TOXECON™ Retrofit for Multi-Pollutant Control on Three 90-MW Coal-Fired Boilers

Topical Report: Performance and Economic Assessment of Trona-Based SO_2/NO_x Removal at the Presque Isle Power Plant

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List of Acronyms

DOE	**Department of Energy**
PAC	**Powdered Activated Carbon**
NSR	**Normalized Stoichiometric Ratio**
MMacf	**Million actual cubic feet of flue gas**
O&M	**Operating & Maintenance**
EPRI	**Electric Power Research Institute**
CEM	**Continuous Emissions Monitor**
RATA	**Relative Accuracy Test Audit**
TCR	**Total Capital Requirement**

Summary

Under a DOE Clean Coal Program, activated carbon injection has been used to demonstrate continuous mercury removal at We Energies' Presque Isle Power Plant (PIPP). Trona injection tests were also performed at PIPP from July 31 through August 10, 2007. The purpose of these tests was to determine if dry trona injection prior to the TOXECON™ baghouse would result in at least 70% sulfur dioxide (SO_2) reduction, and to assess any related change in mercury removal. Some minor nitrogen oxide (NO_x) reduction was also anticipated from these tests. Balance of plant issues associated with trona injection and subsequent ash handling were also evaluated.

A temporary injection system was set up near the Units 7-9 stack with individual hoses and lances feeding each of the Unit ducts. The injection point was near the existing PAC injection ports in each duct and downstream of the plant NO_x analyzers used for boiler feedback. SO_2 and NO_x analyzers were temporarily installed upstream of the trona injection point on each of the three ducts for monitoring during the tests. Existing analyzers were used at the stack to measure SO_2, NO_x, and opacity.

During the test period, the trona injection rate was varied, which provided the data necessary to complete an SO_2 removal curve. Powdered Activated Carbon (PAC) injection continued at pre-trona injection test levels with trim control on, which allowed some variability (+/- 20%) in injection rate. PAC injection was turned off one day to determine if there was an effect from PAC on SO_2 removal. Due to a negative effect from trona injection on mercury removal, PAC injection was increased on one day to try to regain a >90% removal rate.

The goal of 70% SO_2 removal was achieved during this two week test period when using 5926 lb/hr of trona. This corresponds to an average Normalized Stiochiometric Ratio (NSR) of 1.02. The NSR is the molar ratio of the sorbent injected to that theoretically required for complete reaction with SO_2. The inlet concentration of SO_2 varied from 0.48-0.64 lb/MBtu. The highest removal was 74.1% with PAC injection at 3.8 lb/MMacf. There was very little reduction in total NO_x during the test period, although the presence of the side reaction with NO producing NO_2 was observed during when PAC injection was turned off. Injection of trona for SO_2 control resulted in a decrease in mercury removal using activated carbon. The mercury removal slowly recovered overnight to the pre-trona injection levels of >90%.

An economic assessment of a full-scale trona injection system included equipment and other capital costs along with sorbent cost (trona and increased amount of PAC to maintain 90% removal) and O&M costs. The cost to remove SO_2 varied from $1,448/ton at 45% removal and one silo to $2,231/ton SO_2 at 70% removal with 3 silos.

Introduction

We Energies' Presque Isle Power Plant is the site of a DOE Clean Coal demonstration project being conducted under a cooperative agreement with Wisconsin Energy Corporation and the Department of Energy (DOE). The primary goal of this project is to reduce mercury emissions using a TOXECON™ system designed to clean the combined flue gases of Units 7, 8, and 9 at the Presque Isle Plant. An additional goal is to reduce NO_x and SO_2 emissions.

TOXECON™ is an Electric Power Research Institute (EPRI) patented process in which a fabric filter system (baghouse) installed downstream of an existing particulate control device is used in conjunction with sorbent injection for removal of pollutants from combustion flue gas. The flue gas emissions are controlled from the three units using a single baghouse. Mercury is controlled by injection of activated carbon, while NO_x and SO_2 reduction was tested by injection of sodium-based sorbents. Both the mercury and SO_2/NO_x control sorbents were removed from the gas stream by the baghouse.

The overall objectives of this project are to demonstrate the operation of the TOXECON™ multi-pollutant control system and:

1. Achieve 90% mercury removal from flue gas through activated carbon injection (achieved).
2. Reduce particulate emissions through collection by the TOXECON™ baghouse (achieved).
3. Maintain 100% utilization of fly ash collected in the existing electrostatic precipitator (achieved).
4. Demonstrate reliable, accurate mercury CEM suitable for use in the power plant environment (achieved).
5. Evaluate the potential for 70% SO_2 control and trim control of NO_x from flue gas through sodium-based or other novel sorbent injection, while maintaining 90% mercury removal.
6. Recover 90% of the mercury captured in the sorbent.

Objective #5 was the focus of the test program described in this report.

Background

Testing of SO_2/NO_x control sorbents to date in the TOXECON™/COHPAC® configuration included:

- Full-scale tests injecting sodium bicarbonate and sodium sesquicarbonate (trona) upstream of the Big Brown COHPAC® baghouse for SO_2 control.[1]
- Pilot tests of sodium and lime sorbents injected upstream of COHPAC® for SO_2 control at Southern California Edison's Mohave Station.[2]
- Slipstream tests of sodium-based materials, lime, activated carbon, and a proprietary catalyst for NO_x, SO_2, SO_3, HCl, HF, and Hg at the PSEG Hudson Generating Station.[3]

Test results indicate that sodium-based products can achieve from 30% to 70% SO_2 reduction. At normal flue gas temperatures, lime/calcium products are not effective for SO_2 control. Sodium-based sorbents also reduced NO_x by 10% to 20%. HCl removal was as high as 50% at Hudson using sodium sesquicarbonate.

Test and Equipment Description

This test effort was designed to support the overall objectives of the TOXECON™ retrofit at Presque Isle as well as to further the technical understanding of the TOXECON™ technology for both We Energies and the greater industry. Parametric and continuous tests were planned to assess the capability of trona injection upstream of the TOXECON™ baghouse to control SO_2 and NO_x. Injection equipment and measurement instrumentation were installed specifically for these tests. The following were the objectives of the testing program:

1. Quantify the trona injection rate versus SO_2/NO_x removal.
2. Record baghouse performance over the test period, showing how pressure drop, cleaning frequency and mercury removal change.
3. Determine if there is any negative effect of trona injection on emissions (NO_2 production).
4. Evaluate the technical and economic performance of trona as an option for full-scale SO_2 control.

The tests for SO_2/NO_x control were conducted in two phases, baseline and parametric testing, as shown in Table 1. Measurements were taken during July to determine baseline conditions. Parametric testing data was used to characterize the performance of trona across a range of injection concentrations and at different PAC injection concentrations. Originally, a 5 day continuous test was scheduled but due to shipping and material handling issues this phase was cancelled.

