Thermal Discharge, Best Available Technology Economically Achievable Analysis*, March 15, 2018, (B&M BAT Report) – which screens a wide range of cooling technologies for Labadie and then provides a more detailed assessment of those technologies identified as most appropriate for application to Labadie. A copy of the B&M BAT Report is attached as Appendix A.

As explained at Part IV and Part V below, our evaluation has, to date, found that the B&M BAT Report (a) identifies a reasonable and appropriate range of alternative cooling technologies, (b) reasonably estimates the extent of thermal load reduction associated with each alternative cooling technology, and (c) presents a screening analysis which correctly identifies the most viable and appropriate potential retrofit cooling technologies for Labadie for more detailed analysis. I have further determined, however, that while the B&M BAT Report appropriately uses Labadie-specific information, its more detailed cost estimates for the finalist alternative technologies present sums that are too low as are their initial estimates of the required plant auxiliary power and energy impacts. That is, I have concluded that several additional important design, installation and performance elements must be prudently considered to provide reasonable cost estimates beyond those of the B&M BAT Report (See Part V, below). Finally, I conclude that the facility's existing cooling technology, once-through cooling with discharge channel, is reasonable for Labadie's thermal discharges and should continue to be used for Labadie. The alternative cooling technologies are not reasonable for Labadie and are not recommended.

II. Background

My name is John M. Burns and I am the President, founder and hands-on Director of Engineering at Burns Engineering Services Inc. of Topsfield, Massachusetts, a consulting company that specializes in the engineering and improvement of power plant cooling systems, particularly the technology of condensers and cooling towers.

During the majority of my over 50 year career, I have been involved with well over a hundred condenser and cooling tower related projects in North America, Europe and Asia. I was the

cooling system specialist for 24 years at Stone & Webster Engineering Corporation, a major architect-engineering company that engineered, purchased and constructed equipment for over 1,000 power plants worldwide. While working there, I was specifically responsible for the detailed plant design, specifications, testing, engineering and maintenance activities related to the sizing, design installation and operation of steam condensers and cooling towers of all types. Along with the project, I was involved in the design and installation throughout the process. Before my tenure at Stone & Webster, I was employed by the Ingersoll-Rand Company for about 14 years; initially I was part of the design group and ultimately became the Manager of Engineering Development for the Condenser Division. Ingersoll Rand, now owned by SPX, was a major manufacturer of steam surface condensers, direct contact condensers, barometric condensers and steam jet air ejectors (SJAEs). At Ingersoll Rand, with my development team, I was instrumental and responsible for the design/testing/development of a natural draft cooling tower and a direct contact condenser, both new products for the Company.

My work at Ingersoll Rand was in concert with over 25 other members of the factory staff and with the aid of draftsmen, I used engineering methods, tests, standards and other quantitative criteria to produce condensers and related equipment for the fossil and nuclear markets. As the Development Manager, this kind of engineering work continued but with more of a focus on the new cooling tower and other new products. As the cooling system specialist at Stone & Webster Engineering Corporation Inc., during the phases of a project, I advised the project personnel on many technical aspects of their cooling system related equipment. For example, I checked the adequacy, sizing, costs and impacts of cooling systems, condensers and towers of all varieties to function and perform properly. I wrote furnish and erect cooling tower specifications and condenser manufacturing specifications for procurement and construction that ensured cooling system adequacy for that utility project. I further analyzed bids, tested cooling systems, conducted studies, evaluated retrofit closed-cycle cooling system designs, and performed engineering troubleshooting after commissioning or later for utility clients.

My consulting company, with its specialized staff, has continued to concentrate on the improvement of the efficiency and the operation of power plant cooling systems as an extension of my past work. Since its inception, we have served over 70 utilities, architect-engineers and manufacturers in our almost 20-year history.

My staff and I have been troubleshooting poorly performing condensers, cooling systems with poor performance and mechanical problems. Our work has involved conducting many condenser, wet and dry cooling tower tests using the American Society of Mechanical Engineers (ASME) Codes as guidelines; producing dry and wet closed-cycle cooling system retrofit and alternative cost estimates and their generation impacts for both new and existing stations; retubing studies and projects; extended power uprate studies associated with the cooling

system; inspections; numerous condenser finite element analyses to estimate stresses, loads and deflections; condenser hotwell reheat studies; cooling equipment cost estimates; predictions of the potential for condenser tube vibration and damage; modular condenser specifications; condenser retubing specifications, tube material evaluations and recommendations; tube corrosion and tubesheet field evaluations; hydraulic analyses; 316(b) studies concerning once-through, dry and wet cooling system and equipment retrofit design and cost estimates and numerous other condenser and cooling tower related projects. We have also peer-reviewed other expert's work.

In summary, my engineering experience encompasses the entire cooling system and how its components interrelate, affect turbine generation and capital costs, regardless of the type of plant or cycle. I have written and co-authored more than 40 articles and papers related to condensers and cooling towers. I have also given many seminars on condensers and cooling towers at national conferences and for specific utilities. I have been awarded four US patents during my career.

Currently I am the Chairman of ASME PTC 12.2, the Surface Condenser Performance Test Code Committee; Code was published as the U.S., ANSI national standard in 2010. I additionally Chair ASME PTC 23, the Cooling Tower Test Code Committee whose document was published in 2003 as the present national U.S., ANSI test Code. I am also Chairman of ASME PTC 30.1 on Air Cooled Steam Condensers, a new national test code effort that was published in 2008. Lastly, since 1992 I have been a participating Member of the senior ASME Standards Committee on Performance Test Codes that reviews and approves the entire ASME test Code program on some 40 Codes ranging from steam engines to turbines to pumps to cooling towers.

Note that with a balanced committee participation from manufacturers, utilities and consulting/academia organizations, the Codes are produced by technical Code Committees consisting of national and international experts in their respective fields. I was privileged to have been peer elected to Chair each of my above Code Committees by its Members. My separate ASME committees were in active communication for several years and by their cooperative attitude and our collective skills, produced the cited updated or new versions of these Codes on a fast-track basis. Further, I was honored to be awarded the 2002 ASME Annual Performance Test Code Medal for my contributions to test technology and my ASME Code development efforts. During 2004, I was elected as a Life Fellow of ASME.

I hold a Bachelor's Degree in Marine Engineering from the New York Maritime College (1958). I have also earned a Master of Science Degree in Mechanical Engineering from Lehigh University (1962) where as a Graduate Assistant, I taught the engineering seniors traditional and advanced laboratory methods and testing.

I am a licensed professional engineer in five U.S. states-New York, New Jersey, Massachusetts, Texas and Minnesota. My experience is further outlined at Appendix B.

III. Appropriate Retrofit Study Approach

Retrofitting a large power plant such as Labadie to use an alternate cooling technology would inherently be a very substantial and complex project. Perhaps in part for that reason, no retrofit of a U.S. power plant cooling system is known to have ever been accomplished and driven by a thermal BAT analysis.[1] To understand the complexity of such a project, including designing and estimating costs of the retrofit, it is useful to consider the overall process used to design a power plant's original cooling system. A discussion of that topic is included below. Also discussed below is the need for a detailed site-specific cost assessment addressing most major cooling system design features.

Original Cooling System Design Process

Based on my experience with a major Engineer-Purchase & Construct (EPC) company, which designed and built power plants and associated cooling systems for many years, the design and construction of a facility such as Labadie would be accomplished by a large-scale project team consisting of a group of perhaps 50 engineers, practiced respectively in the science and arts of mechanical, civil and electrical engineering fields. They would be further supported by people with many other skill-sets including procurement, cost estimating, drafting, schedulers, as well as construction and specialists in hydraulics, intakes, the environment, structures, computers, instrumentation, heat exchangers, condensers, cooling towers, boilers, and pumps.

The overall plant cooling system would be established after the site, plant size and expected number of units was selected and the turbine and boiler purchased. Though the names of the major components of this system were always the same such as intake, pumps, condenser, cooling tower and outlet, from plant to plant, the size, technical characteristics and installation of the actual equipment were usually very different. The cooling system is comprised of huge equipment, piping and pumps and is spread extensively from the plant inlet to its discharge. It would be one of the first systems designed.

That design would be accomplished by the project team from coordinated, in-depth inputs by the civil and mechanical groups supported by all the above technical specialties available in the organization, including statistics of the Missouri River seasonal inlet water temperatures, weather and other fundamental site conditions. With regard to Labadie, in approximately 1970, a once-through cooling system was chosen. Initial cooling system design results would have been reviewed and critiqued by project management for compatibility with the basic requirements of its function and operation, the situation, operator preferences and again

[1] All known cooling tower retrofit projects are known to have instead been driven by CWA Section 316(b) or (a) requirements. I understand that 316(b) and (a) studies for Labadie are currently ongoing.

periodically as the design progressed toward finality. It is notable that, within this design process, overall installed costs would be a major consideration. Though the piping and condenser are inherently large for all once-through systems, a major problem at Labadie would be physically accommodating each of the four 600 MW units while conveying the circulating water efficiently with a relatively low hydraulic pressure. After final system design approvals, written specifications for the pumps, piping and condenser that closely reflected the design parameters defining the cooling system would be issued to manufacturers and contractors for bidding, procurement and installation by the EPC project. The locations and features of the resulting cooling system would then be located as a permanent design feature on the plant layout, yard piping and elevation drawings, documents and data files. The rest of the many facets of Labadie designs and project would continue, working around the embedded cooling system as needed to avoid interferences. As explained in the next section, 45 years later, modifying and replacing the existing imbedded equipment and piping (often covered by 10 ft. of concrete under the turbine hall) with a massive new retrofitted cooling system is an immense, complex and costly project.

Retrofit Cooling System Designs & Estimates

Accurately estimating costs of alternate cooling systems for Labadie is a major challenge in many respects. First, the plant was designed 45 years ago without any consideration of a later retrofit to closed-cycle cooling systems for its four 600 MW units. Retrofitting must consider the potential impact of new systems upon all existing systems. Second, the estimates of alternate technologies must recognize the soil conditions and many above and below ground obstacles and plant features installed 45 years ago that will inherently interfere with extensions of the huge piping and cooling tower related structures. Third, the necessity of including and reconstructing (on paper) a different cooling system - with its many attendant details and costs provided by the multiple engineering disciplines that would have been utilized during the Labadie design project many years ago today - would be very demanding to successfully accomplish because a new, smaller group of assigned engineers and their technical support people in a retrofit project presumably would not have had the long design and construction experiences and familiarity with Labadie uniqueness's that the former engineers and support people had.

Site-Specific Evaluations Provide Accuracy

It is recommended that engineers knowledgeable in the allied fields take and apply a site-specific approach, considering all the many particulars and major specifics tailored to Labadie, and then have that approach reviewed by me as applicable. A site-specific study with its many facets is lengthy, complicated and costly but necessary if one wishes to estimate alternative costs with reasonable accuracy. A more cursory assessment runs a significant risk of overlooking aspects of a project. The effects of overlooked aspects can, and typically do, strongly influence and increase associated costs. Alternative cooling system retrofit design

evaluations are wide-ranging and must encompass many engineering, plant, cost and environmental design estimates that are complex.

Applicability of Non-Site-Specific Retrofit Model Estimates and Other Plant Designs

The complexity, time-consuming nature and cost of accurate site-specific engineering evaluations have led many to look to generic estimates derived from some level of study experiences at other plants. The Electric Power Research Institute (EPRI) produced a report[2] which was used, in part, by the Missouri DNR in the thermal BAT determination of Appendix H.[3] Although the EPRI report acknowledged that a detailed, site-specific review and analysis is best, it produced overall tables that it considered at least generally indicative of cooling retrofitting costs. It recognized that only a few closed-cycle retrofit projects had actually been completed, done for compelling reasons or in physical situations that were easily adopted to closed-cycle cooling. As a result, the EPRI study does not consider the many differences between plants. The EPRI study must thus be viewed, at most, to provide general cost information that can be used as a starting point for a more detailed, site-specific evaluation.

In conclusion, though some minor scaling and modelling is inevitable due to the large number of variables involved, the major parameters of a retrofit must be established by conducting site-specific studies in order to produce reasonably accurate BAT estimates.

---

[2] EPRI, Closed-Cycle Cooling System Retrofit Capital & Performance Cost Estimates, 2011.

[3] See Appendix H of the Fact Sheet issued with the Labadie NPDES permit dated May 3, 2017. Appendix H also partly relied on Labadie-specific information from prior reports.

ED_005618_00000108-00013

IV. Retrofit Cooling Technologies Screening Evaluation

The B&M BAT Report identifies once-through cooling with discharge channel, mechanical draft, natural draft, dry and plume-abated (hybrid) cooling towers, cooling ponds and helper cooling towers as alternative technologies for Labadie. It assessed application of each alternative technology to Labadie both at one and four Unit levels. The identified technologies mostly encompass those commercially available for the electric power industry (although not all have been shown to be feasible for retrofitting an existing facility), and the report considers the identified technologies as a range of application that are reasonable and appropriate.

In addition to identifying an appropriate range of alternate cooling retrofit technologies for Labadie, the B&M BAT Report presents a screening evaluation to determine those technologies which may be most viable for Labadie. Based on my review of the B&M BAT Report's screening evaluation and my professional experience, I agree with the report's conclusion that the existing technology (once-through cooling with discharge channel), mechanical draft cooling towers and permanent helper towers are those most likely to be BAT for Labadie.

The mechanical draft, natural draft and dry cooling towers identified by the B&M BAT Report are illustrated in Figure 1 below. The depiction is taken directly from a textbook article [Ref 3] on cooling towers I wrote approximately 30 years ago. Despite the figure's age, it still embodies the basic technology and commercial state-of-the-art today.

Note that a drawing of a cooling pond is not included because, to be an effective cooling component, ponds must be sized at between 0.5 to 2 acres/MW (and usually closer to the 2 acre figure). To use this range, a cooling pond for Labadie would be between 1,200 and 4,800 acres to address all four units. Since sufficient area around Labadie is not available, cooling ponds are clearly an impractical retrofit choice.

ED_005618_00000108-00014

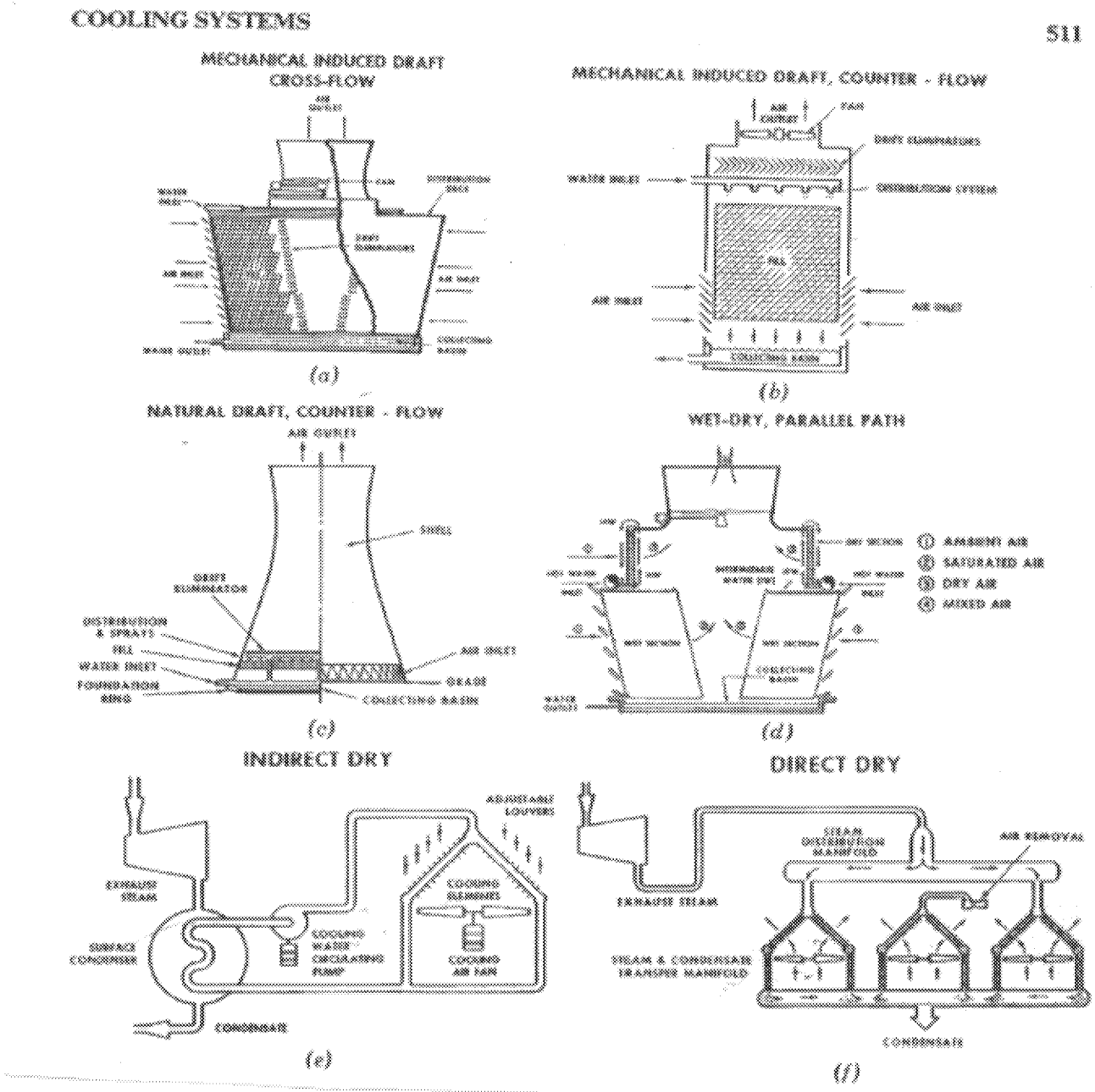


Fig. 4.8-17 Types of cooling towers. (Courtesy of Marley Cooling Tower Co.)

