6.0 Sensitivity Analysis

This section represents the second part of Black & Veatch's evaluation. It contains the findings of Black & Veatch's analysis of the technology alternatives available to treat FGD wastewater. The Sensitivity Analysis with full scenario breakdown is in Appendix B.

Two main treatment alternatives are considered in this analysis: (1) FGD treatment and discharge and (2) ZLD. Within these two treatment alternatives, three technology types with multiple vendors were evaluated: physical/chemical pretreatment with biological treatment, and for ZLD, the spray dryer evaporator (SDE) and brine concentrator/crystallizer.

Each technology, and subsequent vendor, was evaluated at different operating scenarios to further assess their sensitivity to changes in capital cost, O&M costs, and adaptability to these scenarios. In addition, a comparison was performed amongst the vendors to properly assess the risks associated with each system. Several site visits occurred to observe specific technology systems. Site visit details are summarized further in this section of the report.

Throughout the course of the sensitivity analysis, it was assumed that FBC will achieve the target treatment flow rate of 50 gpm. FBC is working with [redacted] to throttle the flow rate lower through testing and analysis. As discussions have taken place during this evaluation period, it was noted that the flow rate has been successfully throttled to around 100 to 120 gpm thus far. It is assumed that the flow rate will continue to decrease before installation of the FGD wastewater treatment system; however, further analysis will need to be completed if the flow rate is unable to throttle below 80 gpm due to failure of the SDE to feasibly operate above this flow rate. Further explanations and detailed cost comparisons are shown in the Sensitivity Analysis Matrix (Appendix B).

6.1 EVALUATION OVERVIEW

As previously mentioned, Black & Veatch and Vectren have established the base conditions for FBC with a wastewater flow rate of 50 gpm, assuming a 60 percent operating capacity factor, an ambient temperature of 50° F, and 24 hours per day operation. The Sensitivity Analysis evaluated the various operating scenarios against the base case.

6.1.1 Evaluation Parameters

The Sensitivity Analysis for FBC includes an evaluation of various operating scenarios for the physical/chemical pretreatment and biological treatment (discharge), spray dryer evaporator (ZLD) treatment, and brine concentrator/crystallizer (ZLD) treatment technologies amongst all vendors. The analysis modeled the capital costs, O&M costs, and treatment capabilities provided by the vendors for the different operating scenarios. This analysis determined the impact of the variables and the best treatment solution to meet compliance. The following is a list of the operating scenarios considered:

Scenario 1 – High Capacity Factor: 50 gpm, 75 percent capacity, 50° F.

Scenario 2 – Low Capacity Factor: 50 gpm, 15 percent capacity, 50° F.

Scenario 3 – Cycling: 50 gpm, 60 percent capacity, 50° F, 8 to 10 hours per day on line.

Scenario 4 – Off-line: 50 gpm, 60 percent capacity, 50° F, 24 hours per day, 3 months off-line.

Scenario 5 – Low Ambient Temperature: 50 gpm, 60 percent capacity, -23° F, 24 hours per day.

Scenario 6 – Increased Flow Rate: 80 gpm, 60 percent capacity, 50° F, 24 hours per day.

Scenario 7 – High Flow Rate: 135 gpm, 60 percent capacity, 50° F, 24 hours per day.

These operating scenarios will be referenced throughout this section.

The following accompanying documents are integral pieces of this evaluation and should be viewed in conjunction with this report. Appendix B contains the full Sensitivity Analysis Matrix that highlights the three different technology operations and costs. Appendix D contains the Spray Dryer Evaporator Impacts memorandum.

The vendors evaluated in the sensitivity analysis are listed in Table 6-1. Each vendor is listed with its respective technology.

Table 6-1 Sensitivity Analysis Vendors

VENDOR	ELG TECHNOLOGY CLASS	TECHNOLOGY TYPE	TECHNOLOGY NAME
[redacted]	Treat and discharge	Physical/chemical pretreatment	[redacted]
[redacted]	Treat and discharge	Biological	[redacted]
[redacted]	Treat and discharge	Physical/chemical pretreatment and biological treatment	[redacted]
[redacted]	ZLD	SDE	[redacted]
[redacted]	ZLD	SDE	[redacted]
[redacted]	ZLD	SDE	[redacted]
[redacted]	ZLD	Evaporator and brine concentrator/crystallizer	[redacted]
[redacted]	ZLD	Thermal vapor recompression	[redacted]

6.2 TREATMENT AND DISCHARGE TECHNOLOGY

Physical/chemical/biological treatment of the FGD wastewater has been shown to be a reliable option to meet the ELG regulations. This is based on observations and firsthand accounts by operators stating that transient conditions do not upset the biological system as long as the pretreatment is functioning properly. This treatment option is advantageous because of the low energy consumption/auxiliary load and the low production of solids. However, this technology requires an increased number of operators who are able to properly maintain and regulate the operation of the pretreatment and biological systems. This technology also leaves the FBC site and FGD discharge open to potential additional treatment under possible future environmental regulations.