Table 1. Schedule of Activities for SO_2/NO_x Control Testing.

SO_2-NO_x Control Activity	Duration (Days)	Start Date	Boiler Load
Baseline Testing	21	07/09/2007	Normal Operation
Equipment Installation and Shakedown	2	07/30/2007	Normal Operation
Parametric Testing	10	08/1/2007	Full Load 6AM–6PM

The final test plan for injecting trona to control SO_2 and NO_x was distributed to the project team in July. The plant completed the installation of SO_2 and NO_x analyzers at each of the three ducts upstream of the sorbent injection point in early July. These analyzers provided data on untreated SO_2 and NO_x levels for both baseline and injection testing.

Plant operators kept the three units at full, steady load during the two week test period. The boiler soot blowers were used every hour on a staggered schedule with the three units to keep the flue gas temperature from fluctuating during testing. PAC injection was left unchanged initially. The logic allowed for the injection rate to vary +/- 20% to keep 91% mercury removal.

Trona Background Information

Trona is a sodium-based, naturally occurring mineral (sodium sesquicarbonate). The trona used during this test program was obtained from Solvay Chemicals, Inc. and was mined in Green River, Wyoming. The purified SOLVAir Select 200 trona was shipped by rail to Chicago then loaded into hopper trucks for delivery to Marquette, Michigan. The hopper trucks typically carried 45,000 – 48,000 lb of trona depending on the test schedule. The particle size of the trona averaged 26 µm according to the Certificate of Analysis accompanying the material.

The formula for sodium sesquicarbonate is:

$$\underset{\text{sodium carbonate}}{Na_2CO_3} \cdot \underset{\text{sodium bicarbonate}}{NaHCO_3} \cdot \underset{\text{water}}{2H_2O}$$

When heated to 257-482^{o}F in a duct or a calciner, the sodium trona decomposes to sodium carbonate according to the formula:

$$2(Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O) \rightarrow 3Na_2CO_3 + CO_2 + 5H_2O$$

When injecting trona into a coal fired power plant flue gas, it reacts with hydrochloric acid and SO_2 according to the following:

$$Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O + 3HCl \rightarrow 3NaCl + 4H_2O + 2CO_2$$

$$2(Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O) + 3SO_2 \rightarrow 3Na_2SO_3 + 4CO_2 + 5H_2O$$

$$3Na_2SO_3 + 1.5O_2 \rightarrow 3Na_2SO_4$$

Review of industry literature emphasizes the benefit of injecting trona in a hot-side (greater than 700 °F) location. Trona experiences what is referred to as a “popcorn effect” where at high temperature the thermal decomposition reaction results in an expanded particle with a high surface area to mass ratio, improving the chemical availability of the sodium compound. This change improves the effectiveness by a factor of between 5 and 10. Trona will still react with SO_2 if injected at lower temperatures (typical cold-side temperature around 300 to 350 °F) but loses the reactivity otherwise gained by the particle expansion. Consequently, for lower temperature applications more trona is required to achieve the same SO_2 removal efficiency. During the first 10 days of August, the flue gas entering the baghouse at Presque Isle varied from 333 – 372 ^{o}F.

Trona Injection Equipment

The injection equipment for this test program was obtained from Bulk Conveyor Specialist, Inc. and staged near the Units 7-9 stack as shown in Figure 1. This equipment consisted of a trailer holding approximately 40 tons of trona and a separate trailer housing the blowers and controls (Figure 2). This system injected sorbent at the shipped particle size. Feed rate for the trona was from 2,200 lb/hr up to 5,900 lb/hr at full load to cover a wide range of stoichiometric ratios.

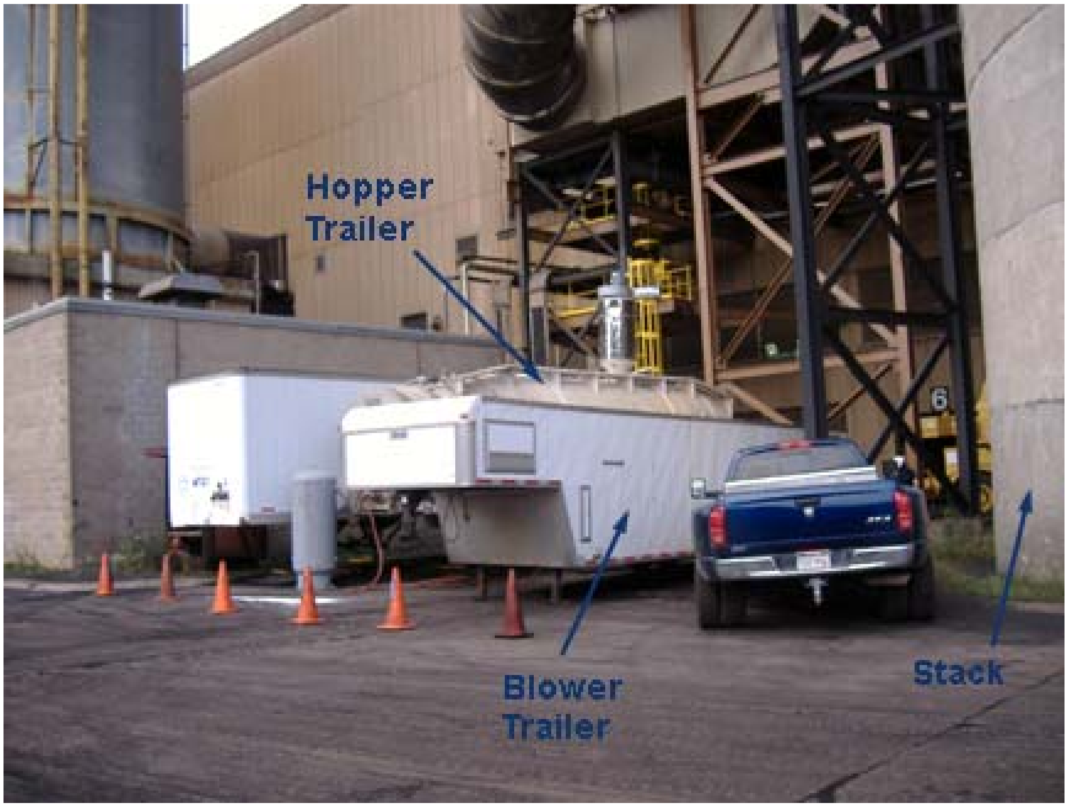

Figure 1. Staging Area for Trona Injection Equipment

Figure 2. Trona Injection Trailer Blowers and Controls.