Figure 1 - Illustrations of Types of Retrofit Cooling Towers of B&M BAT Report

Dry cooling towers are not a viable alternate technology for Labadie. Dry cooling towers use giant, inefficient radiators. In the case of direct dry designs, their heat exchangers must be connected with huge steam ducts to the turbine exhaust. Indirect dry designs are additionally inefficient compared to the direct type and have never been utilized in the U.S. Basically however, the size of those radiators preclude the viability of dry cooling towers as an alternative technology for Labadie or to use for a retrofit of another large power plant. Mechanical draft and natural draft closed-cycle wet cooling towers are potentially viable retrofit choices for consideration. Mechanical draft cooling towers on a closed-cycle system would reduce the river intake flow by about 95% or more and entail a relatively modest small evaporation requirement. Mechanical draft cooling towers and permanent mechanical draft helper towers would potentially produce both an objectionable view of the operating Labadie plant and major airborne effects, including the potential for icing, drift, Particulate Matter (PM) emissions, noise and pluming. As indicated, when operating, permanent helper mechanical draft towers have identical airborne effects as the closed-cycle, mechanical draft tower above along with a small amount of river water evaporation. The permanent helper tower alternative would notreduce either the plant's intake or discharge flow but, depending on various factors (i.e., the performance capability of the helpers, their wet bulb temperatures, river temperatures and load conditions), would reduce the waste heat discharged from the plant to the river. Such waste heat reduction to the river would be to a much lesser degree than the mechanical draft and natural draft closed-cycle cooling system alternatives. The temporary helper towers alternative is not viable given the size of the Labadie plant and the highly variable commercial availability of such temporary helper towers.

Although it would not affect the screening evaluation's ultimate conclusion, the screening evaluation of natural draft towers should have been based on a 15°F design performance approach rather than the 10°F approach used by the B&M BAT Report. This increased design target would reflect the poor past industry experience with that type of tower which produces a further reduction in annual plant electrical output. That factor and others would cause the actual costs and performance associated with natural draft towners to be appreciably higher than those estimated by the B&M BAT Report.

V. More Detailed Estimates of Finalist Alternate Retrofit Cooling Technologies

Mechanical Draft Towers

Based on my professional experience, review of this matter, and independent estimates of the expected costs in 2018 dollars, aspects of the B&M BAT Report capital cost estimates for the four-unit mechanical draft cooling towers alternative appear to be low. For example, a more accurate capital cost estimate should consider the following items which do not appear to have

been fully considered by the B&M BAT Report: (1) the existing circulating water piping and condenser would need to be significantly reinforced or replaced to allow reliable operation; (2) basin foundation and wiring associated with the fans with motor control centers; (3) the need to install piping on both sides of the cooling towers to prevent inlet cooling air blockage; (4) the substantial piling support which would be needed given soil conditions and the weight of the towers and piping; and (5) the current intakes, pump house and its existing piping to the vicinity of the powerhouse should be demolished to remain in a safe condition for the future. With these additional considerations in mind, my independent estimates indicate as much as an additional $90 million should be prudently added beyond the B&M BAT Report capital cost estimate. That would potentially also increase the other capital-related B&M BAT Report estimated costs.

The B&M BAT Report also underestimated the operating hydraulic losses plus fan power (auxiliary power) and plant energy loss effects associated with application of the mechanical draft cooling towers alternative at Labadie. These cost estimates were determined by my independent consideration and evaluations of the major auxiliary power needs of the entire existing plant at full load along with a summer operating scenario for the mechanical draft tower retrofit option. My design condition auxiliary power resulted in a 28 MW need and was slightly higher by 2 MW to that of the B&M BAT Report of 26 MW.

It is recognized that many conditions can be assumed to evaluate the loss in plant energy but the following scenario and method are reasonable and realistic: Labadie was assumed to be at full power in summer operation at an average summer Missouri River inlet water temperature of 78.9°F while the average summer wet bulb temperature was 79.9°F. Incrementally comparing (1) the resulting nominal Labadie turbine power loss with its 45-year-old multi-pressure condensers at a typical apparent cleanliness of 65% with the existing once-through cooling system, to (2) that of the warmer condenser inlet water produced by the B&M conceptual closed-cycle mechanical draft tower, the energy (power) loss was 46 MW. This comparative energy loss of the turbines was higher than the 12 MW B&M BAT Report estimate.

In summary, my mechanical draft towers estimates suggest that, if these cooling towers are installed for all four Labadie units, it would be very costly and that the net full load electrical generation from Labadie would be reduced by a total of about 74 MW (or approximately 3% of the existing once-through cooling system plant power expectations) during an average warm summer day without any commensurate reductions in costs to ratepayers, operational complexity, boiler stack emissions or other compensations.[4]

[4] The complexity of such a project is difficult to understate. It would be an enormous undertaking entailing significant uncertainity for the addition of four mechanical draft tower structures containing 80 separate cells (each about 50 ft. by 50 ft. in area and served by more than 4 miles of piping more than 11 ft. in diameter).

Helper Towers

Based on my professional experience, review of this matter and independent estimates of the expected 2018 costs, the B&M BAT Report capital costs estimates for the four-unit helper cooling towers are also underestimated. For example, a more accurate capital cost estimate for the four-unit helper towers alternative should consider the following items which were not fully accounted for by the estimates of the B&M BAT Report: (1) basin foundation and wiring associated with the fans with motor control centers; (2) the need to install piping on both sides of the cooling towers to prevent inlet cooling air blockage; and (3) the substantial piling support which would be needed given soil conditions and the weight of the towers and piping. With these additional considerations in mind, my independent estimates indicate as much as an additional $20 million should be prudently added beyond the B&M BAT Report capital cost estimate. That increase in cost estimate would also proportionately increase the other capital-related B&M BAT Report estimated costs.

The B&M BAT Report also underestimated the operating hydraulic losses plus fan power (auxiliary power) effects associated with helper cooling towers at Labadie. These cost estimates were determined by my independent consideration and evaluations of the major auxiliary power needs of the entire existing plant at full load along with a summer operating scenario for the helper tower retrofit option. My design condition auxiliary power resulted in a 36 MW need and was slightly higher by about 2 MW to that of the B&M BAT Report of 34 MW.

I certainly agree that the helper tower identified by the B&M BAT Report correctly retrofits crossflow, mechanical draft towers with splash fill, in order to better accommodate any river debris carry-over or macrofouling that is conveyed to it by the existing once-through cooling system. My many experiences with these towers, however, indicate that their cold water design approach to the wet bulb temperature would be at least 10°F, somewhat higher than the B&M BAT Report value. Everything else being the same, during operation, the higher approach of the cold water from tower to the wet bulb temperature would decrease the inherent effectiveness of such mechanical draft towers in reducing the waste heat conveyed in the circulating water from Labadie back to the river. And, depending on the difference between the variable river inlet temperatures, the coincident wet bulb temperature and the operating load, the quantity of waste heat removed would be different. Thus, the evaluation of that reduction is related to the operating condition, weather and inlet temperature presumed by a scenario. My experience suggests that one should evaluate a helper tower in summer on the basis of the average summer wet bulb temperature of 79.9°F against the average summer river inlet temperature at 78.9°F and at a full load condition. Doing so demonstrates that helper towers would remove approximately 48% of the waste heat from the plant discharge to the river. The B&M BAT Report lists an 87% reduction in waste heat, likely due to the inlet river water temperature and wet bulb temperature they selected combined with the closer 7°F design approach crossflow tower they utilized for the B&M summer operating condition scenario.

In summary, my independent helper tower estimates suggest that it would be very costly to install these helper towers for all four Labadie units, and the net full load electrical generation from Labadie would be reduced by a total of about 36 MW (or approximately 2% of the existing plant power expectations) while reducing the waste heat to the river by 48% during an average warm summer day without any commensurate reductions in costs to ratepayers, operational complexity, boiler stack emissions or other compensations.[5]

VI. Conclusion

Although both the mechanical draft cooling towers and permanent helper tower alternatives are potentially viable at Labadie from an engineering perspective, both alternatives would be very costly and difficult to implement. Based on my professional experience, neither alternative technology would be reasonable for Labadie and are not recommended. Rather, I recommend continued use of the facility's existing cooling technology, once-through cooling with discharge channel, for Labadie's thermal discharges.

VI. References

1. Burns & McDonnell, Ameren Labadie Energy Center Thermal Discharge, Best Available Technology Economically Achievable Analysis, March 15, 2018.
2. RS Means CostWorks 2018- Heavy Construction Costs, 2018.
3. Burns, J.M. and Brochard, D.; "Cooling Towers," Section 4.8, Handbook of Energy Systems Engineering, Reference text, John Wiley & Sons, N.Y., 1985.
4. Heat Exchange Institute Standards for Steam Surface Condensers, 11th ed., 2012.
5. Kelly's Handbook of Crossflow Cooling Tower Performance, N. Kelly, Kansas City, 1976.
6. Crane Co., Engineering Data, 1976.
7. Cameron Hydraulic Data, Ingersoll Rand Co., 1965.
8. Burns, J.M., Burns, D.C., Burns J. S.; "Estimates Required to Achieve the Next Level of CWA 316(b) Compliance", presented at the International Joint Power Generation Conference, Electric Power, March 2004.
9. Burns, J.M.; Nicholson, J.M.; Annett, J.H.; and Alexander, D.N.; "The Impacts of Retrofitting Cooling Towers at a Large Power Station", EPRI Cooling Tower Conference, August 1994.
10. Burns, J.M.; Titus, P.; and Phillips, R.; "The Practical Application of Finite Element Stress Analysis to Problems of Operating Steam Condensers." 1990 EPRI Condenser Technology Conference.
11. EPRI, Closed-Cycle Cooling System Retrofit Capital & Performance Cost Estimates, 2011.
12. Missouri State Operating Permit No. MO-0004812, Appendix H to Fact Sheet, pp. 67-77, Missouri Department of Natural Resources, 2015.

[5] Like the closed-cycle mechanical draft cooling tower alternative, the four-unit helper towers alterantive would be very complex. It would entail structures containing 84 separate cells, more than 4 miles of piping larger than 11 ft. in diameter, and significant uncertainty.

Appendix A -- Burns & McDonnell, *Ameren Labadie Energy Center Thermal Discharge, Best Available Technology Economically Achievable Analysis*, March 15, 2018.

Appendix B – JM Burns Resume, 3/2018

Appendix A

BURNS McDONNELL

Ameren Labadie Energy Center Thermal Discharge Best Available Technology Economically Achievable Analysis

Project No. 103550

Final
3/15/2018

Ameren Labadie Energy Center
Thermal Discharge
Best Available Technology
Economically Achievable Analysis

Project No. 103550

Final
3/15/2018

prepared by

Burns & McDonnell Engineering Company, Inc.

COPYRIGHT © 2018 BURNS & McDONNELL ENGINEERING COMPANY, INC.

INDEX AND CERTIFICATION

Ameren Labadie Energy Center
Thermal Discharge
Best Available Technology
Economically Achievable Analysis
Project No. 103550

Report Index

Chapter Number	Chapter Title	Number of Pages
1.0	Introduction	2
2.0	Existing Cooling System	1
3.0	Plant Parameters	2
4.0	Identification and Screening of Technologies	20
5.0	Detailed Analysis of Screened Technologies	10
6.0	Summary	1
7.0	References	1
Appendix A	Screening Analysis Summary Matrix	2
Appendix B	Detailed Analysis Conceptual Sketches	6
Appendix C	Life Cycle Cost Basis Parameters	1
Appendix D	Discharge Channel Temperature Reduction	1

Certification

I hereby certify, as a Professional Engineer in the state of Missouri, that the information in this document was assembled under my direct personal charge. This report is not intended or represented to be suitable for reuse by any party or individual without specific verification or adaptation by the Engineer.

Daniel Holland, P.E., Missouri, 2011000900

Date: March 15, 2018

TABLE OF CONTENTS

Page No.

1.0 INTRODUCTION 1-1
1.1 Purpose 1-1
1.2 Qualifications 1-1

2.0 EXISTING COOLING SYSTEM 2-1
2.1 Age of Equipment & Process Employed 2-1

3.0 PLANT PARAMETERS 3-1
3.1 Ambient Conditions 3-1
3.2 Plant Cooling System 3-1
3.3 Plant Performance 3-2

4.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES 4-1
4.1 Heat Load Reduction Levels Evaluated 4-2
4.2 Total Life Cycle Costs 4-2
4.3 Capital Costs 4-4
4.4 Operating and Maintenance Costs 4-5
4.5 Auxiliary Load Impact 4-6
4.6 Plant Efficiency Loss 4-6
4.7 Estimated Outage Duration and Costs 4-6
4.8 Water Consumption 4-7
4.9 Equipment Footprint and Height 4-7
4.10 Particulate Matter Emissions 4-7
4.11 Noise Emissions 4-7
4.12 Vapor Plume Impacts 4-7
4.13 Screening Analysis Design Basis Parameters 4-8
4.14 Screening Analysis of Each Technology 4-10
4.14.1 Once-Through Cooling with Discharge Channel 4-10
4.14.2 Mechanical Draft Cooling Towers 4-11
4.14.3 Plume Abated (Hybrid) Mechanical Draft Cooling Towers 4-12
4.14.4 Natural Draft Cooling Towers 4-14
4.14.5 Dry Cooling 4-15
4.14.6 Permanent Helper Cooling Towers 4-16
4.14.7 Temporary Helper Cooling Towers 4-17
4.14.8 Cooling Pond 4-18
4.15 Screening Analysis Results 4-19

5.0 DETAILED ANALYSIS OF SCREENED TECHNOLOGIES 5-1
5.1 Technologies Screened Forward and Method of Detailed Analysis 5-1
5.2 Detailed Analysis 5-2
5.2.1 Detailed Analysis Design Basis Parameters 5-2

ED_005618_00000108-00025

5.2.2 Detailed Analysis Costs 5-4
5.2.3 Once Through Cooling With Discharge Channel 5-7
5.2.4 Mechanical Draft Cooling Towers 5-7
5.2.5 Permanent Helper Cooling Towers 5-9

6.0 SUMMARY 6-1

7.0 REFERENCES 7-1

APPENDIX A - SCREENING ANALYSIS SUMMARY MATRIX
APPENDIX B - DETAILED ANALYSIS CONCEPTUAL SKETCHES
APPENDIX C - LIFE CYCLE COST BASIS PARAMETERS
APPENDIX D – DISCHARGE CHANNEL TEMPERATURE REDUCTION

ED_005618_00000108-00026

LIST OF TABLES

Page No.

