

Colstrip Power Plant Study

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Executive Summary

This order-of-magnitude energy efficiency study is provided to summarize the potential improvements that were identified at Colstrip Power Plant Units 3 and 4, a coal-fired power generation facility, also termed as the “host site”. In 2016, Gov. Bullock of Montana requested a U.S. Department of Energy (DOE) review of emissions reductions and efficiency improvements at the host site as part of a technical assistance effort in response to the proposed 2015 Clean Power Plan (CPP) - Colstrip plant was the largest (94%) emitter of CO₂ in Montana. Leonardo Technologies Inc. (LTI), assisted the DOE in the initial phase of the study, which included a first-pass analysis of several options to improve energy efficiency and reduce emissions to meet Montana CPP requirements. The second phase of the study was performed in 2017, and involved a deeper analysis of potential options to improve energy efficiency and to potentially reduce carbon dioxide (CO₂) emissions. In addition, technologies that could be used for novel business opportunities were also surveyed and evaluated in this study. The energy efficiency improvements summarized in this study may also be relevant at other power generation facilities in addition to the host site.

The study is focused primarily on improving the efficiency of electricity production, one measure of which is the plant heat rate (HR), or the amount of fuel input energy consumed to generate one kilowatt hour of electricity. In a 2009 report, the United States Environmental Protection Agency (EPA) noted that the heat rate at coal-based power plants could be improved by up to 4% [1]. This is a generic value and the actual gains in efficiency would vary from plant to plant. The EPA study by Sargent & Lundy [2] noted that plant efficiency improvements could be realized from equipment upgrades, upgrades to boilers, steam turbines, and control systems. A site visit by representatives from LTI, DOE, Siemens, and GE Power was conducted, with support from the plant, to identify the potential improvements at the host power plant. Siemens and GE Power are the original equipment manufacturers (OEM) of the turbine and boiler equipment, respectively. The team developed a list of potential improvements and identified baseline plant conditions for the study. The list of potential heat rate improvement options was thoroughly analyzed through plant simulation modeling and by incorporating modeling inputs and feedback from the turbine and boiler OEMs. Feedback was also sought from outside vendors that provide specialized technology or equipment for the proposed improvement options. In addition, a high-level review of several coal beneficiation technologies that would improve coal’s heating value and produce other hydrocarbon products that can be used as fuel or chemical feedstock was also performed.

Currently, plant operators face high-venturi pressure drops due to opacity/particulate matter (PM) control requirements, and loss of efficiency due to flue gas reheating. In the near future, the plant plans to install a flue gas desulfurization (FGD) water treatment facility to limit salt buildup in the recirculating water from the ponds. FGD waste is currently dewatered in a paste plant to 65% solids content. Under impending dry disposal requirements, this 65% solids content paste would be further dewatered to about 80% solids (20% moisture), at a level almost equaling the moisture content of the soil [3]. The plant also faces challenges from decreasing margins between the

generating cost and the sales cost of electricity and the need to operate efficiently at low-load conditions.

Heat rate improvements evaluated in this study can form a basis for addressing some of the challenges facing the plant discussed previously. Further detailed engineering analyses into options such as coal drying, reducing or eliminating flue gas reheat, and increasing the reheat steam temperature are required. In addition, examining potential for heat rate improvements at low-load conditions represents another opportunity for the plant.

Summary of Heat Rate Improvement Options

Baseline data collected from the plant during October 6-12, 2016 were used for the study. Power plant performance was estimated from Thermoflex plant modeling and by estimating impacts on the heat rate using OEM turbine thermal kit curves. Any plant heat rate improvement estimated in this study was translated into lower fuel consumption, maintaining the same gross electric power generation as the baseline case. The list of options and associated impact on power plant performance are provided in Table 1. Permitting/New Source Review (NSR) requirements would need to be considered for any plant efficiency enhancement implementations.

The estimated heat rate improvement gain for each option was based on the best-available information and power plant retrofit cost estimates for the study are conceptual in nature. Various resources, including power plant OEMs and other technology developers were consulted to provide the AACE Class V (-20% to -50%, +30% to +100%) cost estimates.