The trona was fed to three injection lances which were located downstream of the ID fan discharges, but upstream of the point where the ducts combine. Each lance discharged sorbent into the center of its duct, where turbulent flow provided gas/sorbent mixing. The lances were located below the current PAC injection lances (white hose in Figure 3). This is downstream of the NO_x analyzer probe used for boiler feedback.

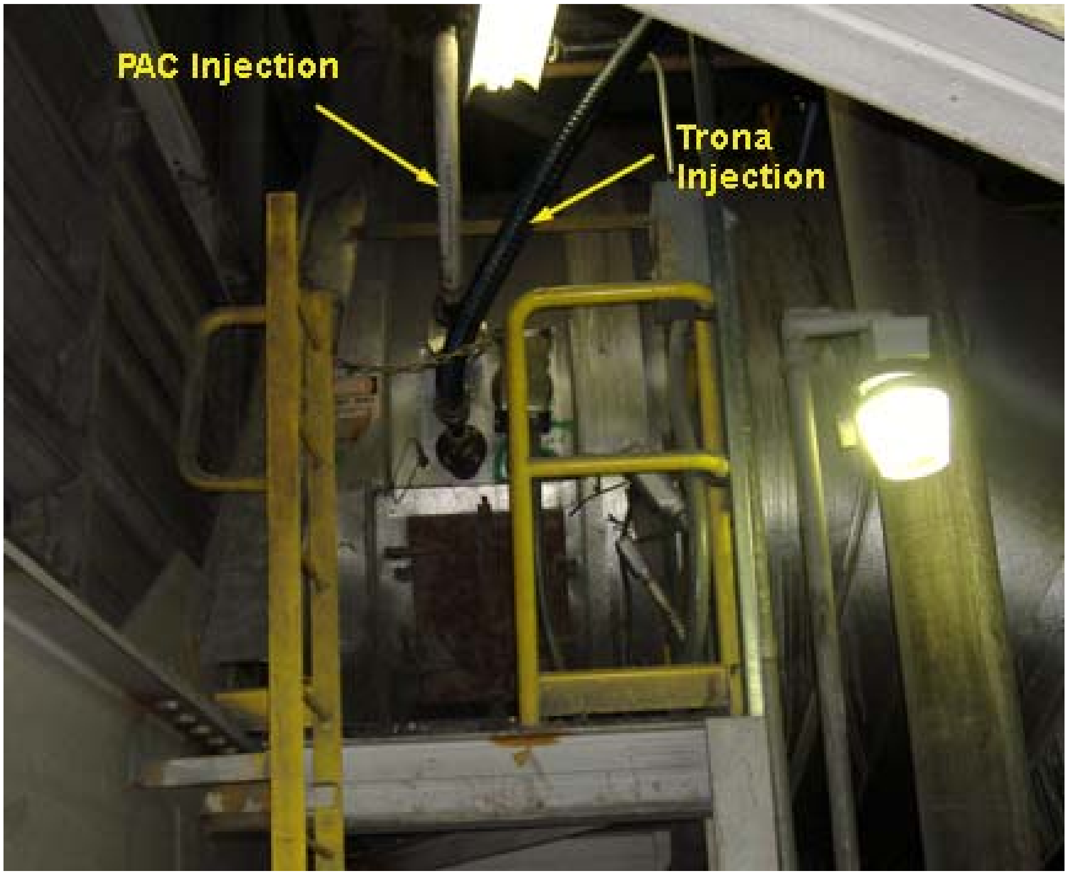

Figure 3. Injection Ports

Trona/Ash Unloading Issues

Prior to field testing, there was some concern that the reacted trona/ash/PAC from the baghouse would be difficult to unload and transport using the existing ash-handling equipment. The reacted trona hardens when wetted, and Presque Isle typically uses a wet unloader for the PAC/ash mixture. This mixture is then hauled by truck to the landfill.

Benetech, Inc. performed a series of laboratory tests on the anticipated final product from the baghouse and developed a chemical to prevent hardening of the mixture. A tanker truck of the chemical along with injection equipment was prepared and shipped to Presque Isle for the testing. Provisions were made to add this chemical to the water spray used in the wet unloader.

SO_2, NO_x and Opacity Measurement

SO_2 and NO_x monitors were installed on a temporary basis by We Energies near the exit of the ID fan on each duct to establish baseline levels coming from each boiler. At the stack, the plant continued to utilize the installed SO_2 and NO_x monitors to establish native removal across the TOXECON™ system and provide removal rates during trona injection.

Data from the inlet and stack monitors was collected continuously by the plant data acquisition system (EDS) and saved on the historian computer. The data was downloaded every week during baseline and every day during trona injection.

Prior to the trona injection testing, three Relative Accuracy Test Audits (RATAs) were performed on the SO_2 and NO_x monitors in the Units 7, 8, and 9 flues. The Unit 7 RATA was performed on June 13, 27, and 28, 2007. The Unit 8 RATA was performed on June 5 and 6, 2007. The Unit 9 RATA was performed on June 5 and 6, 2007.

The results of the RATAs reported by the testing company were:

> "The test results from this test program indicate that each CEM system meets the United States Environmental Protection Agency (USEPA) annual performance specification for relative accuracy as published in 40 CFR Part 60 and/or 40 CFR Part 75."

Test Results

Baseline Testing

The purpose of the baseline test was to establish the concentrations of pollutants leaving the air preheater and to determine if there was any native capture across the TOXECON™ fabric filter without sorbent injection. Figure 4 shows inlet and outlet data for SO_2 and NO_x for the three ducts and flues during July. As expected, none of the three graphs show any removal across the baghouse prior to trona injection. In addition to the flue gas measurements for SO_2/NO_x, ash samples were taken from the baghouse hoppers. A composite sample of ash from four hoppers was used to characterize the ash during this time.