Table 4-1: Life Cycle Cost Parameters 4-3
Table 4-2: Screening Analysis Design Basis Parameters 4-9
Table 4-3: Once-Through Cooling with Discharge Channel Screening Results 4-10
Table 4-4: Mechanical Draft Cooling Tower Screening Results 4-12
Table 4-5: Plume Abated Mechanical Draft Cooling Tower Screening Results 4-13
Table 4-6: Natural Draft Cooling Tower Screening Results 4-14
Table 4-7: Dry Cooling Screening Results 4-15
Table 4-8: Permanent Helper Cooling Towers Screening Results 4-16
Table 4-9: Temporary Helper Cooling Towers Screening Results 4-17
Table 4-10: Cooling Pond Screening Results 4-18
Table 5-1: Detailed Analysis Design Basis Parameters 5-3
Table 5-2: Detailed Analysis Cost Summary 5-6

ED_005618_00000108-00027

LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
AACE	Association for the Advancement of Cost Engineering
ACC	air cooled condensers
ACHE	air cooled heat exchangers
AFUDC	Allowance for Funds Used During Construction
Ameren	Ameren Missouri
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAT	Best Available Technology Economically Achievable
BPS	Brayton Point Station
Burns & McDonnell	Burns & McDonnell Engineering Company, Inc.
FAA	Federal Aviation Administration
HP	horsepower
HVAC	heating, ventilation, and air conditioning
Labadie	Labadie Energy Center
MCC	Motor control center
MGD	million gallons per day
MMBtu	million British thermal units
MS	Merrimack Station
MW	megawatt
MWHR	Megawatt-hour
NPDES	National Pollutant Discharge Elimination System
NPV	net present value

ED_005618_00000108-00028

Abbreviation	Term/Phrase/Name
O&M	operating and maintenance
PA	plume abated
PM	particulate matter
$PM_{2.5}$	particulate matter with a diameter less than 2.5 microns
PM_{10}	particulate matter with a diameter less than 10 microns
PSD	Prevention of Significant Deterioration
TMY	typical meteorological year

ED_005618_00000108-00029

1.0 INTRODUCTION

1.1 Purpose

Union Electric Company d/b/a Ameren Missouri (Ameren) owns and operates the Labadie Energy Center (Labadie) which is located near Labadie, Missouri on the Missouri River about 50 miles upstream of St. Louis. Labadie entails four 600 megawatt (MW) pulverized coal units that use a once-through cooling water system to condense turbine exhaust steam and to provide plant auxiliary cooling water. The once through cooling water system withdraws water from the Missouri River and pumps it through unit condensers to an artificial channel, which discharges the water back to the Missouri River. Labadie is among the largest coal-fired power plants in the United States, providing power to approximately 1.5 million people.

Burns & McDonnell Engineering Company, Inc. (Burns & McDonnell) was retained to conduct a thermal discharge Best Available Technology Economically Achievable (BAT) analysis to (a) identify the range of alternative cooling technologies generally available for use in the electric power industry, (b) estimate the potential thermal load reduction associated with those alternative control technologies if used at Labadie, (c) perform a screening level cost and impact to plant performance estimate for each of the reviewed technologies, (d) identify the non-water quality environmental implications of each alternative, and (e) determine more detailed cost estimates for those alternatives determined to represent a reasonable and appropriate range in terms of thermal load reduction, cost and overall environmental impact. The following factors were considered as part of the BAT analysis:

1. The age of the equipment and facilities involved
2. The processes employed
3. The engineering aspects of the application of various technologies
4. Process changes and in-plant controls
5. Non-water quality environmental impacts, including energy requirements
6. Total costs of technologies in relation to effluent heat reduction

1.2 Qualifications

Burns & McDonnell is an engineering firm founded in 1898 and today consists of more than 6,000 employees. Burns & McDonnell provides detailed design and construction services for the electric utility industry on all types of generating plants and processes including the cooling and thermal discharge systems. Burns & McDonnell has a team of plant performance engineers, civil, structural, mechanical, electrical, construction engineers, aquatic ecologists, fisheries biologists, National Pollutant Discharge

ED_005618_00000108-00030

Elimination System (NPDES) permitting specialists, and hydrodynamic and hydraulic modelers, who have worked together in power plant design and construction including projects to obtain compliance at existing thermal discharges as well as design of new discharges at electrical generating facilities throughout the United States. Burns & McDonnell has direct experience designing and estimating power plant cooling system retrofit projects using each of the feasible control technologies described in this report. Burns & McDonnell is particularly well-positioned to conduct the analysis of this report due to its extensive first-hand experience with Labadie over many years.

ED_005618_00000108-00031

2.0 EXISTING COOLING SYSTEM

2.1 Age of Equipment & Process Employed

Labadie consists of four generating units with a net capability of 2,433 MW. The first unit started operating in May 1970 and the plant was fully operational in June 1973. The typical annual generation capacity is approximately seventeen million megawatt hours (17,000,000 MWHR). Labadie was designed, and is operated, as a base load plant with once-through cooling with an artificial discharge channel.

The plant's cooling water intake structure consists of four cells, one for each unit. The intake structure is designed to withdraw up to 1,438 million gallons per day (MGD) of water and averages 966 MGD. Cooling water withdrawn from the Missouri River via the intake structure is passed through condensers (one for each unit), other heat exchangers and the artificial discharge channel before being discharged to the Missouri River. More specifically, water from the four condenser units flows through four eight-foot diameter pipes to a seal well, where the water flows over a weir into the 0.22-mile artificial discharge channel. A warming line recirculates a volume of heated water back to the intake structure to prevent ice buildup in the winter.

Since the original construction of the plant, there have been several upgrades to equipment involved with the thermal discharge of the plant. All four condensers have had original brass tubes replaced with stainless steel tubes. The tube replacement allowed for more water flow by reducing wall thickness while maintaining thermal conductivity. The tube replacement also improved erosion and corrosion resistance. Additionally, circulating water pump impellers are replaced every few years due to wear and these pumps have been upgraded to a more efficient design. All steam turbine sections (HP/IP and LP) have been upgraded from original Westinghouse and GE turbines to higher efficiency Alstom (GE) turbines.

ED_005618_00000108-00032

3.0 PLANT PARAMETERS

This section presents an overview of the plant design, unit design, and evaluation basis that was applied to each of the technologies evaluated.

3.1 Ambient Conditions

The following ambient temperatures were determined based on Burns & McDonnell's professional experience and use of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and typical meteorological year (TMY) weather data from the weather station nearest Labadie, Spirit of St. Louis station. The 0.4% wet bulb temperature was used as the design wet bulb temperature for the wet cooling technology options and the 0.4% dry bulb temperature was used as the design dry bulb temperature for the dry cooling technology options.

1. Average annual dry bulb temperature: 56.7°F based on TMY3 normals weather data[1]
2. 0.4% of year dry bulb temperature: 95.3°F based on ASHRAE data[2]
3. Average annual wet bulb temperature: 51.1°F based on TMY3 normals weather data[1]
4. 0.4% of year wet bulb temperature: 79.9°F based on ASHRAE data[2]

These ambient parameters are conservative and appropriate for the purposes of identifying and evaluating cooling technology alternatives.

3.2 Plant Cooling System

Plant operating data during the summer months (June through September) for 2016 and 2017 was analyzed to determine the design basis parameters for the plant cooling systems. This data represents actual unit and plant performance based on the most recent equipment changes and conditions.

Units 1 and 2 are substantially similar in design, as are Units 3 and 4. Design differences between Units 1-2 versus Units 3-4 are not believed to be material for the purposes of this report, especially since the low-pressure steam turbine modifications were completed on all units. Therefore, this report assumes all four units to be identical in terms of the following design basis parameters. The differences in unit locations do not impact the below parameters, but were considered in cost estimates developed within this evaluation.

[1] Typical Meteorological Year Data, Spirt of St. Louis Station (2013).
[2] ASHRAE Handbook – Fundamentals, Spirit of St. Louis Station (2013).

ED_005618_00000108-00033

1. Maximum summer plant capacity cooling load: 3,101 MMBtu/hr (one unit); 12,404 MMBtu/hr (all four units)
2. This load includes unit condenser heat load and auxiliary cooling loads based on peak summer heat rejection load from operating data.
3. Design cooling water flow: 251,500 gpm (one unit); 1,006,000 gpm or 2,241 cfs (all four units) This cooling flow includes water for the condenser and auxiliary cooling users. It is based on operating data corresponding to the coincident peak summer heat rejection load (above).
4. Summer peak and summer average river water temperatures: 88.1°F (peak), 78.9°F (average) Summer peak temperature is based on the 0.4% incident rate from 15-year operating data for the plant[3] and summer average temperature is based on the average during the summer months (June through September) from the data[1]. The 0.4% incident rate was used to be comparable to the 0.4% incident dry bulb and wet bulb values used as the design basis for the cooling technologies. Both summer peak and average values were used in estimating performance impacts from each technology option. For reference, the maximum measured river (plant inlet) temperature over the last 15 years is 89°F.

These plant cooling system parameters are conservative and appropriate for the purposes of identifying and evaluating cooling technology alternatives.

3.3 Plant Performance

1. Condenser:

   Condenser performance was not directly used in this evaluation because operating data[4] was used which relates steam turbine output to inlet water temperature and flow rate. However, the condenser was modeled using GateCycle® thermal modeling software to validate the operating data, along with steam turbine performance correction curves. The condenser was modeled based on original manufacturer performance curves and data.
2. Steam turbine: 634 MW/unit

   The steam turbine gross output used as the basis of performance impact estimates was based on recent operating data for all four units at 70°F inlet cooling water temperature.

These plant performance parameters are conservative and appropriate for the purposes of identifying and evaluating cooling technology alternatives.

[3] Labadie Operating Data for 2002-2017 for MDNR
[4] Labadie Water Temperature and Output Operating Data

ED_005618_00000108-00034

4.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

This report section discusses the range of technologies identified to reduce thermal discharges, the screening methodology employed, and the results. The screening methodology is consistent with the BAT analysis approach prescribed by the Clean Water Act which requires that the following be considered: the age of the equipment and facilities involved; the manufacturing processes used; the engineering aspects of the application of the control technologies including process changes; non-water quality environmental impacts including energy requirements; costs; and other factors deemed appropriate. Each of these factors is evaluated and used in the determination to screen technologies forward and in the detailed evaluation of the screened technologies (Section 5.0).

At Ameren's request, Burns & McDonnell reviewed the site-specific thermal discharge BAT evaluations conducted in 2002 for the Brayton Point Power Station in Somerset, Massachusetts (BPS). Burns & McDonnell further reviewed the 2011 draft thermal BAT analysis published for public comment concerning the Merrimack Station (MS) in Bow, New Hampshire. Burns & McDonnell recognizes that each thermal BAT evaluation is site-specific and understands that no authority requires a site-specific thermal BAT evaluation to follow a particular format or methodology, to consider a similar range of alternatives or to arrive at similar conclusions. The referenced prior BAT evaluations (all of which concerned power plants significantly smaller than Labadie) were nonetheless reviewed for comparative purposes at Ameren's request with respect to the identification of potential alternative cooling technologies.

The below-listed range of technologies for reducing thermal discharges from the plant were identified based on Burns & McDonnell's direct experience and knowledge of industry used, commercial-scale cooling technologies employed at electric generating plants. Emerging technologies at the lab or pilot scale and which have not been commercially employed were not considered. Therefore, the range of technologies identified is considered to be comprehensive.

1. Existing Once Through Cooling with Discharge Channel
2. Mechanical Draft Cooling Towers
3. Natural Draft Cooling Towers
4. Dry Cooling (Air Cooled Condensers)
5. Permanent Helper Cooling Towers
6. Temporary Helper Cooling Towers
7. Cooling Pond

ED_005618_00000108-00035

Each of these listed alternative technologies was evaluated to assess its overall feasibility if applied at Labadie. The below subparts to Section 4.0 describe values used in the evaluation.

4.1 Heat Load Reduction Levels Evaluated

The "heat load reduction value" is the expected percent reduction in heat load (MMBtu/hr) which would be discharged to the river as a result of implementing each alternative technology. Each of the technologies (except cooling pond) was evaluated at two heat load reduction levels: (a) application of the alternative technology to one unit (the One Unit Level) and (b) application of the alternative to all four units (the Four Unit Level). That is, while each alternative control technology could theoretically be applied to all four Labadie units, or to a portion of only one unit, this report assumes an One Unit Level minimum (cooling pond is based on a portion of one unit). Heat load reduction values are stated for each alternative at both the One Unit Level and Four Unit Level and are estimated at summer peak conditions.

Burns & McDonnell believes these levels represent a reasonable and appropriate range of heat load reduction for each alternative. Heat load reduction values for application of each technology to two or three units were not calculated for this report but, for the purposes of the screening assessment of this report, can be assumed to be relatively linear.

4.2 Total Life Cycle Costs

The total life cycle net present value (NPV) project costs (2018 dollars) were estimated for each alternative. The total life cycle costs include the following:

- Capital costs (described in Section 4.3): life cycle costs are based on capital cost expenditures occurring in 2018 for each alternative
- O&M costs (described in Section 4.4)
- Outage costs (based on Section 4.7)
- Capacity loss (costs) (based on Sections 4.5 and 4.6)
- Loss power revenue (based on Sections 4.5 and 4.6)

The total life cycle costs were based on immediate implementation of each alternative, with capital cost expenditures occurring in 2018. Based on estimated project durations, the outage costs occur in 2018 for the permanent helper cooling towers and in 2019 for all other alternatives. The O&M costs and loss power revenue (includes loss revenue due to auxiliary load and plant efficiency loss) begin in 2019 for the permanent helper cooling towers and in 2020 for all other alternatives.

ED_005618_00000108-00036

The total life cycle costs presented in Appendix A were developed using the following economic parameters, which were determined from industry experience unless directed by Ameren to use more conservative values. The values requested by Ameren are within the range of those known to be used by the industry and with Burns & McDonnell experience.

Table 4-1: Life Cycle Cost Parameters

NPV Analysis Parameter	Value	Source/Basis
Analysis Duration	30 years	Ameren / Industry Exp
Cost of Capital / Discount Rate	5.94%	Ameren Economics
Capital Cost Escalation	2.4%	Handy-Whitman Index[5]
O&M Cost Escalation	2.5%	Industry Experience
Capacity Factor (each unit)	82%	Historical Labadie Values
Capacity Value, $/kW	See Appendix C	Ameren Market Projections
Energy Value, $/MWh	See Appendix C	Ameren Market Projections
Outage Cost, $/MWh	See Appendix C	Ameren Market Projections
Cost of Full-Time Equivalent (FTE)	$140,000/yr	Ameren Economics

The total life cycle costs developed as part of this evaluation represent technology retrofit at both the One Unit Level and Four Unit Level. Life cycle costs to retrofit a design within this range, such as two (50%) or three (75%) units, can be assumed to be relatively linear for the purposes of the screening evaluation of this report. However, there will be some non-linear cost behavior since the capital costs makeup a majority of the life cycle costs.

It should be noted that the BPS thermal BAT analysis used a discount rate of 11.8%, which is significantly higher than the discount rate used in this evaluation. However, the discount rate used in this analysis is based on Ameren's current accounting practices and consistent with discount rates observed by Burns & McDonnell for other investor-owned electric utilities. Additionally, the analysis duration of 30 years is consistent with the conservative option developed for BPS. The BPS thermal BAT utilized a constant inflation rate for O&M costs and used forecasted wholesale electricity prices and variable costs to determine power revenue and applicable outage costs. The BPS thermal BAT and supporting documents are unclear on the actual values used for these parameters along with maintenance costs. However, the methodology and sourcing for these parameters are very similar to those for Labadie.