6.2.1 [redacted] with Physical/Chemical/Biological Treatment Evaluation

[redacted] notes that the pretreatment system will be affected if the system contact time is varied. A change in capacity factor (Scenarios 1 and 2) will not affect the system as severely as low temperature (Scenario 5); a very low temperature will increase the viscosity of the water and lead to an increased time for the proper reaction to take place. Cycling the system (Scenario 3) and turning the system off-line for an extended period of time (Scenario 4) will not affect the physical/chemical pretreatment equipment. As the flow rate is increased for Scenarios 6 and 7, the sizes of the reaction tanks and clarifiers will also need to be increased. This will affect the capital cost along with the overall footprint required for the equipment. Fixed costs, such as utilities and air, will remain the same as long as the system is on line. Chemical consumption will increase exponentially with an increased flow rate.

As discussed in the FGD Treatment Evaluation previously issued to Vectren on November 22, 2016, the proposed GE [redacted] biological system would include bioreactors along with an MBR system to reduce the level of nitrates. This system is affected by the various operating scenarios, but it is still able to adequately perform. In response to any scenario where the [redacted] system is not receiving influent, it should be operated in recirculation mode with a dosing of a supplemental nitrate-selenium solution in addition to nutrient. If the system will not receive influent for less than 3 weeks, it should be in a high load recirculation with a large dosage of nitrate-selenium solution. If the outage is longer than 3 weeks, the system shall be in low load recirculation with a smaller dosage of nitrate-selenium solution. The equipment operates best around 50° F. A heating system will likely need to be placed upstream of the system if the potential exists to operate below 50° F. The mechanical equipment shall also be located indoors while the tanks and outdoor piping shall be insulated and heat traced to prevent freezing. Scenarios 6 and 7 allow for an elimination of the MBR system upstream of the [redacted] system due to lower nitrate concentration levels. The reduction of the MBR system, however, leads to an increase in the number of filters to the [redacted] system to accommodate for the increase in flow. Overall, the system would be easier to operate at a higher flow rate, and the capital cost would be reduced.

Black & Veatch and Vectren visited the [redacted] site to view a physical/chemical pretreatment system followed by the [redacted] biological treatment system. The following notes relate to physical/chemical pretreatment with ABMet treatment as observed during the site visit:

Three full-time and dedicated professionals are employed to control and operate the treatment system. Very small upsets can have a large impact on the physical/chemical pretreatment system leading to underperformance of the treatment system as a whole. Time, attention, and culture shift may be required with this type of system. It is estimated that for FBC at 50 to 80 gpm FGD wastewater flow a minimum of two workers, a chemist/operator and lab technician, would be required.

The full wastewater treatment system at AEP is designed for 600 gpm throughput: 350 gpm from the FGD blowdown and 250 gpm from the collected landfill leachate. Even during a plant outage the system still receives leachate, so the unit has never truly been off-line more than 7 days without flow.

The incoming FGD wastewater has a low enough nitrate level so an upfront MBR is not necessary. This is different than FBC's proposed process.

The [redacted] system required approximately 5 years of troubleshooting and fine tuning, but there are no serious issues with the system and it runs very well.

There is a large quantity of complex equipment that can compromise the system if it is not operating properly.

6.2.2 [redacted] Evaluation

The [redacted] technology is also a biological treatment system. The [redacted] technology utilizes modules to combine the physical/chemical pretreatment and the biological treatment into one system provided by [redacted]. This system is able to adjust and operate at all scenarios as listed previously in this report. If necessary, the bioreactors are able to sit idle (as required by Scenarios 3 and 4). To take the system off-line for an extended period of time, it should be mothballed and set up for weekly flushing of the bioreactors with water and nutrient. In Scenario 5, a low ambient temperature is presented, which may cause a longer startup time with a decrease in denitrification capabilities of the sand filter. To handle a flow of 135 gpm (as in Scenario 7), both the physical/chemical equipment and biological equipment would need to be increased. The load and chemical consumption would also increase proportionally, raising the capital and O&M costs.

Black & Veatch and Vectren visited Hoosier Energy to view a [redacted] technology. This system was designed to treat 1 gpm of FGD wastewater. The following are key takeaways from the site visit:

> Tim Pickett developed the original [redacted] technology for GE and then created the [redacted] technology for [redacted] approximately 5 years ago. The redeveloped system has a reduced footprint and a greater emphasis on selenium treatment.
>
> Minimal manpower is needed to operate the [redacted] technology; one to two operators is suggested.