Upon review of the available improvement options, the least-cost improvements involve coal drying and interpretation of the permit and potential re-examination of the requirement to reheat the flue gas to provide the buoyancy needed for atmospheric dispersion. Reducing the stack flue gas exit temperature to 175°F instead of 190°F (case 13) will improve heat rate by 0.54%, and does not involve any major equipment changes to the plant. Eliminating the steam for flue gas reheating (case 14) would improve the heat rate by 1.07% at a cost of approximately \$10 million to modify the induced draft (ID) fans to operate with wet flue gas. A re-examination of the plant's air permit would be needed and atmospheric modeling would need to be conducted to reduce or eliminate the steam used for flue gas reheating. This may not be attractive from the plant's perspective. A related option that was evaluated was the elimination of steam for flue gas by mixing hot air from the air preheater with flue gas exiting the scrubber (case 6). Gas flow through the ID fans increased by 13% in this option, leading to higher auxiliary load. This offsets the improvements in heat rate due to the reduced fuel flow to the boiler (at the same gross power output).

Drying the coal to 13.44% moisture content is expected to improve the heat rate by 1.42% to 2.58%, and is expected to cost \$20 million to \$65 million (cases 5, 10). This is viewed as a viable option because at least one coal drying technology supplier has commercialized their technology with lignite coals which have significantly higher moisture content (~40%) compared to the 25.6% moisture sub-bituminous coal used at the plant. In this study, coal drying was assumed to occur

outside the boiler boundaries and the impacts of the drier coal on the boiler were addressed. Future studies would require small pilot-scale tests along with modeling the heat integration between the plant and the coal drying process to refine the heat rate improvement estimates.

Table 1: Summary of heat rate improvements

	Description	Expected NPHR (Btu / kWh)	Decrease from baseline		Cost, million \$ ¹	Notes
			(Δ Btu / kWh)	%		
	Baseline Design	10,820				
Boiler	Coal drying to reduce coal moisture content	10,666	154	1.42%	20-50	Case 5: 21.4% excess air
		10,541	279	2.58%	25-65	Case 10: 18% excess air, LTSH + economizer surface.
	Provide / modify air preheater to utilize heated air in lieu of steam for flue gas reheat	10,782	38	0.35%	8-20	Case 6: New APH needed. Additional gas flow = increased aux load.
	Increase steam reheat outlet temperature leaving boiler	10,688	132	1.22%	14-36	Case 4: 21.4% excess air
		10,563	256	2.37%	20-50	Case 9: 18% excess air, LTSH + economizer surface.
A Q C S	Optimize flue gas flow	$\leq 10,802$	17	0.16%	Additional work needed to quantify costs	Case 12
	Reduce steam for flue gas reheating	10,769	58	0.54%		Case 13: Permitting, atmospheric modeling needed.
	Eliminate steam for flue gas reheat	10,719	116	1.07%	18-45	Case 14
	Reduce venturi pressure drop: Fabric filter installed before FGD	10,642	178	1.65%	65-170	Case 15
	Complete replacement of AQCS (NID system)	10,557	263	2.43%	180-460	Case 16

¹ The range of variability in the costs represents AACE Class V estimates

Replacement of the existing high pressure loss venturi scrubber with a new state-of the-art circulating dry scrubber (CDS) flue gas desulfurization (FGD) system will improve the plant heat rate by 2.43% and is expected to cost \$180 million to \$460 million (case 16). The heat rate improvements in this option arise from both a reduction in draft due to the higher efficiency scrubbers and PM removal, and also due to the almost complete elimination of steam consumption for flue gas reheating. In addition, the use of a CDS at other similar facilities will eliminate the need for wet FGD waste water treatment. At Colstrip, installing a CDS will likely lower the operating costs of the planned waste water treatment facility. It will also expand the parameter space for plant operators, who currently strive to balance excess air, steam temperatures, NO_x levels and opacity with the venturi-based FGD and PM collection system. Further, CDS systems from other vendors are expected to cost as low as \$100/kW, indicating that the installed costs of such a system could be lower than the estimated cost of \$180 million to \$460 million. Similarly, replacing the plumb bob with a fabric filter installed ahead of the existing FGD system, which accounts for a major portion of the FGD pressure drop, would improve the heat rate by 1.65% at a cost of \$65 million to \$170 million (case 15). This may be a less expensive improvement compared to the full replacement of the wet FGD system and can alleviate the opacity issues currently faced by the plant operators. Increasing the reheat steam outlet (RHO) temperature to 1,050°F can improve the heat rate by 1.22% to 2.37% compared to the baseline (cases 4, 9) at a cost of \$14 million to \$50 million. The turbine OEM did not specify detailed impacts from the higher RHO temperature. Costs for this option do not include upgrading the IP turbine's outer casing/shell, and impacts on existing LP turbine were also not addressed. Because of the extensive changes to the boiler and the turbine, and the potential for adverse impacts on plant operations, the 1,050°F RHO option was not considered to be one of the top-most options.