[5] Handy-Whitman Index of Public Utility Construction Costs, 2017

ED_005618_00000108-00037

4.3 Capital Costs

An indicative screening-level capital cost estimate, consistent with the Association for the Advancement of Cost Engineering (AACE) Class 5, was developed for each technology alternative at the One Unit Level and Four Unit Level as applied to Labadie. The One Unit Level and Four Unit Level capital costs provide adequate range and "bookend" costs for implementing each technology. The estimates were developed based on Burns & McDonnell's first-hand experience at Labadie, with other projects, and using parametric models and previous projects and quotes as reference. Major design parameters (i.e., circulating water flowrate, steam turbine output, piping lengths, etc.) representing the application at Labadie were utilized to adjust cost factors based on established cost relationships and functions. The major design parameters used to develop the cost estimates are summarized in Section 4.13. Cost scale factors were applied to all major equipment and major material and installation costs to adjust cost groups based on site-specific design parameters. Additionally, primary engineering quantities (i.e., civil quantities for cooling ponds or circulating water pipe linear footage) were developed and used as a basis for cost estimating. Costs were also captured for differences in scope. All cost groups were combined to develop screening level total direct costs. St. Louis area specific labor rates were considered to adjust associated costs.

Indirect and other costs were determined based on recent similar projects and include the following.

- Construction management (including managing of multi-sub contracts) based on the size of the project and recent Burns & McDonnell projects
- Engineering costs based on the size of the project and recent Burns & McDonnell projects
- Start-up management and materials based on project size and application
- Escalation during project duration

All sales taxes and financing fees are excluded from the estimates, except for Allowance for Funds Used During Construction (AFUDC). AFUDC of 6% was included for every alternative.

Project contingency (20 percent of total direct and indirect costs) was included to cover accuracy of pricing, commodity estimates, and omissions from the defined project scope. This contingency is not intended to cover changes in the general project scope (i.e., addition of buildings, increased redundant equipment, addition of systems, etc.) nor major shifts in market conditions that could result in significant increases in contractor margins, major shortages of qualified labor, significant increases in escalation, or major changes in the cost of money (interest rate on loans).

ED_005618_00000108-00038

Costs were included for traditional owner's costs (four percent of total direct costs, indirect costs, and project contingency) such as project support staff, additional operators, financing, and permitting. This allowance is based on project experience and size and not based on a specific buildup of expected owner costs for this project. Owner contingency was also included as four percent of the total project cost to cover potential change orders that could occur over the project duration.

The costs developed as part of this evaluation represent technology retrofit at the One Unit Level and Four Unit Level, which establish the low and high end of the cost range. Capital costs to retrofit a capacity within this range, such as two (50%) or three (75%) units, were not estimated for this report but, for the purposes of this screening assessment, can be expected to be relatively linear in between the presented low and high costs. However, there will be some non-linear cost behavior due to economies of scale and step changes in design (i.e., circulating water pipe common supply among units and water treatment installation costs – sharing among units).

4.4 Operating and Maintenance Costs

Annual operating and maintenance (O&M) costs were estimated for each technology alternative at Labadie. The O&M estimates are comprised of two main categories: fixed and variable. O&M costs are not inclusive of the entire plant O&M, but are representative of the estimated net additional O&M costs for the operation of added equipment (applicable decommission of existing equipment (i.e., intake screens, existing pumps are included).

Fixed O&M costs include additional staffing and general maintenance costs, which are estimated as a percentage of the capital costs and generally include items such as: electronics; controls; electrical maintenance and replacements; lighting; heating, ventilation, and air conditioning (HVAC); preventative maintenance for pumps, valves, and any other equipment; and equipment inspections.

Variable O&M costs include water consumption and chemical treatment for water and are based on an 82 percent capacity factor. O&M costs exclude wastewater treatment (wastewater chemical feed is included) because wastewater treatment equipment is not included in the design scope. Estimated O&M fixed and variable costs are presented in Appendix A.

O&M costs associated with retrofitting within the One Unit Level and Four Unit Level range, such as two (50%) or three (75%) units, were not estimated for this report but, for the purposes of the screening assessment of this report, can be assumed to be relatively linear, even though the actual relationship is expected to be somewhat non-linear.

ED_005618_00000108-00039

4.5 Auxiliary Load Impact

Each technology alternative would add equipment that would impact the auxiliary load of the plant (i.e., which would require power from the plant to operate). Preliminary sizing of equipment was completed for each alternative to estimate the auxiliary load required by the new equipment. The auxiliary load impact reported in Appendix A accounts for reduction in auxiliary load due to decommissioning of some existing equipment (i.e., existing intake pumps), when applicable, and contribute to lost power revenue in the life cycle cost analysis.

4.6 Plant Efficiency Loss

The considered alternative technologies would result in a range of different cooling water supply temperatures or operating backpressures (dry conversion). Preliminary design of the cooling technology equipment was completed for each alternative to estimate the resulting impact to steam turbine output based on change in operating backpressure at summer peak (0.4% incident rate), summer average, and winter average conditions. These impacts were estimated using operating data which relates steam turbine output to inlet water temperature and flow rate. These values are included in the life cycle cost analysis results reported in Appendix A and contribute to lost power revenue.

4.7 Estimated Outage Duration and Costs

Outage durations were estimated for each technology alternative based on Burns & McDonnell experience with Labadie and with similar projects. These expected outage durations were used to determine the cost of lost power sales. These outage durations were considered separately from and additional to normal plant scheduled outages for maintenance (does not include overlap outage benefit) because planned outages are not lined up among multiple units due to the high capacity factors/dispatch of the units. The actual outage duration could vary substantially based on the following potential factors:

- Underground utilities and interferences – these were not investigated as part of this study. Outage duration may increase if there are substantial underground utilities and interferences needing repositioning for tie-ins.
- Condition of existing circulating water pipe and infrastructure. There is potential that some upgrades are required, due to increased system pressure requirements for the new technologies, once piping and infrastructure are evaluated in more detail. If upgrades are required, the outage duration will likely increase significantly.
- Changes to existing equipment requiring modifications or upgrades as a result of new heat rejection system.

ED_005618_00000108-00040

4.8 Water Consumption

Water consumption was estimated for each alternative based on the estimated evaporation (towers and ponds/basins) and water losses through water treatment, if applicable. Estimated water consumption was used to estimate variable O&M costs for water treatment for each applicable alternative.

4.9 Equipment Footprint and Height

Footprint and height of each technology alternative were estimated based on preliminary sizing of major equipment and systems and equipment supplier input. Footprints are an important consideration when there are space constraints or interferences. The equipment height is considered when locating near transmission lines and when there are local ordinances regulating allowable heights.

4.10 Particulate Matter Emissions

During an evaporative cooling process, a small portion of liquid water droplets are carried along with the evaporated water (cooling tower drift) in the tower exhaust. Constituents in the makeup water stream can become entrained in these liquid water droplets and these constituents can be emitted as total particulate matter (PM), particulate matter less than 10 microns in diameter (PM_{10}), and particulate matter less than 2.5 microns in diameter ($PM_{2.5}$). Drift occurs with all wet cooling towers and may occur with cooling ponds. The addition of such alternatives would create a potential new source for particulate matter emissions at Labadie, which could potentially trigger Prevention of Significant Deterioration (PSD). A PSD net emissions change evaluation was not completed for this study, but it should be noted that the wet evaporative cooling alternatives would impact particulate matter emissions at Labadie.

4.11 Noise Emissions

The addition of new equipment and movement of water produce additional noise that have potential to increase plant noise emissions. Each technology alternative's noise emissions potential was considered based on its specific noise sources and noise magnitude. The noise emissions potential should be considered when developing a project when local noise requirements and surrounding areas may be impacted. The costs included in the estimates for all screened options do not include noise abatement measures or special noise mitigation costs.

4.12 Vapor Plume Impacts

Traditional wet cooling towers emit plumes of saturated air which can result in ground fog and rime icing during cold conditions, known as plume impacts. These plume impacts can increase safety and Federal Aviation Administration (FAA) permitting risks associated with the cooling tower technology. Each

ED_005618_00000108-00041

appropriate technology alternative was evaluated for potential plume impacts at Labadie based on consideration of equipment, transmission lines, plant logistics, and winter prevailing wind direction.

4.13 Screening Analysis Design Basis Parameters

Table 4-2 summarizes the major design basis parameters for each technology option evaluated in the screening analysis.

ED_005618_00000108-00042

Table 4-2: Screening Analysis Design Basis Parameters

Technology Option	Design Wet / Dry Bulb	Design Approach	Design Flow Rate	New Major Scope			
Once Through Cooling with Discharge Channel	N/A	N/A	251,500 gpm / unit	N/A			
Mechanical Draft Cooling Towers	79.9°F	7°F + 2°F recirc	251,500 gpm / unit	Circ water pumps	Water treatment / chem feed	Collector well makeup	Transformers / electrical feed
Plume Abated Cooling Towers	79.9°F	7°F + 2°F recirc	251,500 gpm / unit	Circ water pumps	Water treatment / chem feed	Collector well makeup	Transformers / electrical feed
Natural Draft Cooling Towers	79.9°F	10°F	251,500 gpm / unit	Circ water pumps	Water treatment / chem feed	Collector well makeup	Transformers / electrical feed
Dry Cooling (ACC)	95.3°F	40°F ITD	Design steam flow	Remove condenser(s)		Transformers / electrical feed	
Permanent Helper Cooling Towers	79.9°F	7°F + 2°F recirc	251,500 gpm / unit	Circ water pumps	Chem feed	Transformers / electrical feed	
Temporary Helper Cooling Towers	79.9°F	11°F + 2°F recirc	251,500 gpm / unit	Rental equipment	Chem feed	Transformers / electrical feed	
Cooling Pond	79.9°F	15°F	251,500 gpm / unit	Periodic chem feed for biological growth		Transformers / electrical feed	

Note: All alternatives also include costs for access road to major equipment (i.e., water treatment area, pump structures)

ED_005618_00000108-00043

4.14 Screening Analysis of Each Technology

A description of each technology is provided below along with a table reflecting estimated thermal load reduction, total life cycle costs, capital costs, annual additional O&M costs, costs per load reduction, and a discussion of associated anticipated process changes which would be necessary to retrofit the technology at Labadie. A matrix more fully summarizing the screening analysis is included in Appendix A. The stated heat load reductions are based on peak summer conditions and are expressed in terms of reduction from once through cooling with no discharge channel. The actual heat load reductions would vary with ambient conditions and unit load.

4.14.1 Once-Through Cooling with Discharge Channel

Labadie's existing once-through cooling system extracts water from a body of water, in this case the Missouri River, and passes it through heat exchangers where it absorbs heat (i.e., via the condenser), and then discharges it to a long artificial discharge channel. The channel then discharges water to the original body of water. The artificial discharge channel dissipates some of the heat gained in the cooling stream by transference to the atmosphere via convective and radiative heat transfer. This technology is currently utilized at Labadie and is clearly technically feasible for Labadie with reliable performance. Its continued use would not entail additional costs, additional emissions, or vapor plume impacts.

Table 4-3: Once-Through Cooling with Discharge Channel Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	N/A	850 MMBtu/hr (6.8%)[6]
Total Life Cycle Costs	N/A	$0
Capital Costs	N/A	$0
Annual O&M Costs (additional)	N/A	$0
Cost per heat load reduction	N/A	$0/MMBtu

[6] Appendix D.3 of *The Determination of Appropriate Thermal WQBEL and TBEL for the Ameren Labadie Energy Center* dated March 5, 2018 demonstrates a discharge temperature drop of approximately 2%. That Appendix D.3 also illustrates an average temperature drop during the summer months of approximately 1.5%. At peak summer conditions, the plant adds approximately 24.8 F worth of heat to the intake flow and has maximum discharge temperature (to the discharge channel) of 112.9 F. A 1.5% reduction of that maximum temperature yields a 1.7 F temperature drop from the discharge channel. By providing 1.7 F of cooling, the discharge channel provides approximately 6.8% of thermal load reduction (1.7 F / 24.8 F).

ED_005618_00000108-00044

4.14.2 Mechanical Draft Cooling Towers

Wet cooling towers reduce the temperature of a water stream by extracting heat from the water and emitting it to the atmosphere via evaporation of a small portion of the water stream. Mechanical draft towers use fans to draw air through falling circulated water. The water falls over fill surfaces, which helps increase the contact time between the water and the air, maximizing heat transfer between the two. A portion of the water evaporates, which cools the remainder of the water. Cooling rates of mechanical draft towers depend upon various parameters, such as air to water surface area which affect the size of the tower and air volume which affect the auxiliary power load, and the volume of water flowing through the tower.

There are two predominate methods for air flow direction in cooling towers, counterflow and crossflow. In crossflow towers the air flows horizontally, across the downward fall of water. In counterflow towers the air moves vertically upward through the fill, counter to the downward fall of water. Counterflow towers require a higher pump head and more maintenance than crossflow towers because of their complex water distribution system. However, they are more efficient than crossflow towers and, therefore, are typically much smaller.

There are two main groups of tower fill: film fill and splash fill. Film fill has a high surface area to volume ratio making it more efficient, but can only be used in relatively clean water (low suspended solids and low biological growth water) so it is typically used in closed loop applications where a treated makeup water source is used with chemical feed systems. The mechanical draft cooling tower alternatives are based on using counterflow high efficiency film fill with a treated makeup water source because the tower cost savings with this type of tower (much smaller than crossflow and splash fill) outweigh the additional costs for water treatment.

Mechanical draft towers are available in a large range of capacities and can be grouped together in assemblies of two or more individual cooling towers or "cells." Multiple-cell towers can be linear, square, or round depending upon the shape of the individual cells and whether the air inlets are located on the sides or bottoms of the cells. The most efficient and common designs are long rectangular configurations. The mechanical draft tower basis was a long rectangular configuration.

The air exhausted from a mechanical draft tower has a high moisture content from the evaporative heat transfer process within the tower. During cooler ambient condition the moist air can cause fogging near and down-wind of the tower. Fogging can inhibit visibility creating safety issues that impact plant operation. The moist air can also condense and form rime ice on down-wind facilities creating excessive

ED_005618_00000108-00045

structural load on nearby over-head power lines and slick surfaces creating safety issues that impact plant operations.

Table 4-4: Mechanical Draft Cooling Tower Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	3,100 MMBtu/hr (24.99%)	12,400 MMBtu (99.97%)
Total Life Cycle Costs	$271 million	$821 million
Capital Costs	$152 million	$394 million
Annual O&M Costs (additional)	$4.4 million	$15.5 million
Cost per heat load reduction	$87,400/MMBtu	$66,200/MMBtu

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the new water treatment systems, chemical feed systems, collector well pumps and equipment, and cooling tower equipment. Additional new solid waste management and disposal costs would be incurred, and a new wastewater discharge stream would need to be permitted for the continuous blowdown from the tower(s). Mechanical draft cooling towers would further involve: consumptive water loss; potentially significant noise emissions increase compared to existing conditions; and the possibility of adverse vapor plume impacts on transmission lines proximate to Labadie.

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

4.14.3 Plume Abated (Hybrid) Mechanical Draft Cooling Towers

Plume abated towers are a form of a mechanical draft cooling tower with hybrid cooling characteristics. These towers have very similar designs and operations to non-plume abated mechanical draft cooling towers discussed in Section 4.14.2. However, they reduce visual plumes by reducing the exhaust air relative humidity. Plume abatement can be done various ways, specific to each supplier. Some methods include mixing dry ambient air with the wet air leaving the tower fill to reduce the moisture in the exhaust air. Other methods include using coils to cool a portion of the water by a dry method to reduce overall

ED_005618_00000108-00046

evaporation and moisture in the exhaust air, which is why these towers are considered a form of hybrid (wet and dry) cooling towers. These are the most cost-effective hybrid towers for a retrofit, and therefore other types of hybrid cooling (i.e., parallel hybrid cooling) were not evaluated. By reducing the relative humidity of the exhaust air, the plume abated towers dramatically reduce the potential development of ground fog and rime icing (plume impacts).

This alternative is very similar to the mechanical draft cooling tower alternatives, with similar tower locations, circulating water pipe routing, and water makeup and treatment design.