There have been several pilot systems of the [redacted] technology implemented with one full-scale system in operation treating 25 gpm of wastewater.

6.3 SPRAY DRYER ZLD TECHNOLOGY

A spray dryer evaporator is a reliable technology for FGD wastewater treatment. The SDE reduces the solids and load on the CWTS while eliminating a wastewater stream, making this a true ZLD technology. The SDE also requires minimal maintenance with no need for additional operators to ensure that the equipment is operating properly.

For the SDE to evaporate wastewater, however, a unit must be on line and there will be a heat rate impact to the system. The heat rate impact is based on both an increase in heat input to make up the heat extracted for the evaporation process and an increase in auxiliary power usage associated with the increased fuel burn rate. When the unit is operating at low load, higher gas flow through the SDE would result in a gas backflow problem caused by the higher pressure drop through the SDE. A fan may be required downstream of the SDE to accommodate for this condition. Table 6-2 highlights the heat rate impact as a measure of the differential heat rate and differential auxiliary power for the four flow rates evaluated in the Sensitivity Analysis at full-load capacity and low-load capacity. Further explanation of the heat rate impacts can be found in the Spray Dryer Evaporator Impacts Memorandum located in Appendix D.

Table 6-2 Differential Heat Rate and Auxiliary Power with Various FGD Flow Rates

CASE	50 GPM	80 GPM	100 GPM	135 GPM
Full Load: Differential Heat Rate, Btu/kWh	105.07	168.29	210.50	284.49
Full Load: Differential Auxiliary Power, kW	205.78	332.23	417.36	567.97
Low Load: Differential Heat Rate, Btu/kWh	253.36	404.11	504.92	681.95
Low Load: Differential Auxiliary Power, kW	260.13	395.55	487.33	650.82

In addition to the heat rate impacts, there are potential fly ash impacts associated with use of an SDE for FGD wastewater treatment. Black & Veatch evaluated the expected fly ash composition with use of an SDE. Assuming the Oaktown Mine Coal fuel is utilized, the fly ash byproduct will still be suitable for fly ash sales without the need for a separate fabric filter based on the amounts of silicon dioxide, di-aluminum dioxide, and ferric oxide in the byproduct. Vectren is to confirm that the new fly ash byproduct would still meet the standards of the fly ash sales contractor(s). In addition, if fuel other than Oaktown Mine Coal is used, further analysis is necessary. Further explanations of the fly ash impacts can be found in the Spray Dryer Evaporator Impacts Memorandum located in Appendix D.

6.3.1 [redacted] Spray Dryer Technology Evaluation

While evaluating the various scenarios for the Sensitivity Analysis, [redacted] indicated that Scenarios 1 and 2 will not have a great impact on the SDE other than power consumption and coal feed increases. To cycle the SDE (Scenario 3), there are two options: (1) operate the SDE at a reduced flow rate when the boiler is operating at a reduced load to maintain steady inventory and (2) operate the SDE in a "batch mode." The system is able to be placed out of service for Scenarios 3 and 4 using the inlet and outlet isolation dampers. To bring the SDE back on line, the system must be heated up before injecting the wastewater into the vessel. Depending on the external conditions, including the ambient temperature, it could take up to 2 hours to sufficiently warm up the vessel. Scenario 6, with a FGD flow rate of 80 gpm, would require 60 percent more gas flow than operating the SDE at 50 gpm. It may be beneficial to adjust the design of the SDE to operate for a rotary atomizer design in lieu of the current dual fluid nozzle design. The rotary atomizer design would increase the footprint of the vessel along with the power consumption to account for the rotary atomizer motor. While evaluating [redacted] SDE at 135 gpm for Scenario 7, it was determined that the current design of the equipment cannot operate at this flow rate; therefore, a cost was not provided.

Black & Veatch and Vectren visited the Kansas City Power & Light Iatan site to observe and evaluate an operating full-scale GE SDE system. Iatan is successfully treating FGD wastewater using [redacted] rotary atomizer SDE. This equipment has been in operation with no issues since January 2017. The SDE designed for Iatan can treat a wastewater flow rate of 15 to 55 gpm; this design could be utilized for FBC if a rotary atomizer SDE is favored in lieu of the dual fluid nozzle SDE. The rotary atomizer design will require a larger footprint because of the larger diameter of the SDE vessel. There is a greater turndown with the atomizer design versus the dual fluid nozzle design; however, both will work equally as well to treat the FGD wastewater.