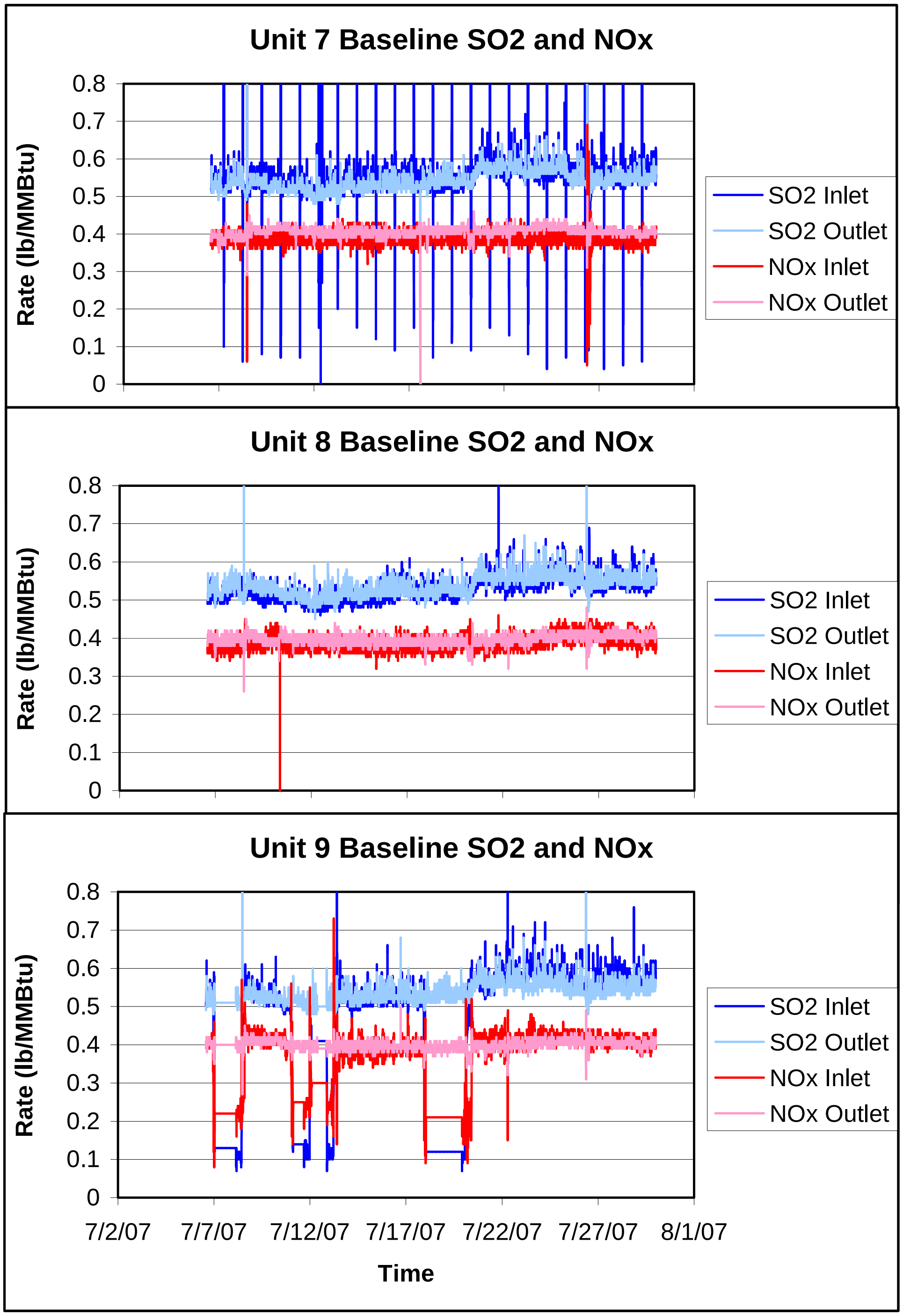

Figure 4. Baseline SO_2 and NO_x Data

Parametric Testing

Schedule and Materials Handling

The trona injection equipment was set up at Presque Isle on Monday, July 30, 2007. All of the injection hoses and lances were installed by late afternoon. Electricity was connected to the blower trailer by 3:30 pm.

The first truckload of trona arrived on site Tuesday morning. This truck carried 48,000 lbs, which partially filled the hopper truck. In order to test the wet unloader and the effect of the anti-setup chemical supplied by Benetech, four hours of injection at 2,200 lb/hr was performed on Tuesday, July 31. At the end of the four hours, the ash silo was unloaded using the chemical in the water feed to the pin mixer. The ash silo had been unloaded earlier in the day so the majority of the ash in the silo contained reacted trona.

There were no problems with hardening or setting up of the reacted trona/ash/PAC in the wet unloader or in the ash truck. Benetech also provided 10 gallons of a "trona release chemical" for spraying on the inside of the ash truck bed and the inside of the pin mixer. Bottom ash from Units 5 and 6 (bituminous coal) was used to line the bottom of the ash truck also since the efficacy of the release chemical or anti-setup chemical had not been tested at full scale yet. Figure 5 shows the material being unloaded at the landfill. The consistency was similar to wet sand. The next day the material still had not changed in consistency.

Figure 5. Unloading Reacted Trona/PAC/Ash Mixture

On Wednesday morning, August 1, the ash silo was unloaded to remove the accumulated material from overnight. This material contained significant amounts of reacted trona that had been cleaned from the bags over the course of several hours after injection had stopped. This unloading process was inadvertently performed without the anti-setup chemical, and there were no problems with the material setting up in either the mixer or the truck. Over the course of the next few days, unloading at the end of injection was done with the chemical, and in the morning without. There were no issues with setup either with or without the chemical. The wetted material showed a significant heat of reaction and was still steaming when unloaded at the landfill.

During the second week of testing, the ash silo was unloaded after injection using water only (no anti-setup chemical). Although there was a noticeable heat associated with the mixing, the material didn't set up in the pin mixer or in the truck. A sample was taken at the landfill and the next day it still hadn't set up. The reaction with water to form a solid hydrate may have occurred in the pin mixer but the action of the mixer may have kept the material from solidifying. The main risk of wetting the trona/ash/PAC without the anti-setup chemical is that if the mixer stops, the wet material in the mixer would likely solidify and would be very difficult to remove.

Parametric testing began August 1, 2007. During this test phase all three units were at full load. The original plan was to vary the sorbent injection rate from approximately 2,200 lb/hr up to 5,400 lb/hr. There was some concern that the ash system could not handle a sorbent injection rate above 5,400 lb/hr. The vacuum system used to pull ash from the hoppers and transport it to the silo was rated for 5,000 lb/hr. Adding the ash and PAC (110 lb/hr and 130 lb/hr approximately) put the highest injection rate well above the rating for the vacuum system.

SO_2 and NO_x Removal

Table 2 shows the injection rate and SO_2 removal for the test period. The maximum removal achieved during the testing was 74.1% when co-injecting 3.8 lb/MMacf PAC.

Table 2. Trona Injection Results.