Table 4-5: Plume Abated Mechanical Draft Cooling Tower Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	3,100 MMBtu/hr (24.99%)	12,400 MMBtu (99.97%)
Total Life Cycle Costs	$310 million	$953 million
Capital Costs	$186 million	$509 million
Annual O&M Costs (additional)	$4.4 million	$15.5 million
Cost per heat load reduction	$100,000/MMBtu	$76,900/MMBtu

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the new water treatment systems, chemical feed systems, collector well pumps and equipment, and cooling tower equipment. Additional new solid waste management and disposal costs would be incurred, and a new wastewater discharge stream would need to be permitted for the continuous blowdown from the tower(s). Plume abated cooling towers would further involve: consumptive water loss (less than for mechanical draft cooling) and potentially significant noise emissions increase compared to existing conditions. This technology would reduce the potential vapor plume impacts associated with traditional mechanical draft cooling towers.

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

ED_005618_00000108-00047

4.14.4 Natural Draft Cooling Towers

Natural draft towers are a form of a wet cooling tower configured in a vertical hyperbolic stack configuration and rely on differential air density to achieve air flow through the tower. These towers have no fans. Air at the base of the tower is heated by the cooling water flowing through the tower fill, thus making it less dense than the ambient air. These towers need to be extremely tall, often more than 500 feet in height, to achieve the stack effect. As hot air moves upwards through the tower, cooler ambient air is drawn into the tower through an inlet at the bottom and passes by water falling over fill surfaces, which transfers heat from the water to the air.

This alternative is very similar to the mechanical draft cooling tower alternatives, with similar tower locations, circulating water pipe routing, and water makeup and treatment design.

Table 4-6: Natural Draft Cooling Tower Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	3,100 MMBtu/hr (24.99%)	12,395 MMBtu (99.91%)
Total Life Cycle Costs	$316 million	$977 million
Capital Costs	$208 million	$581 million
Annual O&M Costs (additional)	$3.9 million	$14.1 million
Cost per heat load reduction	$101,900/MMBtu	$78,800/MMBtu

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the new water treatment systems, chemical feed systems, collector well pumps and equipment, and cooling tower equipment. Additional new solid waste management and disposal costs would be incurred, and a new wastewater discharge stream would need to be permitted for the continuous blowdown from the tower(s). Natural draft cooling towers would further involve consumptive water loss and vapor plume impacts (at a higher elevation due to the increased stack height, resulting in minimal ground fog and rime ice) but minimal noise emissions increase compared to existing conditions. This alternative has the potential to raise concerns associated with the stack height.

ED_005618_00000108-00048

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

4.14.5 Dry Cooling

Dry cooling systems use ambient air as the cooling medium to condense the steam turbine exhaust. There are two main dry cooling options: direct cooling and indirect cooling. Direct cooling systems, known as air cooled condensers (ACC), directly transfer heat from the steam to the atmosphere and condense the steam inside tubes. Indirect cooling systems, sometimes considered air cooled heat exchangers (ACHE), transfer heat from the circulating water (inside tubes) to the atmosphere. Both options utilize fans to force ambient air across finned-tube heat exchangers to increase heat transfer. Dry cooling performance is based on ambient dry bulb temperature, while wet cooling tower performance is based on ambient wet bulb temperature. Consequently, wet cooling typically results in better cooling performance.

Dry indirect cooling was initially considered in this evaluation but was eliminated because it would result in extremely high backpressure that would trip the steam turbine and it would result in exceptionally high costs. Therefore, it was considered infeasible for this application and eliminated from the evaluation.

ACC relies on close coupling the heat exchanger to the turbine to reduce high pressure drops in piping. An ACC requires space to attach a large steam duct on the steam turbine exhaust in place of the wet condenser and to route the steam duct to an area large enough to place the heat exchanger. If investigated in further detail, it is likely this technology would be deemed technically infeasible for Labadie because of one or more of the following: 1) space allocations at the turbine exhaust do not exist to attach the steam duct 2) insufficient space to route steam duct from the turbine to an open area where the ACC can be located 3) steam duct length would be extremely long causing a high pressure drop in the duct, resulting in a steam turbine backpressure which exceeds the alarm/trip.

Table 4-7: Dry Cooling Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	3,060 MMBtu/hr (24.66%)	12,240 MMBtu (98.63%)
Total Life Cycle Costs	$332 million	$1,067 million
Capital Costs	$193 million	$570 million

ED_005618_00000108-00049

Annual O&M Costs (additional)	$3.6 million	$11.3 million
Cost per heat load reduction	$108,500/MMBtu	$87,200/MMBtu

This technology is not known to have been used to retrofit an existing power plant, which makes the technical feasibility of this alternative for Labadie questionable. Moreover, Labadie space constraints would likely preclude the necessary close-coupling of the heat exchangers to the turbines. A more remote location is expected to result in high turbine back pressure, likely exceeding turbine trip limits. Therefore, this retrofit alternative is viewed to be technically infeasible at Labadie.

Parallel hybrid cooling (wet and dry cooling) was considered for this evaluation, but was not included for the screening evaluation because it is subject to the same feasibility challenges as the dry cooling alternative, discussed above, with high associated costs. Since plume abated towers can act as a form of hybrid cooling and are more cost-effective than parallel hybrid cooling, and because dry cooling was viewed as technically infeasible for Labadie, parallel hybrid cooling was eliminated as an alternative for the screening evaluation.

4.14.6 Permanent Helper Cooling Towers

The permanent helper cooling tower alternative is like the mechanical draft cooling tower alternative, except it cools untreated water from the discharge channel and returns it to the discharge channel instead of recirculating cooling water through the units. This alternative reduces the heat load to the river but barely reduces the flow discharged to the river (some water is consumed by evaporation). Additionally, this alternative was based on the use of splash type fill because, although less efficient than film fill, splash fill allows the use of untreated river water with high suspended solids without concern for plugging. The helper tower is crossflow to minimize footprint, pump head, and because it is the most cost-effective tower type when using splash fill.

Table 4-8: Permanent Helper Cooling Towers Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	2,690 MMBtu/hr (21.70%)	10,760 MMBtu (86.76%)
Total Life Cycle Costs	$143 million	$483 million
Capital Costs	$92 million	$291 million

ED_005618_00000108-00050

Annual O&M Costs (additional)	$1.1 million	$3.9 million
Cost per heat load reduction	$53,200/MMBtu	$44,900/MMBtu

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the new chemical feed systems (periodic), pumps, and cooling tower equipment. This alternative would further involve: consumptive water loss; potentially significant noise emissions increase compared to existing conditions; and vapor plume impacts. This screening analysis identified the possibility of adverse vapor plume impacts on transmission lines proximate to Labadie. The associated outage period would be less than for closed loop mechanical draft cooling. However, the helper tower(s) could be operated only part of the year, such as the summer, which would reduce these requirements and costs.

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

4.14.7 Temporary Helper Cooling Towers

The temporary helper cooling tower alternative is like the permanent helper tower alternative, except it utilizes rented temporary towers, pumps and piping rather than permanent facilities. This alternative would still require permanent facility modifications to supply power and foundation for the rental equipment. This technology would only be rented and used when necessary, providing a non-permanent alternative. This technology also has widely variable pricing based on market demand and rental duration.

Table 4-9: Temporary Helper Cooling Towers Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	2,250 MMBtu/hr (18.12%)	8,990 MMBtu (72.48%)
Total Life Cycle Costs	$188 million	$706 million
Capital Costs	$21 million plus $6.9 million per 3 months	$51 million plus $27.5 million per 3 months
Annual O&M Costs (additional)	$0.5 million	$1.2 million

ED_005618_00000108-00051

Cost per heat load reduction	$83,600/MMBtu	$78,500/MMBtu

This technology is not known to have been used to retrofit an existing power plant at a scale approaching the size of Labadie. The technical feasibility of the alternative for Labadie is questionable for that reason alone. Furthermore, this alternative may be technically feasible for one unit, but because of unpredictable market fluctuations in terms of helper tower rental availability and cost, it is likely difficult to procure sufficient rental towers for all four units when they are needed. Given the lack of a pertinent proven prior application and the unreliability of market conditions, this alternative is considered technically infeasible for Labadie.

4.14.8 Cooling Pond

The cooling pond alternative is like the permanent helper tower alternative, except the cooling pond consists of a shallow large body of water where cooling water is circulated from one end to the other to allow the water to cool through surface evaporation and convective heat transfer. The cooling pond drains to the artificial discharge channel. The cooling pond would inherently require a large surface area to cool the water. There is around 600 acres available for a cooling pond. A pond this size would adequately reject a fraction of the heat load of one unit (~65%). Therefore, this alternative is not feasible for the entire plant heat load and was not evaluated for any size larger than a portion of one unit.

A closed loop cooling pond was initially considered as an alternative but was eliminated because there is insufficient land readily available to fully retrofit one unit and because there are no known uses of this technology to retrofit an existing power plant near the size of Labadie.

Table 4-10: Cooling Pond Screening Results

	Portion of One Unit Level
Heat Load Reduction	1,420 MMBtu/hr (11.43%)
Total Life Cycle Costs	$227 million
Capital Costs	$197 million
Annual O&M Costs (additional)	$1.0 million
Cost per heat load reduction	$159,900/MMBtu

ED_005618_00000108-00052

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the additional pumps and the pond, which would be subject to biological growth which would need to be controlled to maintain pond performance. This requires periodic chemical treatment and cleaning. This alternative would further involve a consumptive water loss.

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

4.15 Screening Analysis Results

The alternative technologies were screened based on the criteria and information described in Section 4.14. That screening process (summarized below) identified the following three technology alternatives for more detailed analysis:

A. Once-Through Cooling with Discharge Channel

B. Mechanical Draft Cooling Tower / Plume-Abated Cooling Tower

C. Permanent Helper Cooling Tower

These three alternatives were, for the purposes of the screening assessment, viewed to be technically feasible. They were identified by the screening assessment as the top three technically feasible alternatives in terms of cost per heat load reduction and total life cycle costs. The Four Unit Level of heat load reduction of each mechanical draft cooling tower and permanent helper cooling tower alternative was determined to be above 86%. The screening results for the remaining alternatives are discussed below.

While cooling ponds are proven at the scale of Labadie, such would require unreasonable land acquisition and development. Additionally, conversion to dry cooling (ACC) is identified as infeasible because of space constraints at and near the steam turbines along with challenges of routing large steam ducts without increasing operating pressure above steam turbine limits. Moreover, even were these alternatives (cooling Ponds and dry cooling) technically feasible, they would not be recommended for further evaluation based on their poor cost per MMBtu heat load reduction value and other criterion relative to other alternatives which could achieve the same or superior thermal load reductions. That is, the cooling pond and ACC alternatives respectively ranked last and second to last, for cost per MMBtu heat load

ED_005618_00000108-00053

reduction. Even though it may be technically feasible, the natural draft cooling tower alternative ranked third to last in that category. The poor rankings of those alternatives mean they are not cost-effective options to reduce heat load to the river compared to other feasible options. Therefore, the cooling pond, dry cooling and natural draft cooling tower alternatives were eliminated from the evaluation for more detailed assessment.

The temporary helper cooling tower alternative poses technical feasibility concerns as well in that the technology is not known to have been applied at a similar scale and would entail likely high variability in terms of cost and equipment availability. Additionally, it did not rank among the top three alternatives in terms of cost per heat load reduction. This alternative was eliminated from the evaluation for more detailed assessment.

The plume-abated cooling tower alternative was merged with the mechanical draft tower alternative for more detailed evaluation.

ED_005618_00000108-00054

5.0 DETAILED ANALYSIS OF SCREENED TECHNOLOGIES

5.1 Technologies Screened Forward and Method of Detailed Analysis

The alternative technologies selected from the screening evaluation for a more detailed analysis are considered potentially reasonable and appropriate for Labadie for the following reasons:

- Each is a proven technology at scales equal to or similar to Labadie. These technologies are well understood in the industry.
- Each ranked among the top three of technically feasible alternatives in terms of cost per MMBtu of heat load reduction.
- Each could encompass an appropriate range of heat load reduction (minimum of one unit up to a maximum of all four units)

It is theoretically possible to use different cooling technology alternatives for different Labadie units. However, given the similarity of the units both in terms of design and utilization, there is no apparent basis to apply different technologies to different units. Therefore, neither the screening analysis nor the detailed analyses of this Section 5 considers mixing of different technologies for different units.

The detailed analysis methodology applied to the screened forward alternatives include consideration of many of the same criteria as considered in the screening analysis. However, the detailed analysis went further in the following ways:

- Developed additional design basis for each option to establish more accurate pricing (Class 4 capital cost estimates versus Class 5 in screening analysis)
    - Major mechanical, electrical, and some civil quantities were developed for each option for cost estimating purposes
- Considered additional site-specific criteria which impacted scope and design basis, including, but not limited to the following:
    - Location of equipment because of plume impacts and site constraints
    - Elevation impacts and requirements
    - Existing electrical feed limitations

ED_005618_00000108-00055

- Budgetary quotes and sizing information were solicited for major equipment including cooling towers and transformers

5.2 Detailed Analysis

The narratives of each technology evaluated in the detailed analysis, which are included later in this Section 5.2, focus on the Four Unit Level reduction option since they require the most extensive changes. The One Unit Level reduction option would be similar in scope, but scaled down for just one unit.

5.2.1 Detailed Analysis Design Basis Parameters

Table 5-1 summarizes the design basis used for each screened forward option.

ED_005618_00000108-00056

Table 5-1: Detailed Analysis Design Basis Parameters

Technology Option	Once Through Cooling with Discharge Channel	Mechanical Draft / PA Cooling Tower (Low / High)	Permanent Helper Cooling Tower (Low / High)
Tower Type	N/A	Counterflow, H/E fill	Crossflow, splash fill
Number of Cells (per tower)	N/A	20 – mech draft / 28 – plume abated	21
Tower Dimension (each)	N/A	480 ft (L) x 88 ft (W) / 672 ft (L) x 98 ft (W)	672 ft (L) x 75 ft (W)
Design Wet Bulb	79.9°F	79.9°F	79.9°F
Design Approach (+2°F recirc allowance)	Varies with river temperature	7°F	7°F
Design Range	24.8°F	24.8°F	24.8°F
Water Flow Rate (each)	251,500 gpm	251,500 gpm	251,500 gpm
Drift	N/A	0.0005%	0.0005%
Plume Abatement	N/A	Included for PA option	N/A
Level	N/A	Level 1	N/A
Design	N/A	35°F dry bulb, 90% RH	N/A
Plant Modifications	N/A	Upgrade condenser waterboxes Several specialized tie-ins for large circ water pipe Electrical modifications	Electrical modifications
Circ Water Pipe Largest Diameter	96 inches	138 inches (all units) / 96 inches (one unit)	138 inches (all units) / 96 inches (one unit)
Circ Water Pumps	Existing	New: 2 to 8	New: 4 to 16
Design Flow Rate (per pump)	125,500 gpm	125,500 gpm	125,500 gpm
Design TDH	56 ft	108 ft - 112 ft (varies) / 106 ft - 110 ft (varies) PA	70 ft - 74 ft (varies) / 12 ft – 14 ft (varies)
Water Treatment	N/A	Clarification/filtration (4 COC), chem feed	Chem feed: biological
Raw Water Source	River water	Collector well(s)	River water
Electrical Design	Existing infrastructure	Substation / 345kV xmfr 4160/480swgr/MCC	Substation / 345kV xmfr 4160/480swgr/MCC

ED_005618_00000108-00057

5.2.2 Detailed Analysis Costs

Capital costs, O&M costs, and life cycle costs developed from the detailed analysis are presented in Table 5-2.

5.2.2.1 Detailed Analysis Cost Basis

An indicative Labadie-specific screening-level capital cost estimate, consistent with AACE Class 4, was developed for each selected alternative for One Unit Level and Four Unit Level options. Like the screening analysis, the One Unit Level and Four Unit Level capital costs provide adequate range and "bookend" costs for implementing each technology. The estimates were developed based on parametric models using previous projects and quotes as reference. Quantities were developed for circulating water pipe, civil fill, and electrical for each option and used to adjust reference project costs. Budgetary quotes were received for cooling towers, transformers and some other electrical equipment. Remaining equipment costs were developed by scaling and adjusting recent equipment pricing using established cost and design relationships. Installation costs were estimated by adjusting installation hours from recent similar project based on scope, equipment sizes, equipment costs, and quantities. All cost groups were combined to develop screening level total direct costs. St. Louis area specific labor rates were included to adjust associated costs.