In addition to the Iatan site visit, Black & Veatch and [redacted] visited FBC to evaluate the feasibility of utilizing an SDE to treat FBC's FGD wastewater. The following points summarize the highlights and notes of the site walkdown at FBC to evaluate the concerns of locating and operating [redacted] SDE:

Depending on the treatment flow rate, a common line to pull off of both sides of the air preheater may be best to prevent an imbalance.

While Vectren currently purges FGD wastewater roughly 10 to 12 hours per day, similar to Iatan, the plant capacity factors are different. Iatan operates at a high capacity factor resulting in more availability to utilize the SDE for treatment due to the constant flue gas temperatures. FBC's planned 60 percent or less operating capacity factor may restrict the availability of the SDE for treatment and require additional holding capacity. Operations and holding tank capacities are examined further in Appendix D.

In regard to O&M, there have been no additional operators at Iatan. The SDE has been added to the daily checklist for the operators. For atomizer maintenance, there has been an observed and estimated 6 month atomizer life at Iatan; however, this will vary for each facility. For dual fluid nozzle maintenance, it is estimated that one nozzle will need to be exchanged each week. The nozzles can be exchanged with the boiler on line but the SDE must be isolated. When the nozzles need to be exchanged, it will be evident by an increased pressure drop.

It would be best for an SDE system treating 50 gpm to utilize a dual fluid nozzle design that requires a smaller footprint while a system treating 80 gpm should utilize a rotary atomizer design to prevent the complexity of a large quantity of nozzles on the inside of the vessel.

The SDE is not a feasible solution for a treatment flow rate greater than 80 gpm because of the heat rate impacts.

6.3.2 [redacted] Spray Dryer Technology Evaluation

[redacted] SDE design utilizes rotary atomizers with an optional booster fan. The SDE will have no problems operating at reduced or greater capacities, and it can handle cycling or extended outages. For extended outages (Scenario 4), the atomizers would need to be lifted out of place and blanking plates would need to be installed at the atomizer openings. This prevents debris from falling into the vessel. It is also recommended that a lube oil system is cycled occasionally during an outage. When operating at extremely low ambient temperatures (Scenario 5), the biggest impact will be to the air heaters. Acid condensation and air heater fouling can occur at cold temperatures. It would be advantageous to not operate the SDE at low temperatures but, if needed, the SDE can be operated at reduced capacity to minimize losses. [redacted] SDE is able to operate at higher flow rates, including 135 gpm. At the higher flow rates, there will be a significant increase in the cost of the equipment along with operating costs because of the significant heat rate impacts.

6.3.3 [redacted] Spray Dryer Technology Evaluation

[redacted] also utilizes a rotary atomizer SDE design. When operating at a high capacity factor, B&W anticipates a greater average annual replacement part cost for the atomizer versus operation at lower capacity factors. [redacted] does not recommend intentionally cycling the SDE (Scenario 3) because continuous operation will help minimize the size of the system components and overall cost. The SDE is able to operate at 20 percent load as a suitable flue gas inlet temperature is still available from the economizer outlet, and the flue gas temperature at the air heater outlet does not become problematic. When taking the system off-line for months at a time as presented by

Scenario 4, the SDE requires very little care and maintenance. B&W recommends the following care during outages: rotate the atomizer shaft, atomizer fan shaft, and agitator shaft several times per month; wash out the slurry pumps and rotate the slurry pumps; stroke the dampers; and rotate the seal air fan shaft several times per month. B&W's SDE will not be affected by low ambient temperatures; however, it will be affected by high flow rates. The current design will be able to handle a flow rate of 80 gpm but not 135 gpm. Scenario 7 requires too much flue gas to operate. In order to accommodate the higher flow rate, a duct burner would be recommended as a supplemental heat source. Costs are unable to be provided for Scenario 7.

6.3.4 [redacted] Spray Dryer Technology Evaluation

At the time of this report, this technology was not reviewed past the initial proposal review. This technology is not included in the Sensitivity Analysis.

The SDE proposed by [redacted] includes one SDE vessel utilizing dual fluid nozzles similar to the SDE proposed by [redacted] for the 50 gpm case. It has proposed this design for all three flow cases (50 gpm, 80 gpm, and 135 gpm), noting that two SDE vessels would be required for the 135 gpm case. In addition, [redacted] will supply a wastewater feed tank (size unknown), wastewater feed pumps and all piping/valves, a compressed air system, and inlet and outlet ducts. [redacted] utilizes three major control loops for the SDE: wastewater flow, atomizing air flow, and flue gas bypass to SDE. The SDE vessel will start evaporating wastewater once the flue gas temperature reaches a temperature of 300° F. A supplemental heat source can be utilized to allow for quick startups and assist with evaporation. [redacted] confirms that no additional operators should be needed for O&M of the SDE. A pilot system is not available for the SDE. [redacted] has determined from previous testing that the fly ash will not remain marketable if operating with an SDE system. Budgetary equipment costs for the 50 gpm and 80 gpm units are approximately $[redacted] respectively. These do not represent engineering, procurement, and construction (EPC) total installed costs.