Date	Trona Injection Rate (lb/hr)	Average NSR*	SO_2 Inlet (lb/MBtu)	SO_2 Removal (%)	Comments
8/1/07	2223	0.37	0.50-0.66	46.6	
8/2/07	2223	0.41	0.48-0.63	47.6	
8/3/07	4446	0.81	0.48-0.59	65.4	
8/4/07	4446	0.79	0.50-0.58	65.5	
8/5/07	5432	0.97	0.49-0.57	69.8	
8/6/07	5926	-	-	-	Difficulty feeding trona – test stopped
8/7/07	5926	1.02	0.52-0.60	70.7	
8/8/07	5926	1.02	0.52-0.66	68.5	PAC injection turned off during am
8/9/07	5926	1.03	0.49-0.62	72.1	PAC injection ramped up to 3.8 lb/MMacf
8/10/07	5926	1.02	0.51-0.64	74.1	Started PAC injection at 3.8 lb/MMacf at start of trona injection

* Normalized Stoichiometric Ratio

As seen in Table 2 and Figure 6 below, the best SO_2 removal was observed when PAC was being injected at an unusually high level for this site (3.8 lb/MMacf). This was done to try to recover the >90% mercury removal. This PAC injection rate was at the end of a test day, and the mercury removal was at 89%. During all trona injection tests, mercury removal degraded, and then slowly recovered overnight when no trona was injected (discussed below).

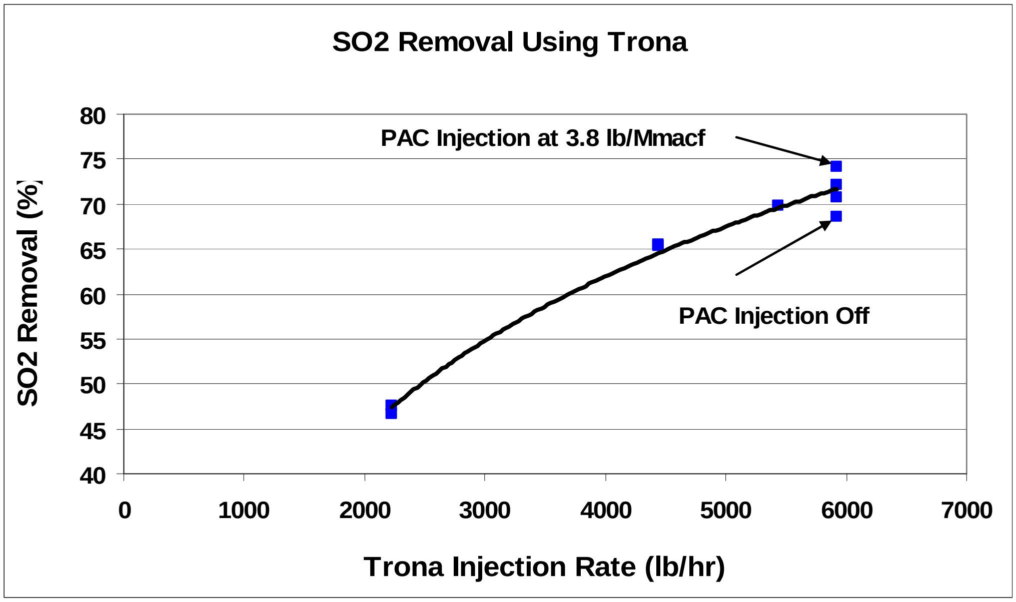

Figure 6. SO_2 Removal vs. Trona Injection Rate.

Figure 7 shows typical SO_2 removal profiles at varying trona injection rates. There was an initial rapid increase in removal but it took 3-4 hours before removal became somewhat steady. Most test periods were 8 hours, but one day was only 6 hours. When trona injection was turned off, there was an initial rapid decrease in SO_2 removal, but it didn't come back to baseline levels for 5-6 hours, which was the time required to perform a full cleaning cycle on the baghouse.

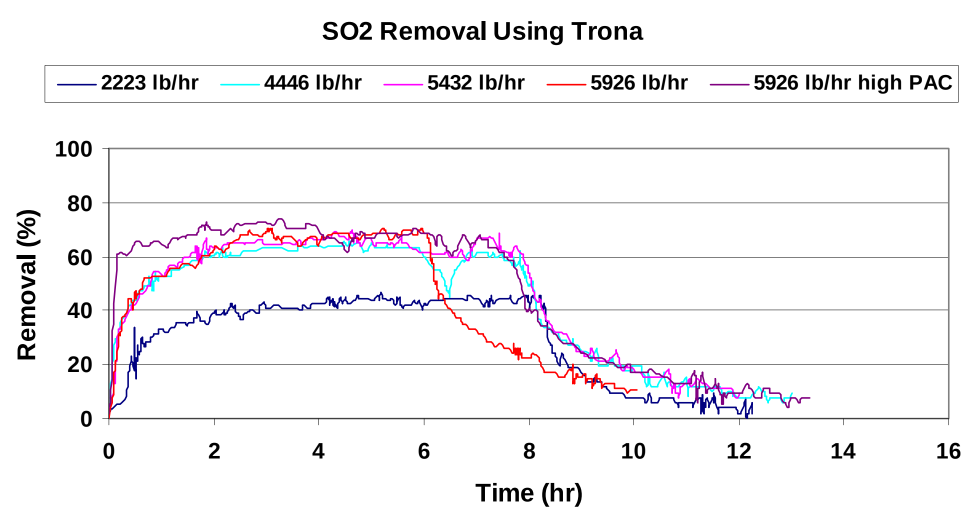

Figure 7. SO_2 Removal Profiles.

In addition to the impacts on SO_2, a small reduction in NO_x emissions was expected based upon work at other test sites. As shown in Figure 8, there was no noticeable reduction in NO_x.

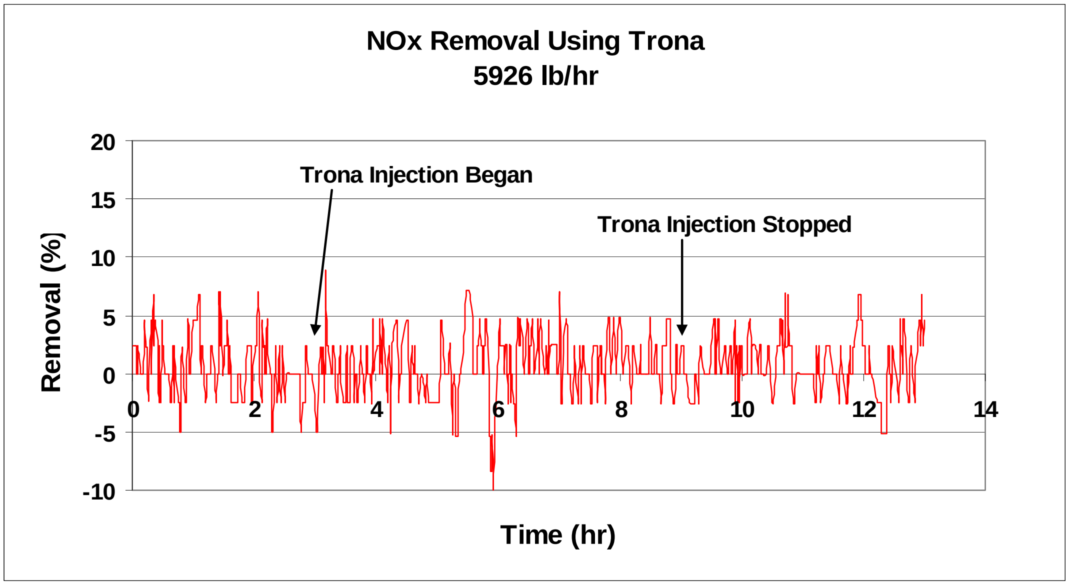

Figure 8. NOx Removal During Trona Injection.