The costs developed as part of this evaluation represent technology retrofit for one unit (One Unit Level) and all units (Four Unit Level), which establish the low and high end of the cost range. Class 4 capital costs to retrofit a capacity within this range, such as two (50%) or three (75%) units, are expected to be mostly linear in between the presented low and high costs for the purposes of this Section 5. However, there will be some non-linear cost behavior due to economies of scale and step changes in design (i.e., circulating water pipe common supply among units and water treatment installation costs – sharing among units).

Capital cost estimates for the detailed analysis are summarized in Table 5-2.

Annual fixed and variable O&M costs were estimated for each screened forward alternative. The O&M cost basis for this evaluation was the same as the basis for the screening analysis (Section 4.4).

Estimated O&M costs are presented in Table 5-2.

ED_005618_00000108-00058

O&M costs to retrofit a design within the One Unit Level and Four Unit Level range, such as two (50%) or three (75%) units, are expected to be mostly linear in between the presented low and high costs for the purposes of this Section 5.

Life cycle costs were developed for each screened forward alternative using the same methodology used for the screening analysis (Section 4.2) based on the same economic parameters summarized in Table 4-1.

ED_005618_00000108-00059

Table 5-2: Detailed Analysis Cost Summary

Item Description	Once Through Cooling with Discharge Channel	Mechanical Draft Cooling Tower[1]	Permanent Helper Cooling Tower
Four Unit Level			
Capital Costs (AACE Class 4)			
Total Direct Costs		$258,900,000	$239,600,000
Total Indirect Costs		$46,800,000	$36,700,000
Total Project Costs		$420,500,000	$380,100,000
O&M Costs		$14,700,000	$4,900,000
Life Cycle Costs		$851,000,000	$614,000,000
$/MMBtu Heat Load Reduced		$68,600/MMBtu	$57,100/MMBtu
One Unit Level			
Capital Costs (AACE Class 4)			
Total Direct Costs		$98,600,000	$82,500,000
Total Indirect Costs		$27,900,000	$21,100,000
Total Project Costs		$174,000,000	$142,400,000
O&M Costs		$4,300,000	$1,700,000
Life Cycle Costs		$297,000,000	$210,000,000
$/MMBtu Heat Load Reduced		$95,800/MMBtu	$70,200/MMBtu

Notes: [1] Mechanical draft cooling tower costs are shown because this alternative resulted in lower cost than plume abated tower alternative.

ED_005618_00000108-00060

5.2.3 Once Through Cooling With Discharge Channel

The existing once through cooling and discharge channel system requires the lowest auxiliary load and no plant efficiency loss (i.e., it produces the lowest average turbine backpressure), and entails no additional life cycle costs. This method of cooling maintains the current thermal load to the river of 11,560 MMBtu/hr (estimated during peak summer conditions for all units). A portion of the plant heat load is dissipated in the discharge channel (about 6.8%) before reaching the river. This method of cooling is the only non-consumptive method of the screened forward alternatives. It also adds no new wastewater or solids disposal requirements to the environment. This alternative requires no process changes and has no additional environmental impacts.

5.2.4 Mechanical Draft Cooling Towers

The mechanical draft cooling tower alternative would reduce the heat load on the river by an estimated 12,402 MMBtu/hr (at summer peak conditions) when retrofitted for all units. However, accomplishing this would require an estimated $421 million capital expenditure and an estimated **total life cycle cost of $851 million**. This alternative would result in an estimated 6,570 GWh of lost power generated by Labadie over the 30-year duration. Conversion would require new cooling towers, pumps and interconnecting piping, new condenser water boxes, a new makeup water system and new water treatment systems (and chemical feed), new electrical power supply systems, new building structures, and waste disposal cost.

During the detailed analysis it was determined that the location of the towers used in the screening analysis cost basis would likely present significant plume impacts at the plant (safety concerns) and potential excessive rime ice development on the transmission lines, which would threaten plant operations. Therefore, all non-plume abated cooling towers were relocated farther northeast from the plant. Conceptual sketches, SK-001 and SK-002, are provided in Appendix B for the One Unit Level and Four Unit Level options, respectively.

For the Four Unit Level conversion, four new 480 ft x 88 ft concrete cooling tower basins with a 52 ft. tall cooling tower and cooling water pump structures would be required. Additional civil fill would be required for all tower options (mechanical draft, plume abated, and helper towers) to increase elevation above the flood plain. This alternative would require eight new 4,200 HP circulating water pumps in the cooling tower pump structures. The existing intake pumps could be decommissioned. The location of the towers would require over 18,000 feet of interconnecting 138” diameter pipe and 4,000 feet of interconnecting 96” diameter pipe between the cooling towers and the existing cooling water pipe. Based

ED_005618_00000108-00061

on design data, the existing circulating water pipe should have sufficient design pressure for the expected operating system pressure. However, this evaluation did not consider the actual condition of the existing pipe.

This alternative would require up to eight new specialized tie-ins to large diameter concrete cooling water piping along with an associated plant outage of several weeks. A new makeup water system with pumps and interconnecting piping would be required. It is assumed the new pumps would be installed in new collector wells. A new water treatment system with clarifier and chemical feed systems would be required. The water treatment system would generate sludge which would require a sludge disposal cost. The new cooling tower would recycle water requiring a chemical feed system for water quality control including chlorination, dispersant, inhibitor, acid and a blowdown for water chemistry control. The blowdown would need de-chlorination equipment and would be a new wastewater discharge to the environment.

During the detailed analysis it was determined there is insufficient power feed capacity at the facility for any of the options evaluated. Therefore, the design and cost basis include a new 345 kV substation, 4160 V and 480 V transformers, switchgear and motor control centers (MCC)s. The new electrical loads will also require raceway and cabling. The stated life cycle costs assume the electrical tie-ins would be completed during the same outage as the pipe tie-ins. New control systems would be required for the new mechanical and electrical systems, which would also require integrations to be completed during the outage. New buildings would be required for the water treatment systems and chemical feed systems, and mechanical and electrical equipment.

As described above, it was determined that the tower locations in the screening analysis would likely produce adverse plume impacts near the plant, which could result in safety concerns and threaten plant operation (rime ice on transmission lines). Therefore, without plume abatement, cooling towers should be located farther northeast from the plant to adequately reduce these concerns. As an alternative to locating mechanical draft towers farther from the plant, this analysis considered plume abated tower(s) located closer to the plant. Conceptual sketches of these plume abated alternatives, SK-003 and SK-004, are in Appendix B. It is expected that this plume abated tower alternative would sufficiently reduce transmission line icing concerns (potential icing may occur during extreme weather events). However, the additional cost of plume abated towers is greater than the costs to relocate the mechanical draft towers farther northeast. The plume abated alternative would have estimated **total life cycle costs of $964 million** (an additional $113 million beyond the total life cycle costs for the mechanical draft cooling towers at the locations shown in SK-002). Since the plume abated alternative results in higher costs than

ED_005618_00000108-00062

the mechanical draft alternative, the mechanical draft alternative is deemed the best alternative between the two for this analysis. Therefore, Table 5-2 summarizes the estimated costs for the mechanical draft alternative.

The mechanical draft cooling tower alternative is expected to have a schedule of about 96 months (eight years) to complete design, permitting, procurement, construction, and startup for all four units. Much of this duration is tied to procurement and construction. This duration is based on completing the first unit conversion and much of the balance of plant work (and all permitting and design) within 48 months. Then, each successive unit is expected to take about 16 months to install, finish associated balance of plant work, complete startup and complete outage tie-ins (separate for each unit). This approach results in an optimized schedule, which reduces overall project duration.

5.2.5 Permanent Helper Cooling Towers

This alternative would reduce the heat load on the river by an estimated 11,960 MMBtu/hr (when operated at summer peak conditions). Accomplishing this heat load reduction would require an estimated $380 million capital expenditure and an estimated **$614 million in total life cycle costs**. This alternative would result in an estimated 6,280 GWh of lost power generated by Labadie over the 30-year duration based on 82% annual capacity factor with towers operating whenever the plant operates. Since these cooling towers would not recirculate water to the units for condenser cooling, their operation would not be required to operate the units. Therefore, these cooling towers could be operated year-round or only operated during the summer.

Plume abated towers were earlier compared to mechanical draft towers located farther from the plant, as summarized in Section 5.2.4, which showed that relocating the towers was the more cost-effective alternative. Therefore, the towers for this alternative were located similarly to the towers for the mechanical draft cooling tower alternative and plume abated options were not evaluated. If the towers were only operated during the summer months, then plume impacts would not be a concern and the towers could be located closer to the plant, which would result in capital cost savings.

Conversion would require similar new equipment as described in Section 5.2.4, except for the makeup water system. The helper tower alternative would not require any water makeup (no collector wells and no water treatment) nor condenser water box upgrades. No-tie ins would be required, but temporary dams would need to be built to construct the new intake and outfalls. However, without some form of permanent dams in the discharge channel, some water will bypass the pump intake to the helper towers and reduce the effectiveness of the helper towers at reducing heat load to the river. Variable gates/dams

ED_005618_00000108-00063

could be installed in the discharge channel to divert all flow to the helper towers when in operation and then allow for normal flow through the discharge channel when the helper towers are not operating. This scope was not considered necessary for the feasibility of this alternative and was, therefore, not included for this report.

This alternative would require smaller and fewer building structures. Furthermore, this alternative would require 672 ft x 75 ft concrete cooling tower basins with 62 ft. tall crossflow cooling towers and cooling water pump structures at the towers and at the discharge channel. It would include eight new 2,700 HP circulating water pumps at the new discharge channel pump structure and eight new 450 HP water pumps at the tower pump structures. This alternative would also require over 18,000 feet of interconnecting 138" diameter pipe between the cooling towers and the existing cooling water pipe and discharge channel along with over 4,500 feet of 96" diameter pipe.

This alternative would require a small chemical feed system (periodic chlorination and de-chlorination), but no water treatment equipment because of the towers' splash fill. A new electrical substation with transformers, switchgear, MCCs, and associated cabling would also be required.

The permanent helper cooling tower alternative is expected to have a schedule of about 89 months (over seven years) to complete design, permitting, procurement, construction, and startup for all four units. Much of this duration is tied to procurement and construction. This duration is based on completing the first unit and much of the balance of plant work (and all permitting and design) within 44 months. Then, each successive unit is expected to take about 15 months to install, finish associated balance of plant work, complete startup and complete outage tie-ins. This approach results in an optimized schedule, which reduces overall project duration.

ED_005618_00000108-00064

6.0 SUMMARY

The purpose of this report was to identify and compare alternative cooling technologies which are or could be applied at Labadie. The evaluation included selection of technically feasible and commercially available technologies with proven capabilities and assessing their capabilities, costs and impacts as applied to Labadie. The evaluation included review of impacts to cooling flow and heat load discharged to the river, overall environmental impacts, site constraints, costs, plant interconnect outages and impacts on plant output and efficiency.

Once-through cooling with an artificial discharge channel and two alternative technologies were identified as technically feasible and the most reasonable and appropriate for more detailed evaluation. The detailed analysis included more detailed cost estimates based on further review of the site arrangement of the new equipment associated with each alternative, options for addressing cooling tower plume issues, and electrical power supply requirements.

ED_005618_00000108-00065

7.0 REFERENCES

Ameren Missouri (Ameren). (2017a). Labadie Operating Data for 2002-2017 for MDNR. St. Louis, Missouri.

Ameren Missouri (Ameren). (2017b). Labadie Water Temperature and Output Operating Data. St. Louis, Missouri.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2013). *ASHRAE Handbook – Fundamentals, Spirit of St. Louis Station.*

Kleinfelder. (2018). *The Determination of Appropriate Thermal WQBEL and TBEL for the Ameren Labadie Energy Center.* Report prepared by R.A. Ferrara of Kleinfelder.

National Renewable Energy Laboratory (NREL). (2013). *Typical Meteorological Year (TMY) Databook, Spirit of St. Louis Station.* Technical Report TP-581-43156. Golden, Colorado.

Whitman, Requardt and Associates, LLP. (2017). *The Handy-Whitman Index of Public Utility Construction Costs.* Baltimore, Maryland.

ED_005618_00000108-00066

APPENDIX A - SCREENING ANALYSIS SUMMARY MATRIX

Privileged and Confidential. Attorney Work Product

Ameren Labadie Thermal Discharge Evaluation
Rev. 4 - 2/23/18 - Draft

Ameren Labadie Screening Matrix

Technologies Evaluated for BAT	Technology Description	*One Unit Level* - Heat Load Reduction	*Four Unit Level* - Heat Load Reduction	*One Unit Level* - Life Cycle Costs	*Four Unit Level* - Life Cycle Costs	*One Unit Level* - Capital Costs	Four Unit Level - Capital Costs	*One Unit Level* - O&M Cost Increase	*Four Unit Level* - O&M Cost Increase	*One Unit Level* - Estimated Auxiliary Load Loss	*Four Unit Level* - Estimated Auxiliary Load Loss	*One Unit Level* - Estimated Tie In Outage	*Four Unit Level* - Estimated Tie In Outage	Level of Risk Increase	Technology Comparative Attributes						
															Footprint	Height	Vapor Plume	PM Emissions Potential	Water Consumption	Noise Emission	Cycle Efficiency Impact (Excludes aux loads)
Once Through Cooling with Discharge Channel	Existing operation. Open loop circulation of cooling water from intake through condensers to discharge channel.	N/A	850 (6.8%)	$0	$0	$0	$0	$0	$0	0 kW	0 kW	N/A	N/A	No additional risks	None	None	No Changes	No Changes	None to minimal	No change	No impact to cycle efficiency
Mechanical Draft Cooling Towers	Counterflow, induced draft, high efficiency fill, fiberglass, evaporative cooling tower(s): Convert to closed loop cooling. New circ pumps supply cooling water to condenser via new pipe tied to existing supply pipe. New pipe tied to discharge pipe returns water to cooling tower for heat rejection.	3,100 MMBtu/hr (24.99%)	12,400 MMBtu/hr (99.97%)	$271,000,000	$821,000,000	$152,000,000	$394,000,000	$4,400,000	$15,500,000	7,100 kW	25,600 kW	2 to 4 weeks	3 to 6 weeks (can be overlapped or staggered)	Medium: Ice damage on adjacent overhead lines	Base: 3 acres for Low to 8 acres for High; 1.3 acres per tower	Typically 40 to 60 ft	Lower elevation plume; fogging / icing can occur	Base: 5 tpy (low) - 20 tpy (high), based on 4 COC (depends on COC design)	8 to 12 gpm/MW	Moderate: Fan and cascading water noise	$4,100,000 life cycle cost per unit; Estimated 3 MW loss per unit during peak summer conditions
Natural Draft Cooling Towers	Counterflow, natural draft, high efficiency fill, concrete, evaporative cooling tower(s): Convert to closed loop cooling. New circ pumps supply cooling water to condenser via new pipe tied to existing supply pipe. New pipe tied to discharge pipe returns water to cooling tower for heat rejection.	3,100 MMBtu/hr (24.98%)	12,395 MMBtu/hr (99.91%)	$316,000,000	$977,000,000	$208,000,000	$581,000,000	$3,900,000	$14,100,000	3,800 kW	12,500 kW	2 to 4 weeks	3 to 6 weeks (can be overlapped or staggered)	Medium: Poor public perception, field labor intensive	Slightly Smaller than Base	High: > 500 ft	Higher elevation plume; minimal, if any, fogging / icing	Base: 5 tpy (low) - 20 tpy (high), based on 4 COC (depends on COC design)	8 to 12 gpm/MW	Low: Minimal cascading water noise	$10,500,000 life cycle cost per unit; Estimated 7 MW loss per unit during peak summer conditions
Plume Abated (Hybrid) Cooling Towers	Plume abated, counterflow, induced draft, high efficiency fill, fiberglass, evaporative cooling tower(s): Convert to closed loop cooling. New circ pumps supply cooling water to condenser via new pipe tied to existing supply pipe. New pipe tied to discharge pipe returns water to cooling tower for heat rejection.	3,100 MMBtu/hr (24.99%)	12,400 MMBtu/hr (99.97%)	$310,000,000	$953,000,000	$186,000,000	$509,000,000	$4,400,000	$15,500,000	7,500 kW	27,400 kW	2 to 4 weeks	3 to 6 weeks (can be overlapped or staggered)	Low: Reduce ice and fogging risks	Slightly Larger than Base	Typically 60 to 75 ft	Minimal to no plume	Base: 5 tpy (low) - 20 tpy (high), based on 4 COC (depends on COC design)	6 to 12 gpm/MW	Moderate: Fan and cascading water noise	$5,200,000 life cycle cost per unit; Estimated 3 MW loss per unit during peak summer conditions
Dry Cooling (ACC)	Wet condensers are replaced with steam duct and air cooled condenser to reject heat from the steam cycle via air cooling instead of the circulating water loop. Aux cooling system remains as wet cooled system.	3,060 MMBtu/hr (24.66%)	12,240 MMBtu/hr (98.63%)	$332,000,000	$1,067,000,000	$193,000,000	$570,000,000	$3,600,000	$11,300,000	8,200 kW	32,600 kW	3 to 6 weeks	5 to 10 weeks (can be overlapped or staggered)	High: No known conversions to dry cooling; STG exhaust retrofit to steam duct may be infeasible; field labor intensive	Large: 2 to 4 x Base	Typically > 70 ft	No plume	No Changes	None	Moderate: Greatest fan noise and no water noise	$17,900,000 life cycle cost per unit; Estimated 16 MW loss per unit during peak summer conditions