6.4 BRINE CONCENTRATOR ZLD TECHNOLOGY

Brine concentrator/crystallizer technology has been used successfully at power generation facilities operating with ZLD waste to treat cooling tower blowdown. There are, however, only two brine concentrator/crystallizer systems at power generation facilities in the United States treating FGD blowdown. Evaporated water from both the brine concentrator and crystallizer is condensed and returned to the plant for reuse. This is a high quality water source that would slightly reduce the overall water requirements for the plant.

6.4.1 [redacted] Concentrator and Crystallizer Technology Evaluation

There is limited information provided for [redacted] technology. This treatment system allows for true ZLD treatment while recovering distillate for plant reuse; however, this type of system is historically prone to upsets and requires additional labor for O&M. At the higher flow rates, as seen in Scenarios 6 and 7, the equipment will need to increase in size, raising both the capital cost and the operating costs caused by increases in power, chemical, and landfill usage. Without a full water analysis of the plant, the various scenarios cannot properly be evaluated.

6.4.2 [redacted] Concentrator Technology Evaluation

The [redacted] technology is an advanced vapor recompression thermal evaporation system. This system utilizes immersion heaters, a steam compressor, and concentrated brine to treat the FGD wastewater. This system effectively recovers 90 percent distillate, outputting

10 percent of the effluent as concentrated brine. This system is predicted to be able to adjust to the various scenarios. In addition, it is able to treat a wastewater flow rate of up to 100 gpm without any issues.

Vectren and Black & Veatch visited [redacted] where an [redacted] system was piloted for a length of time. It was noted that there were no issues present with the treatment system at the time of this visit. Currently, [redacted] has operated only pilot systems for treatment of FGD blowdown. Thus far, [redacted] full-scale systems have been utilized in mining applications with lower total solids loading and concentrations. The following points summarize the highlights and notes of the site walkdown at [redacted]

> Modular systems are sized for up to 35 gpm. Higher treatment flows will require additional modules. The system represents only the upstream brine concentrator component which requires a crystallizer for full ZLD capability.
>
> No capital cost structure is available, only leased systems with services.

Brine produced is 20 percent solids and will require additional dewatering or crystallization treatment prior to landfill or off-site disposal.

6.4.3 [redacted] Evaluation

At the time of this report, this technology was not reviewed past the initial proposal review. This technology is not included in the Sensitivity Analysis.

The [redacted] technology is a ZLD option where hot gases mix directly with the wastewater through turbulent flow. There are no heat exchangers, membranes, or crystallizers required. The [redacted] technology requires little pretreatment, and there will be no contamination of the fly ash. The lack of equipment and moving parts allows for a reduced chance of scaling or fouling of the equipment. The [redacted] system proposed is able to handle all flow rates (50 gpm, 80 gpm, and 135 gpm) and operating scenarios (it recommends a redundant design for the 135 gpm case). While the [redacted] concentrator will not be impacted by boiler capacity factor, daily cycling, or outages, the concentrator may have lower net thermal efficiencies at lower ambient conditions. In less than 5 minutes, the [redacted] system can start evaporating water because of its ability to operate with natural gas or flue gas. There are no cooldown or heat up restrictions. For optimization of cost, a system can be designed to utilize flue gas with a natural gas burner for additional evaporation needs. It is predicted that two operators full-time employees would be required for the [redacted] system to operate smoothly. A pilot system is available for [redacted] mobilization/demobilization costs (length of time of pilot is unknown). Budgetary equipment costs for the 50 gpm and 80 gpm units are approximately [redacted], respectively. These do not represent EPC total installed costs.

7.0 Economic Criteria

The economic criteria shown in Table 7-1 was used for the cost estimates presented in this report. These values represent relative values that have been applied to technology scenarios to determine the most economical alternative.

Table 7-1 F.B. Culley ELG Compliance - Summary of Economic Criteria

ECONOMIC INPUTS	VALUE	UNITS
Present Worth Discount Rate	6.00	%
Economic Life	20	years
Escalation per Year	3	%
Salary – Full-Time O&M Employee	180,000	$/year
Power Price	35	$/MWh
Plant Capacity – FBC Unit 3	60	%
Polymer Costs	3,075	$/tote
Coagulant Costs	7,620	$/tote
Filter Press Polymer Costs	3,650	$/tote
On-site Landfill Costs	24	$/load
On-site Landfill Haul Capacity	30	tons/load
Off-site Landfill Costs	990	$/load
Off-site Landfill Haul Capacity	25	tons/load

7.1 SUMMARY OF ESTIMATES

Table 7-2 presents the cost estimate summary for FBC separated into treatment alternatives for ELG compliance for the base 50 gpm FGD wastewater case (based on 2017 costs). The costs shown are representative of the lowest estimate received from a vendor in that technology type. As indicated in Table 7-2, Class 3 cost estimates were developed for both Alternative 1, Physical/Chemical/Biological Treatment and Alternative 2, Spray Dryer Evaporator. A Class 5 estimate was developed for Alternative 3, Brine Concentrator/Crystallizer.