At other test sites, a side reaction from using trona is the creation of small amounts of NO_2, which results in a brownish plume and an increase in opacity. Figure 9 shows an increase of about 0.75% in the three opacity monitors during the highest injection rate used. There was no visible brown plume during this test.

At the end of the trona injection period on August 7, PAC injection was also turned off and kept off overnight and through the start of trona injection on August 8. At mid-day on August 8 a brownish plume was seen coming from the stack. This is the first time this had occurred. The opacity levels on all three monitors increased by almost 3% (Figure 10). PAC injection was resumed at 1:00 pm and within 30 minutes the plume had been visibly reduced and the opacity decreased.

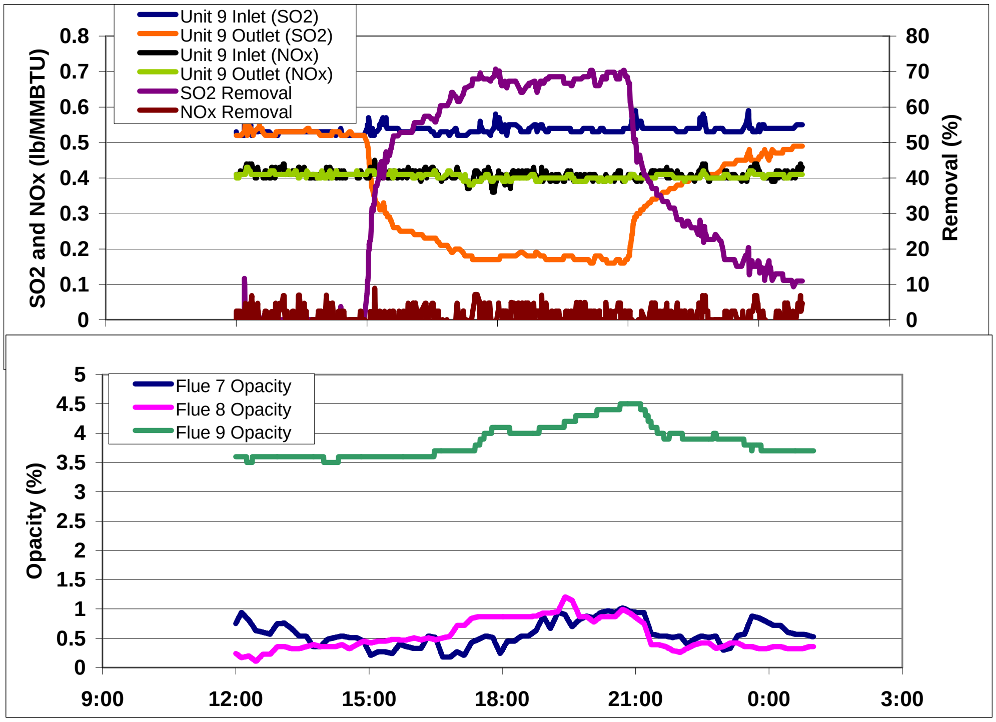

Figure 9. Effect of 5926 lb/hr Trona Injection on SO_2, NO_x, and Opacity.

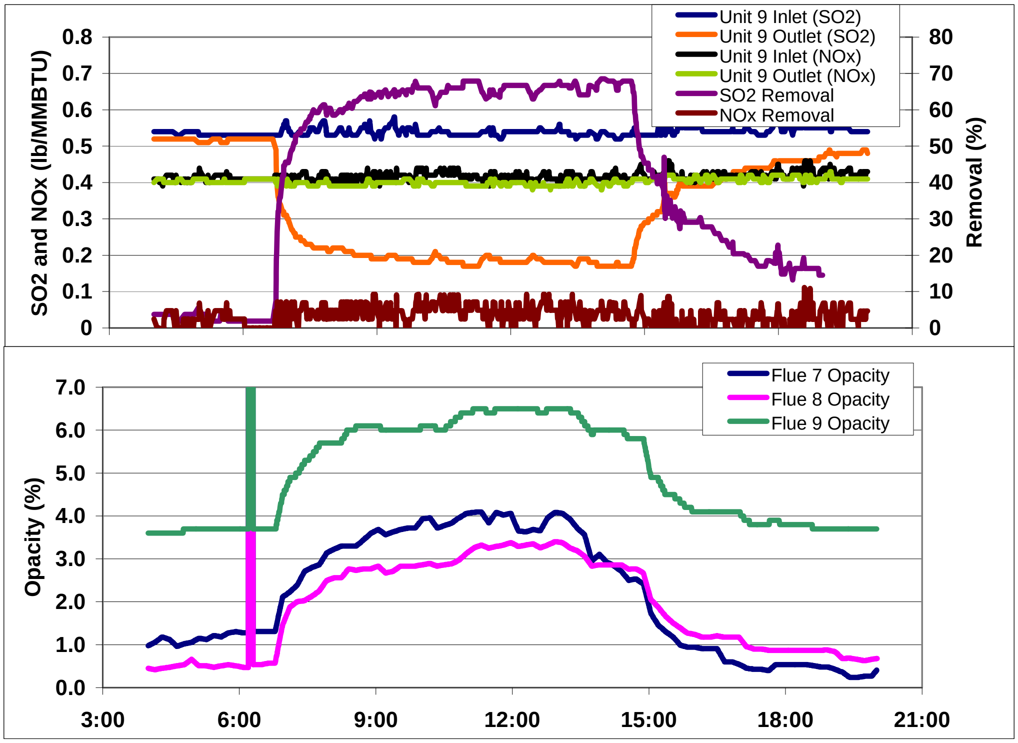

Figure 10. Effect of 5926 lb/hr Trona Injection without PAC Injection

Baghouse Pressure Drop and Cleaning Frequency

Any impacts on the cleaning cycle and pressure drop were closely monitored. The fabric filter was cleaned in an online mode for all parametric tests. Figure 11 shows the effect of trona injection on baghouse operation during the entire injection period. As mentioned earlier, mercury removal was negatively affected during trona injection, but recovered overnight. The air-to-cloth ratio didn't change during testing. The cleaning frequency increased slightly during testing.