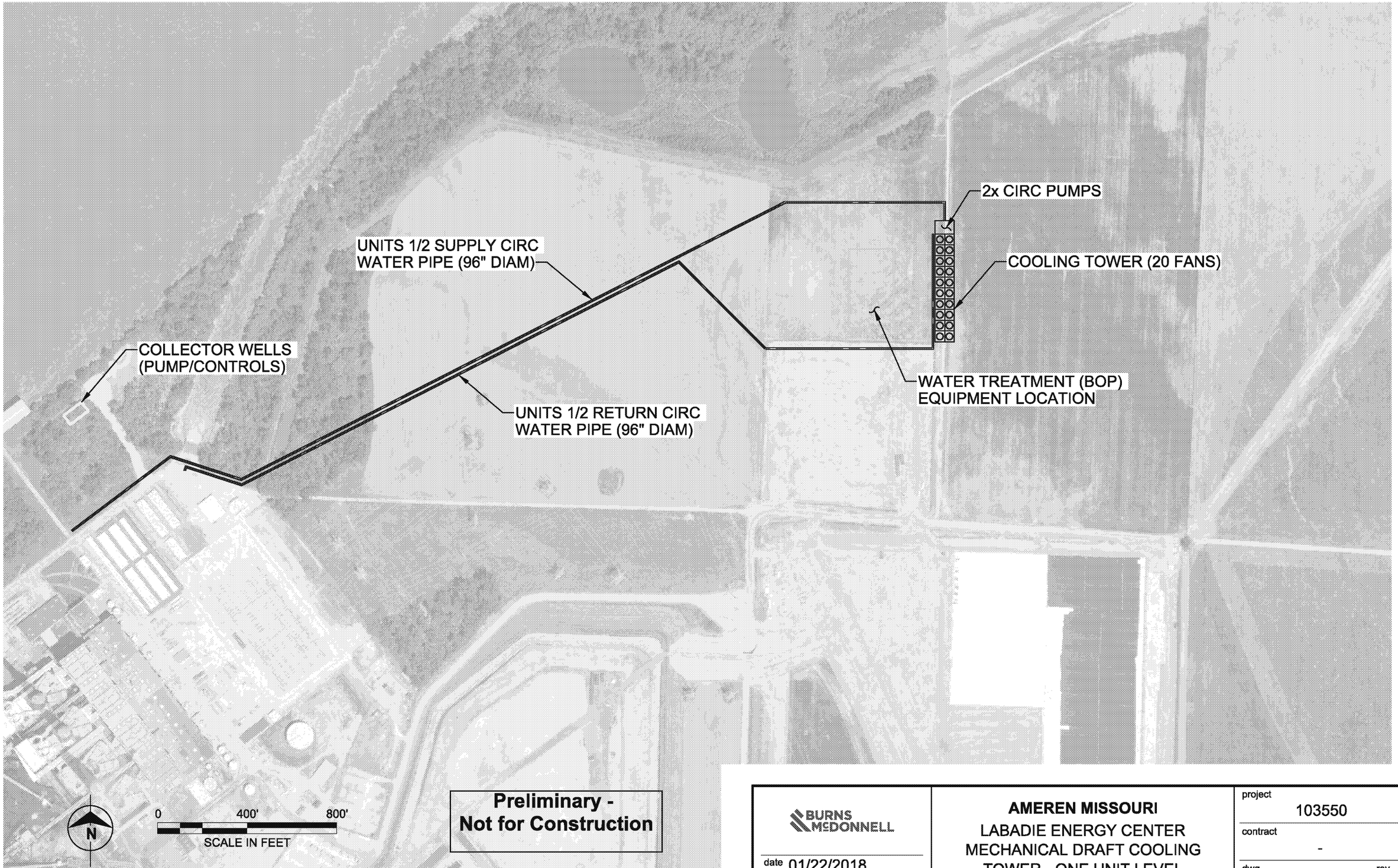
Privileged and Confidential. Attorney Work Product

Ameren Labadie Thermal Discharge Evaluation
Rev. 4 - 2/23/18 - Draft

Ameren Labadie Screening Matrix

Technologies Evaluated for BAT	Technology Description	*One Unit Level* - Heat Load Reduction	*Four Unit Level* - Heat Load Reduction	*One Unit Level* - Life Cycle Costs	*Four Unit Level* - Life Cycle Costs	*One Unit Level* - Capital Costs	Four Unit Level - Capital Costs	*One Unit Level* - O&M Cost Increase	*Four Unit Level* - O&M Cost Increase	*One Unit Level* - Estimated Auxiliary Load Loss	*Four Unit Level* - Estimated Auxiliary Load Loss	*One Unit Level* - Estimated Tie In Outage	*Four Unit Level* - Estimated Tie In Outage	Level of Risk Increase	Technology Comparative Attributes						
															Footprint	Height	Vapor Plume	PM Emissions Potential	Water Consumption	Noise Emission	Cycle Efficiency Impact (Excludes aux loads)
Permanent Helper Cooling Towers	Crossflow, induced draft, splash fill, fiberglass, evaporative cooling tower(s): Maintain open loop cooling. New pumps draw water from discharge channel to supply water to cooling tower(s) for heat rejection. Water exits cooling tower and gravity drains into discharge channel.	2,690 MMBtu/hr (21.70%)	10,760 MMBtu/hr (86.76%)	$143,000,000	$483,000,000	$92,000,000	$291,000,000	$1,100,000	$3,900,000	7,000 kW	27,800 kW	1 week or less	1 week or less	Low/Medium: Ice damage on adjacent overhead lines, if operated in cold weather conditions.	Slightly larger than Base tower (no water treatment): about 1.5 acres per tower	Typically 40 to 60 ft	Lower elevation plume; fogging / icing can occur	Lower than Base: 1.2 tpy (low) - 5 tpy (high)	8 to 12 gpm/MW	Moderate: Fan and cascading water noise	No impact to cycle efficiency
Temporary Helper Cooling Towers	Supplier installs rental towers and associated equipment to operate temporarily (i.e. summer months). Temporary pumps draw water from discharge channel to supply towers. Towers cool water and release back to the discharge channel.	2,250 MMBtu/hr (18.12%)	8,990 MMBtu/hr (72.48%)	$188,000,000	$706,000,000	$21,000,000 one time cost plus $6,900,000 per 3 months	$51,000,000 one time cost plus $27,500,000 per 3 months	$500,000	$1,200,000	7,100 kW	28,500 kW	1 week or less	1 week or less	Medium: Price and availability of rental towers are variable; Ice damage on adjacent overhead lines, if operated in cold weather conditions.	Larger than Base	Typically 15 to 30 ft	Lower elevation plume; fogging / icing can occur if operated during cold weather - unlikely for temporary towers	Lower than Base: 2.5 tpy (low) - 10 tpy (high)	8 to 12 gpm/MW	Moderate: Fan and cascading water noise	No impact to cycle efficiency
Cooling Pond	Maintain open loop cooling. New pumps draw water from discharge channel to suppy water to cooling pond via new pipe for heat rejection via evaporative and sensible cooling. New pipe returns water from pond to discharge channel by gravity drain.	1,420 MMBtu/hr (11.43%)	N/A	$227,000,000	N/A	$197,000,000	N/A	$1,000,000	N/A	2,500 kW	N/A	1 week or less	N/A	Low/Medium: Requires substantial area of land suitable for conversion to pond.	Largest: 600 acres	Developed at higher elevation than discharge channel	Potential fog and ice near pond	Very low	4 to 12 gpm/MW	Low: minimal water noise	No impact to cycle efficiency
Notes about Factor Columns		*Shown as MMBtu/hr and % reduction in heat rejected to river at peak summer conditions. This will vary with load and ambient/river temperature *Assumes all four units are operating with corresponding units retrofitted with technology (one or all four) *Pond options max heat load reduction is for only 65% of one unit because of space limitations		*30 yr NPV *82% capacity factor *5.94% cost of capital *2.4% capital escalation *Power prices: see App C *2.5% O&M escalation *Capacity value: see App C *$0.05/kgal raw water		*Costs are based on preliminary design for One Unit Level (except only part of One Unit Level for pond alternative)	*Costs are based on preliminary design for Four Unit Level	*Includes fixed and variable O&M *Based on 82% capacity factor *Based on $140,000 annual FTE *Does not include replacement power cost (outage) or lost revenue		*Net aux load impact (some options include decomissioning of intake pumps)								*Does not account for potential PM emissions added from other generation source to compensate for lower power production			*Costs based on 30 yr NPV with assumed operating profile: see Appendix C

APPENDIX B - DETAILED ANALYSIS CONCEPTUAL SKETCHES



Preliminary - Not for Construction

BURNS McDONNELL

date 01/22/2018

designed A. MYERS

AMEREN MISSOURI

LABADIE ENERGY CENTER
MECHANICAL DRAFT COOLING
TOWER - ONE UNIT LEVEL

project 103550

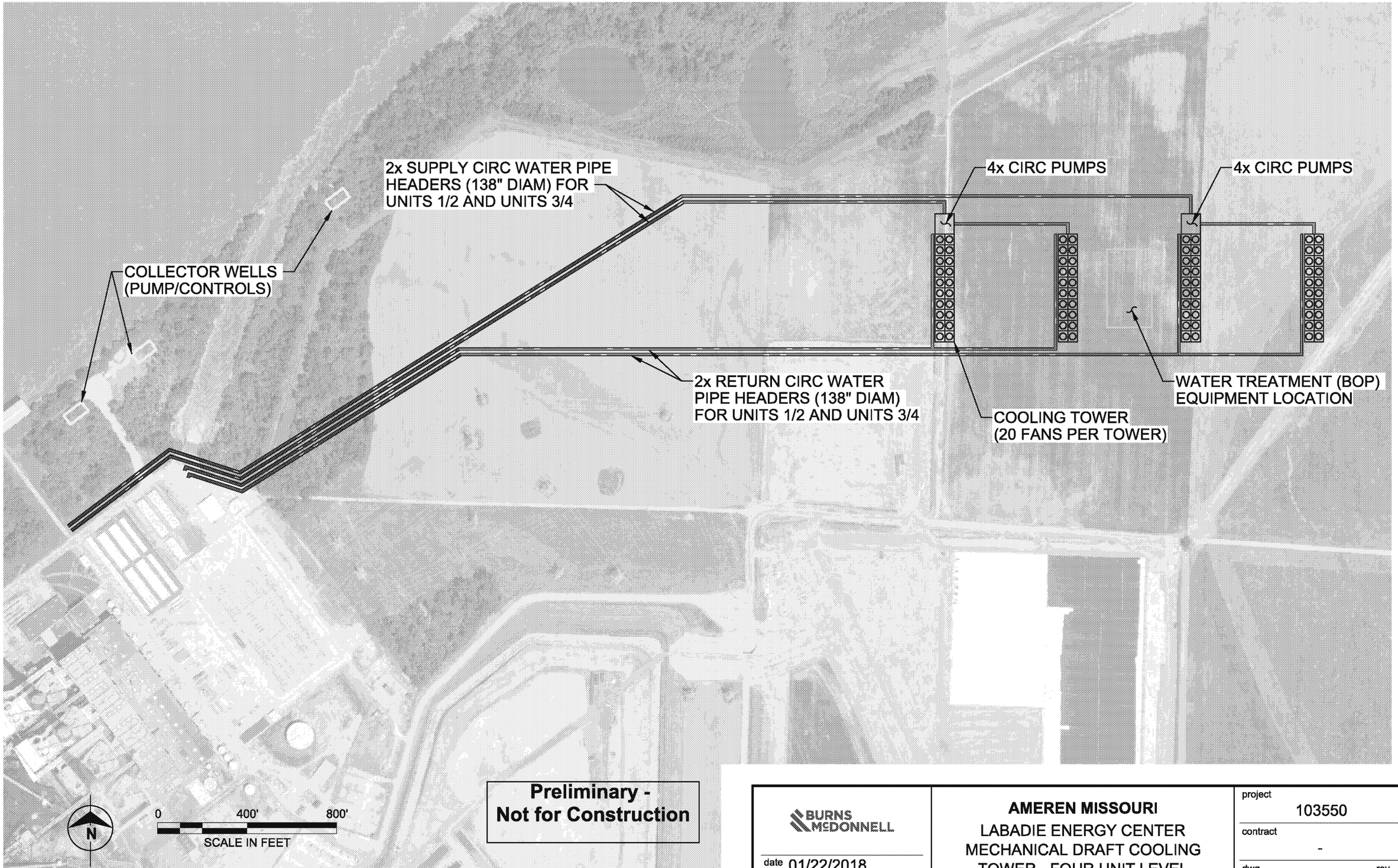
contract -

dwg **SK - 001**

rev -

\\bmcd\dfs\Clients\ENR\AmerenMO\103550_LabadieBAT\Design\Civil\Dwgs\Sketches\103350_SK-001.dgn

COPYRIGHT © 2018 BURNS & McDONNELL ENGINEERING COMPANY, INC.