Table 7-2 Summary of ELG Technologies Costs

COSTS	ALTERNATIVE 1 PHYSICAL/ CHEMICAL/ BIOLOGICAL TREATMENT[1] (CLASS 3)	ALTERNATIVE 2 SPRAY DRYER EVAPORATOR[2] (CLASS 3)	ALTERNATIVE 3 BRINE CONCENTRATOR/ CRYSTALLIZER[3] (CLASS 5)
Total Direct Costs	$15,972,920	$16,279,794	$23,275,000
Total Indirect Costs	$13,576,982	$13,932,430	$19,783,750
Owner's Cost and Escalation	$6,104,738	$6,247,900	$11,863,113
Total Capital Investment	**$35,654,641**	**$36,460,124**	**$54,921,863**
Total Annual O&M Costs	$1,039,349	$610,176	$1,599,586
Net Present Value[4]	**($18,858,186)**	**($15,854,086)**	**($44,599,658)**

[redacted]

4. Six percent discount rate at 20 year life. No taxes or escalation included.

As shown in the Sensitivity Analysis Matrix and Table 7-2, the physical/chemical/biological treatment and discharge technology option presents the lowest capital investment for the base case scenario. Looking further at the Sensitivity Analysis Matrix, the O&M costs vary significantly across technology types. It is evident that the spray dryer evaporator averages the lowest O&M costs across all scenarios while revealing the greatest net present value. A capital cost comparison is provided in Table 7-3. Refer to Appendix B (Sensitivity Analysis Matrix) for full details on costs. Both the biological treatment and SDE systems were rated best with a slight edge to the biological treatment as cost increases were minimal across the three flow rates.

Table 7-3 Capital Cost Comparison

TOTAL CAPITAL INVESTMENT COSTS	50 GPM	80 GPM	135 GPM
Physical/Chemical/Biological Treatment[1]	$35,654,641	$35,599,241	$36,492,141
Spray Dryer Evaporator[2]	$36,588,124	38,530,124	Not Suitable
Brine Concentrator/Crystallizer[3]	$54,921,863	Not Provided3	Not Provided3

[redacted]

3. [redacted]

An O&M cost comparison is provided in Table 7-4. Refer to Appendix B (Sensitivity Analysis Matrix) for full details on O&M costs (based on 2017 costs). SDE systems were rated best based on the lowest O&M costs.

Table 7-4 O&M Cost Comparison

SCENARIO	TOTAL CAPITAL INVESTMENT COSTS	PHYSICAL/ CHEMICAL/ BIOLOGICAL TREATMENT[1]	SPRAY DRYER EVAPORATOR[2]	BRINE CONCENTRATOR/ CRYSTALLIZER[3]
Base	50 gpm, 60% capacity, 50° F	$1,039,349	$610,176	$1,599,586
1	High Capacity Factor (75%)	$1,214,322	$742,948	$1,853,096
2	Low Capacity Factor (15%)	$498,431	$214,154	$899,010
3	Cycling (8-10 h/day on line)	$558,089	$258,214	$984,518
4	Off-line (3-4 months off-line)	$942,676	$478,538	$1,412,053
5	Low Ambient Temp. (-23° F)	$1,035,349	$610,732	$1,668,575
6	FGD Flow Rate of 80 gpm	$1,464,388	$936,910	Not Provided
7	FGD Flow Rate of 135 gpm	$2,609,788	Not Feasible	Not Provided

[redacted]

3. [redacted]

When analyzing each technology type at the various operating scenarios compared to each base case, the same general pattern of average annual operating costs is observed between the three technologies. All technologies show a lower annual O&M cost for Scenarios 2, 3, and 4 when compared to the O&M cost projected at the base case. Further, all technologies show a greater annual O&M cost for Scenarios 1, 6, and 7 compared to the base case. O&M costs for Scenario 5 remain the same for all technologies.