One unexpected side effect due to trona injection into the baghouse was degradation in mercury removal. On August 9, the PAC injection was increased throughout the trona injection period to try to recover 90% mercury removal. By the end of the injection period, PAC injection was at 3.8 lb/MMacf and mercury removal was at 89%. On August 10, PAC injection was increased to 3.8 lb/MMacf at the start of trona injection and there was still a reduction in removal initially. PAC injection reached 4.6 lb/MMacf without regaining 90% mercury removal. Previous tests show an initial drop in removal, then a partial recovery after several hours.

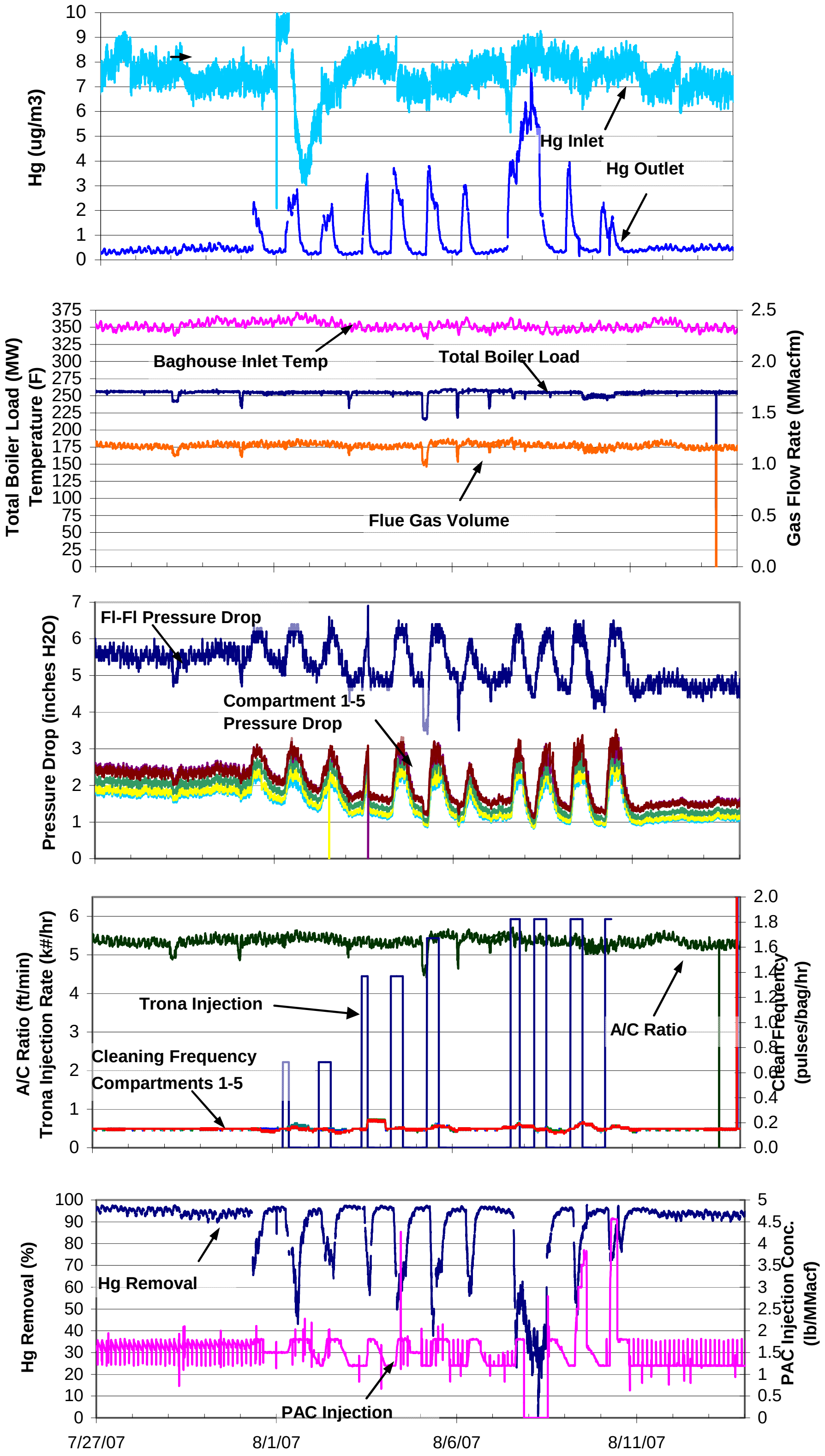

Figure 11. Baghouse Operation During Trona Injection Testing.

Economic Assessment of Full-Scale Trona Injection

Introduction

An economic assessment was performed to determine the cost for the installation and operation of a full-scale, commercial trona injection system at We Energies' Presque Isle Power Plant Units 7, 8 and 9. Based on the results from the tests described above, cost and design estimates were made for a permanent trona injection system. The design premises and the results of the economic analysis are presented here. A detailed description of the economic analysis is presented in Appendix A.

Estimates were made for sorbent usage and costs were estimated for three injection rates of 2223 lb/hr, 4446 lb/hr, and 5926 lb/hr, which include treatment for the flue gas from all three units. From the tests completed in August 2007, these injection rates correlate to SO_2 removal rates of approximately 45%, 64%, and 70%. The cost and design of process equipment has been estimated based on the test results for up to 70% SO_2 control and on the plant-specific requirements such as sorbent storage capacity, plant arrangement, sorbent transportation and delivery options, retrofit issues, controls interface, etc.

A consequence of simultaneously injecting trona for SO_2 control and injecting PAC for mercury control was significant degradation in mercury removal. August 2007 tests showed an initial drop in mercury removal, then a partial recovery after several hours. This economic assessment includes cost estimates for the increase of PAC usage required when injecting trona. Normal average injection rates at Presque Isle of PAC for 90% mercury removal were 1.5 lb/MMacf for DARCO® Hg-LH and 2.5 lb/MMacf for DARCO® Hg. To achieve 90% mercury removal while injecting trona at a rate required for 70% SO_2 removal, DARCO® Hg-LH would need to be injected at approximately 4.5 lb/MMacf and the injection rate for DARCO® Hg was assumed to be at 7.5 lb/MMacf, based on the required increase in DARCO® Hg-LH usage.. The increased requirement for PAC was not measured at the lower trona injection rates. The PAC increase was calculated based on a linear increase from baseline to the highest injection rate. PAC injection rates costs for the SO_2 removal rates are summarized below in the section regarding variable operating costs in Appendix A.

Process Design

Trona Injection System

Costs were estimated for two different equipment setups. The first setup consists of one bulk storage silo with three pneumatic conveying systems. The second setup consists of three bulk storage silos, each dedicated to a single unit with one pneumatic conveying system on each silo. Note that the silo size is the same (150,000 lbs trona/silo) for the one- and three-silo systems. The three-silo setup is the type that is installed at Mirant's Potomac Station.