Preliminary - Not for Construction

BURNS McDONNELL

date 01/22/2018

designed A. MYERS

AMEREN MISSOURI

LABADIE ENERGY CENTER
MECHANICAL DRAFT COOLING TOWER - FOUR UNIT LEVEL

project 103550

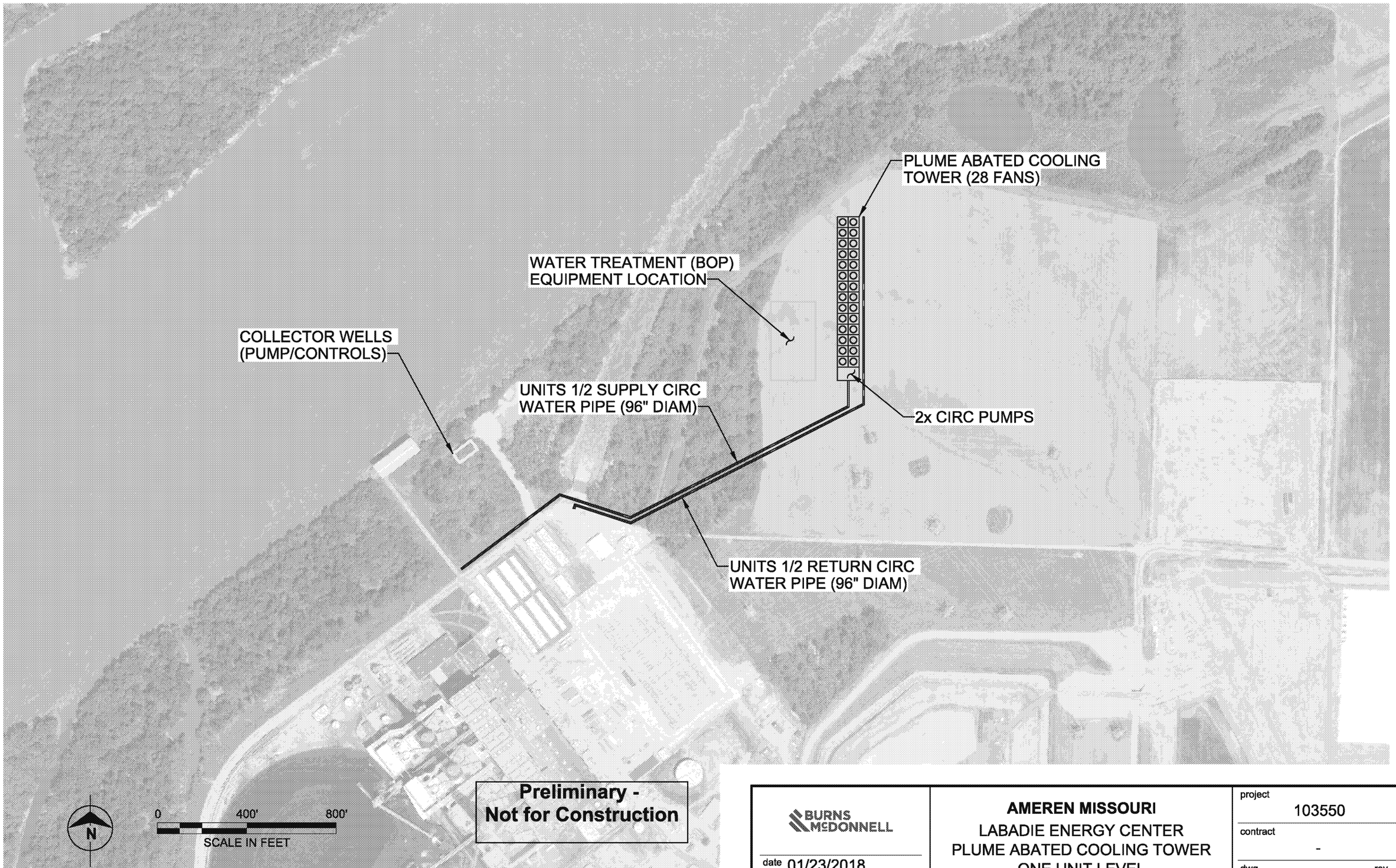
contract -

dwg **SK - 002**

rev -

\\bmcd\dfs\Clients\ENR\AmerenMO\103550_LabadieBAT\Design\Civil\Dwgs\Sketches\103350_SK-002.dgn

COPYRIGHT © 2018 BURNS & McDONNELL ENGINEERING COMPANY, INC.



Preliminary - Not for Construction

BURNS McDONNELL

date 01/23/2018

designed A. ERICKSON

AMEREN MISSOURI

LABADIE ENERGY CENTER
PLUME ABATED COOLING TOWER
ONE UNIT LEVEL

project 103550

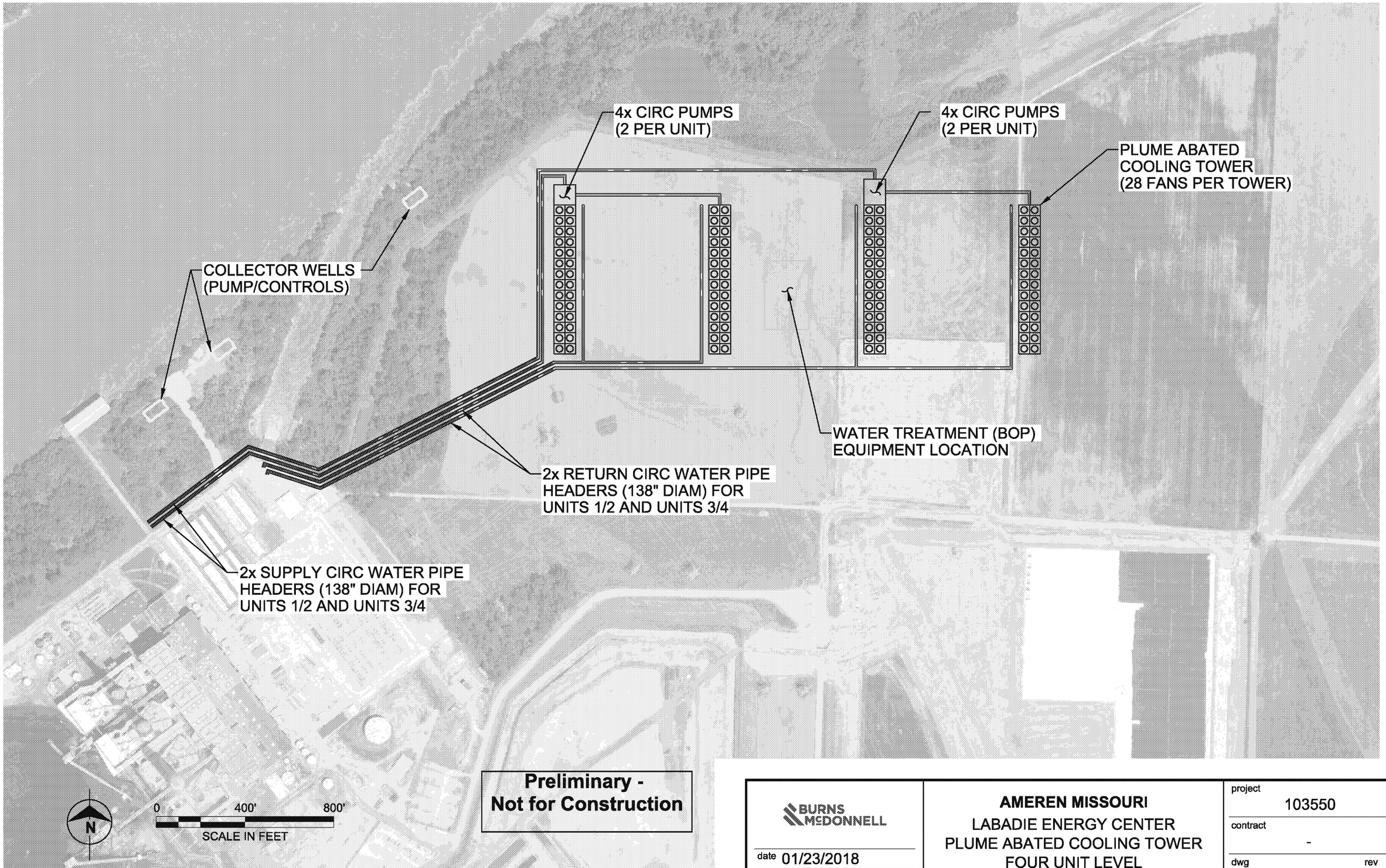
contract -

dwg **SK - 003**

rev -

\\bmcd\dfs\Clients\ENR\AmerenMO\103550_LabadieBAT\Design\Civil\Dwgs\Sketches\103350_SK-003.dgn

COPYRIGHT © 2018 BURNS & McDONNELL ENGINEERING COMPANY, INC.



Preliminary - Not for Construction

BURNS McDONNELL

date 01/23/2018

designed A. ERICKSON

AMEREN MISSOURI

LABADIE ENERGY CENTER
PLUME ABATED COOLING TOWER
FOUR UNIT LEVEL

project 103550

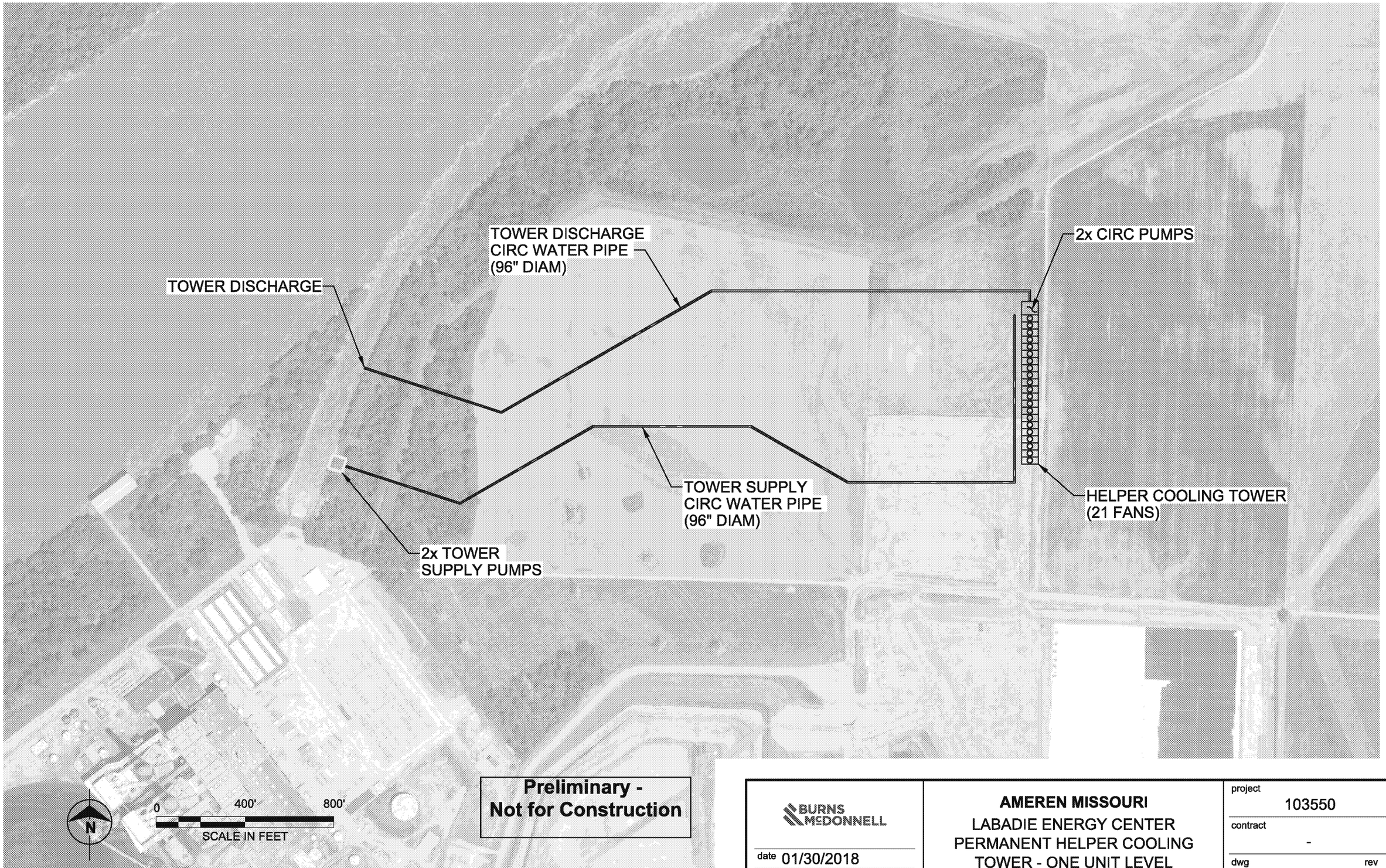
contract -

dwg **SK - 004**

rev -

\\bmcd\dfs\Clients\ENR\AmerenMO\103550_LabadieBAT\Design\Civil\Dwgs\Sketches\103350_SK-004.dgn

COPYRIGHT © 2018 BURNS & McDONNELL ENGINEERING COMPANY, INC.



Preliminary - Not for Construction

BURNS McDONNELL

date 01/30/2018

designed A. ERICKSON

AMEREN MISSOURI

LABADIE ENERGY CENTER
PERMANENT HELPER COOLING
TOWER - ONE UNIT LEVEL

project 103550

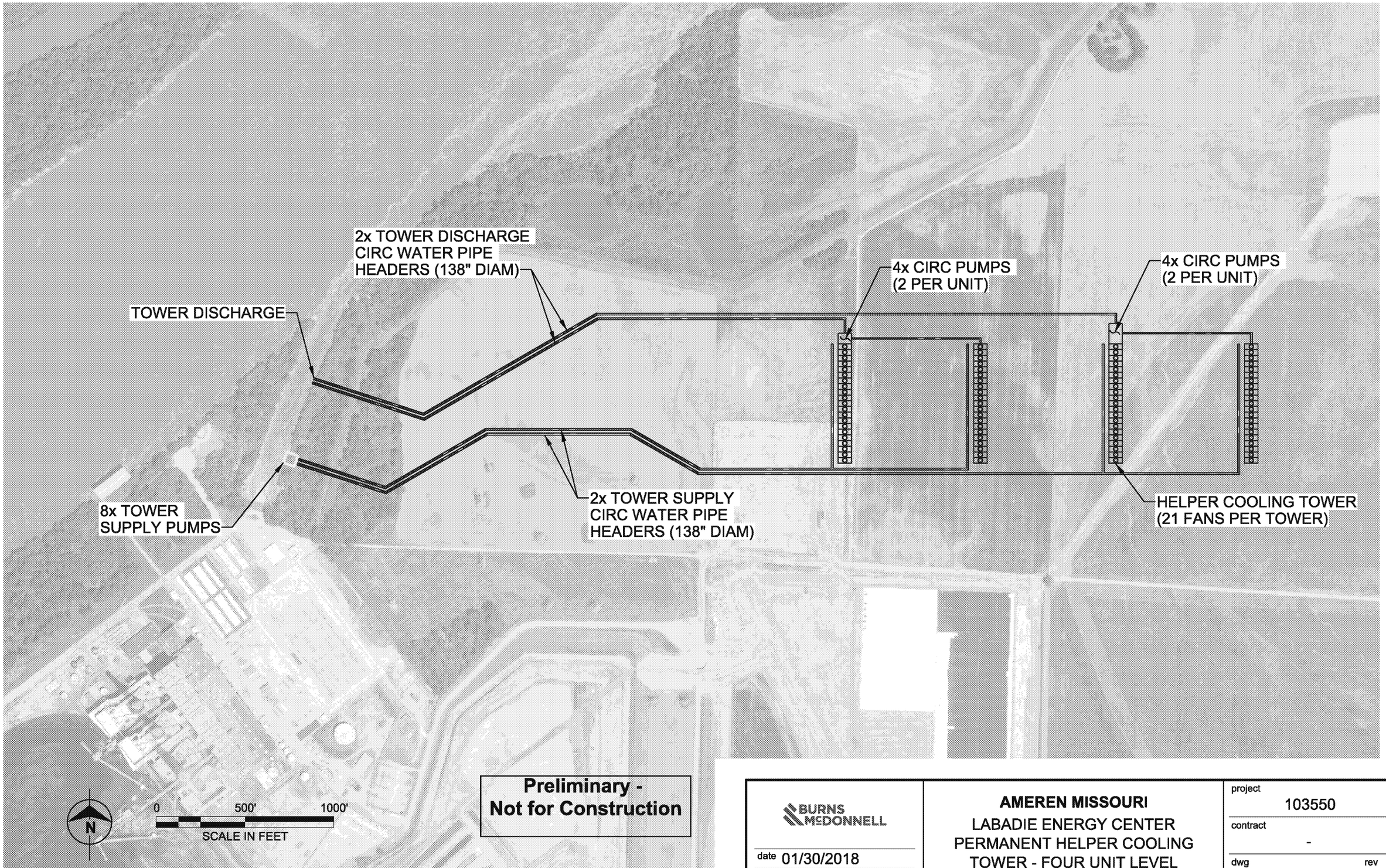
contract -

dwg **SK - 005**

rev -

\\bmcd\dfs\Clients\ENR\AmerenMO\103550_LabadieBAT\Design\Civil\Dwgs\Sketches\103350_SK-005.dgn

COPYRIGHT © 2018 BURNS & McDONNELL ENGINEERING COMPANY, INC.



Preliminary - Not for Construction

BURNS McDONNELL

date 01/30/2018

designed A. ERICKSON

AMEREN MISSOURI

LABADIE ENERGY CENTER
PERMANENT HELPER COOLING
TOWER - FOUR UNIT LEVEL

project 103550

contract -

dwg **SK - 006**

rev -

\\bmcd\dfs\Clients\ENR\AmerenMO\103550_LabadieBAT\Design\Civil\Dwgs\Sketches\103350_SK-006.dgn

COPYRIGHT © 2018 BURNS & McDONNELL ENGINEERING COMPANY, INC.