8.0 Final Assessment

This section provides a high-level overview of the main sections of the Sensitivity Analysis Matrix, found in Appendix B, and provides a final assessment of each technology and vendor offering. The assessment used the following quality attributes to evaluate each technology's capability and applicability:

- Startup/Ramp-Up Reliability
- Technology Readiness Risk
- Adaptability to Scenarios
- Operation and Control Risk
- Heat Rate Impact Risk
- Number of Operators
- Capital and Annual O&M Costs, Including Energy Consumption
- Susceptibility to Future Environmental Regulations
- Energy Consumption
- Overall Financial Stability and Credit Rating

The research and recommendations presented by Black & Veatch are based solely on what has been published and direct interaction with representatives from the respective vendors. Tables 8-1 and 8-2 show how each technology was ranked technically and commercially, respectively. The rankings were then used to complete the Attribute Assessment Matrix in Table 8-3.

At the time of this report, both the [redacted] technology offerings were not reviewed past the initial proposal review. These technologies are not included in the Sensitivity Analysis or overall assessment.

8.1 TECHNICAL ASSESSMENT

Table 8-1 Technical Evaluation of ELG Technologies

TECHNOLOGY EVALUATION RISK ASSESSMENT	PHYSICAL/CHEMICAL/ BIOLOGICAL TREATMENT	SPRAY DRYER EVAPORATOR	BRINE CONCENTRATOR/ CRYSTALLIZER
Startup/Ramp-Up Reliability Idle to Design Flow Good = <1 Hour Fair = 1 to 4 Hours Poor = 4+ Hours	Good	Fair	Fair
Technology Readiness Risk Low = Meets ELGs with Compliant Installations at Operating Facilities Medium = Meets ELGs and No Permanent Installations, Pilots Only High = Basic Concept, Unproven Technology, No Installations or Pilots	Low	Low	High
Adaptability to Scenarios Able to Operate at 80 gpm, 100 gpm, and 135 gpm Flow Good = Can Handle All Flow Rates Fair = Can Handle Two of the Flow Rates Poor = Can Handle One or None of the Flow Rates	Good	Poor	Good
Operation and Control Risk Low = No New Equipment Control Training Medium = Some New Equipment Training High = All New Equipment Training and Knowledge	Medium	Medium	High
Heat Rate Impact Risk Low = Little to No Impacts Medium = < 200 Btu/kWh High = > 200 Btu/kWh	Low	Medium	Low
Number of Operators Good = No New Operators Fair = One New Operator Poor = >One Operator	Poor	Good	Poor

TECHNOLOGY EVALUATION RISK ASSESSMENT	PHYSICAL/CHEMICAL/ BIOLOGICAL TREATMENT	SPRAY DRYER EVAPORATOR	BRINE CONCENTRATOR/ CRYSTALLIZER
Susceptibility to Future Environmental Regulations Good = ZLD, No Regulations Fair = Possible	Fair	Good	Good
Energy Consumption Low = <50 kWh/kgal Medium = 50 to 100 kWh/kgal High = >100 kWh/kgal	Low	Medium	High
Kgal = 1,000 gallons			

8.2 COMMERCIAL ASSESSMENT

Table 8-2 Commercial Evaluation of ELG Technologies

RISK ASSESSMENT	PHYSICAL/CHEMICAL/ BIOLOGICAL TREATMENT	SPRAY DRYER EVAPORATOR	BRINE CONCENTRATOR/ CRYSTALLIZER
Capital Costs [redacted]	[redacted]	[redacted]	[redacted]
Annual O&M Costs [redacted]	[redacted]	[redacted]	[redacted]
Overall Financial Stability Based on DNB; 1 = Best, 5 = Worst	[redacted]	[redacted]	[redacted]
Credit Rating Based on DNB; 1 = Best, 5 = Worst	[redacted]	[redacted]	[redacted]
General Information - Black & Veatch Procurement Status (not included in Attribute Assessment Matrix)			
Black & Veatch Procurement Status Status for Placement on Black & Veatch's Bidders List	[redacted]	[redacted]	[redacted]
Financial Assessment Overall Financial Assessment of Each Vendor	[redacted]	[redacted]	[redacted]

8.3 OVERALL ASSESSMENT

An Attribute Assessment Matrix table was created that compared the technologies to the list of quality attributes from the Sensitivity Analysis Matrix (Appendix B). Each attribute was assigned a number that ranked its importance on a scale of 1 to 5 (1 = Not Important and 5 = Very Important). Each technology was then given a number ranking within each attribute category, based on the risk assessments presented in Tables 8-1 and 8-2, to determine a final assessment score. Table 8-3 shows an example of how the assessment score was determined.

The two treatment technologies that meet the highest ranked quality attributes are the [redacted] system and the [redacted] SDE. However, given the relatively low capital and O&M costs and its high treatment readiness ranking, the [redacted] SDE system ranked highest on the assessment. The one drawback of this system is the SDE's lack of adaptability to handle increased FGD wastewater flow rates. As shown throughout the assessment, 80 gpm is the preliminary design maximum FGD treatment flow rate for the SDE technology.