There also exists the possibility of combining some of the proposed options, thus maximizing the potential heat-rate gain. These heat-rate improvement option costs represent high-level estimates and warrant further engineering analysis to provide a higher level of precision and certainty.

Coal Beneficiation Technology Summary

Two coal beneficiation technologies that were also considered but not evaluated or verified in this study: Clean Energy Technology Association Inc.'s (CETA) coal distillation technology, and LP Amina's BenePlus process.

CETA has developed a low-pressure, moderate-temperature coal distillation technology that produces four products from coal: char ("COALlite™"), crude oil, aqueous solvent, and syngas. The process produces a homogenized, stable, and dry fuel (COALlite™) which is easier to handle and burn, and reduces mercury (90%+) and sulfur (15-20% lower SO₂) content, resulting in lower emissions. The process is primarily applicable to low-rank lignites and sub-bituminous coals, and may also be used for bituminous coals. The overall economic attractiveness of the CETA coal distillation technology is dependent on the value of the byproducts that are produced, along with

the input costs (i.e., raw coal and electricity). The coal distillation process is an energy-intensive process and must be offset with consistent prices for the liquid and gaseous byproducts that are produced. In its technology description, CETA suggests that the additional revenue from the liquid and gas stream products will return a five-year payback on the initial investment over twenty-five to thirty years.

The LP Amina BenePlus process is based on fluidized catalytic cracking (FCC) technology and produces fuel gas for power generation, specialty chemicals, and ‘enhanced’ coal with lower moisture content. The process has been operated over 1,000 hours at the pilot scale with numerous types of coal. LP Amina’s next step is a large-scale pilot (semi-commercial) demonstration. The BenePlus technology can be added to an existing power plant, resulting in an increase of the heating value (~20%), reduced ash (~-50%) and mercury (~-75%) contents of typical Powder River Basin (PRB) low-rank coals, such as the Rosebud coal fired at Colstrip. Additional benefits from integrating the BenePlus process with Colstrip power plant include additional power generation from syngas, revenues from the sale of aromatics, improved boiler efficiency (by up to 7%), robust catalysts that can be modified to fine-tune the product distribution, and scalable technology. A preliminary economic evaluation conducted by LP Amina shows their process can make a beneficial impact on the operation and financial health of an existing plant. Further research and funding are needed for a detailed evaluation of the technology and to develop project-specific costs to retrofit the technology into an existing coal-fired power plant.

Carbon Capture and Utilization Summary

The study also assessed the economics of integrating a CO₂ capture system, whereby the CO₂ could be used for enhanced oil recovery (EOR). The recent expansion of 45Q CO₂ tax credits (signed into law in February 2018) applied to EOR offers additional financial revenue to offset some of the capital and operational costs for the carbon capture, compression and transportation facilities. Capturing and compressing 63% of CO₂ emissions from each unit (4.3 million metric tonnes per year per unit) using steam and power from the coal power plant (instead of providing them through a separate gas-fired combined heat and power plant) could cost around \$1,335 million, along with an annual operating cost of around \$108 million. The techno-economic assessment of CO₂ capture for CO₂-EOR found that due to significant capital, operating and infrastructure costs, this option may not be financially attractive.

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