Table 8-3 Attribute Assessment Matrix

[redacted]

9.0 Conclusions

9.1 SUMMARY OF CONCLUSIONS

This report has shown the following:

- Final updates to ELG regulations include revised wastewater effluent standards related to fly ash and bottom ash transport wastewaters, FGD waste streams, and combustion residual leachate. Fly ash and bottom ash transport waters are now required to be ZLD in accordance with the final rule. The BAT for FGD wastewater is physical/chemical treatment followed by biological treatment or ZLD.
- Based on plant data, the FBC FGD wastewater discharge effluent would not be in compliance with the updated ELG regulations. Additional treatment is required to continue to discharge to the existing outfall.
- Two methods were reviewed to upgrade FBC to be compliant with future regulations for FGD wastewater: (1) enhance the wastewater treatment system to discharge the effluent or (2) provide a means to utilize ZLD.
- Black & Veatch has identified several potential wastewater reduction opportunities upon review of the plant's existing water balances: boiler makeup and blowdown, demineralized water RO operation, floor drains, and potable water treatment. Further investigation of these flows are warranted.
- Based on cost and process applicability, the [redacted] SDE technology is the most feasible treatment technology for the FBC site.
- Utilizing an SDE treatment technology will impact the heat rate at FBC.
- The treatment flow rate greatly impacts the treatment system operations and feasibility, thus proving to be a vital aspect of the solution.

9.2 RECOMMENDATIONS

Black & Veatch recommends that Vectren continues to work on reducing the FGD wastewater flow rate to below 80 gpm. If the flow rate can be reduced to this amount, it is recommended that Vectren moves forward to a detailed engineering phase with [redacted] for the SDE technology. If the flow rate cannot be reduced, Vectren should complete further analysis of the brine concentrator/crystallizer technology to properly compare it with the physical/chemical and biological treatment technology options.

The [redacted] SDE solution ranks the highest among all technologies based on the quality attributes presented in Section 8.3. This solution is economically viable and provides a zero discharge solution if the maximum FGD wastewater flow rate of 80 gpm is achieved. The conceptual design evaluation indicated the SDE can be feasibly located and tied into the existing equipment at FBC. This ZLD solution provides certainty that any future change in EPA regulations such as reducing discharge limitations or adding new parameters would not apply at FBC since there is no discharge of FGD wastewater.

Appendix A. Technology Matrix for FGD Systems

[redacted]

Appendix B. Sensitivity Analysis Matrix

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Appendix C. List of Assumptions for F.B. Culley Station

The conceptual cost estimate is provided for alternative treatment options for FBC FGD discharge to be compliant with new ELG regulations.

The cost estimate is based on the following assumptions. All costs are based on 2017 numbers.

C.1 GENERAL ASSUMPTIONS

The following are general assumptions used for the cost estimate:

- Cost for the process pond and pipe rerouting is not included.

C.2 DIRECT COST ASSUMPTIONS

The following assumptions are included in the base construction cost estimate for direct costs:

- Major equipment costs are based on in-house pricing.
- Direct costs include the costs associated with the purchase of equipment, erection, and all contractor services.

C.3 INDIRECT COST ASSUMPTIONS

The following assumptions are included in the base construction cost estimate for indirect costs:

- General indirect costs include all necessary services required for checkouts, testing services, and commissioning.
- Insurance, including builder's risk and general liability.
- Field construction management services, including field management staff, supporting staff personnel, field contract administration, field inspection/quality assurance, and project controls.
- Technical direction and management of startup and testing, cleanup expense for the portion not included in the direct cost construction contracts, safety and medical services, guards and other security services, insurance premiums, performance bond, and liability insurance for equipment and tools.
- Transportation costs for equipment and materials delivery to the jobsite.
- Construction contractor contingency costs.
- Construction contractor typical profit margin.

The following additional items of cost are not included in the construction estimate. These costs shall be determined by Vectren and included in Vectren's cost estimate:

Owner's contingency costs.

Startup/commissioning spare parts.

Federal, state, and local taxes.

Major equipment spare parts.

Land.

Interest during construction, also known as allowances for funds used during construction (AFUDC).

Cost and fees for electrical, gas, and other utility interconnections.

Project development costs, legal, and community outreach.

All operating plant vehicles.

Permitting costs.

Furniture, maintenance and office equipment, supplies, consumables, communications and plant IT systems, and startup fuel.

Emissions credits.

Environmental mitigation.

Appendix D. Spray Dryer Evaporator Impacts

ATTACHMENT A SPRAY DRYER EVAPORATOR IMPACTS MEMORANDUM

BLACK & VEATCH

[redacted]