The conveying distances and the storage site were assumed to be the same as the test in August 2007. The silo was sized based on the capacity to hold approximately one day worth of trona at the maximum design injection rate of 6,000 lb/hr. This would be approximately 4 truckloads

(40,000 lb) or one rail car load (200,000 lb) for the combined 3 units. The issue of material packing in the silo and inhibiting the flow-ability of the material was considered in the sizing of the silo. The 3-silo option outlined in the tables below would provide the plant with a 3-day supply of trona. Table 3 displays the design criteria for an SO_2 control system.

Table 3. System Design Criteria for SO_2 Control System at Presque Isle (6000 lb/hr injection, >70% SO_2 control).

Parameter	3-Silo System	1-Silo System
Number of silos	3	1
Number of injection trains	3	3
Design feed capacity/train (lb/hr)	2000	2000
Total trona storage capacity (lbs)	450,000	150,000
Conveying distance (ft)	300	300
Sorbent	Trona	Trona
Aerated density (lb/ft^3)	49	49
Settled density (lb/ft^3)	69	69
Particle MMD (microns)	26	26

The trona can be delivered by two methods. One option is to have the trona railed to nearby Ishpeming in 200,000-lb capacity rail cars and then transferred to self-unloading pneumatic bulk tanker trucks and delivered in 40,000-lb batches. Another option is have a rail spur installed to the plant and have rail cars directly unload to the storage silo(s). Both options have been cost estimated; however, the cost for a rail spur was not included.

The silo is equipped with a bin vent filter to contain dust during the unloading process. The silo is a shop-built, dry-welded tank with level indicators and load cells to monitor sorbent level and inventory. If only one silo is used, then that silo will have three hopper cones with a blower for each cone. If three silos are used, then each silo will have one hopper and blower.

The sorbent is fed from the hopper(s) by rotary valves into the conveying lines. The conveying air is supplied by blowers. The air provides suction to draw the sorbent into the conveyer piping and carries it to the injection lances where it is dispersed into the duct. There are three injection lances, which are located downstream of the ID fan discharges, but upstream of the point where the ducts combine. Each lance discharges sorbent into the center of its duct, where turbulent flow will provide gas/sorbent mixing. The lances will be located below the current PAC injection lances. This is downstream of the NO_x analyzer probe used for boiler feedback. Figure 12 shows the schematic of the plant and includes the two options for the trona silo(s).

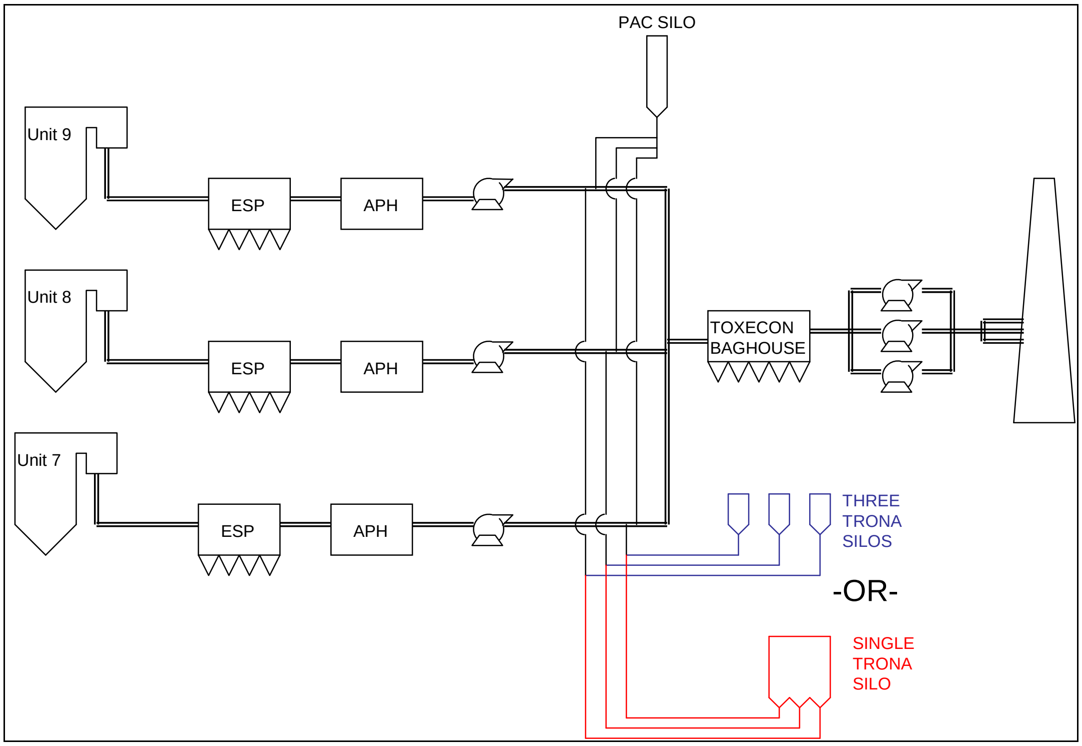

Figure 12: Schematic of the Trona Injection Equipment at Presque Isle Units 7, 8 and 9

Ash Handling System

Some modifications and upgrades to the existing plant equipment would be required to accommodate a full-scale trona injection system. These include upgrades to the electrical supply to provide new service to the injection system as well as intercom phones and area lighting.

The spent trona/ash/PAC mixture will be collected in the baghouse, conveyed to the ash silo and unloaded into ash trucks that dispose of the material in the landfill as is the current operating procedure. The ash handling capacity will need to be increased to accommodate the higher loading of material. The existing 4 in. conveyor piping system is adequate although a new mechanical exhauster capable of up to 15 in Hg will need to be installed. The new mechanical exhauster motor size would need to be increased from 10 HP to 20-25 HP.

The increased vacuum level produced by a new mechanical exhauster increases the gas flow rate in the ash system and therefore creates a larger air-to-cloth ratio in the filter separator. An air-to-cloth ratio of 4:1 is desirable so an increased filter area would be required with trona injection. To achieve this ratio the existing filter/separators could be operated in parallel, however this leaves the system without a redundant filter/separator. Another option is to replace the existing filter/separator with two larger capacity, continuous operating, filter/separators. Modifications to the ash silo building would be necessary, such as extending the bin roof and modifying the bin structure to support the higher loadings of the bigger filter/separators. An alternative would be to install pleated bags in the existing system.

Cost Estimates and Results

Costs for capital equipment, operations, maintenance, and power were provided by vendors as well as estimated using the economic basis provided in EPRI's *Economic Evaluation of Dry-Injection Flue Gas Desulfurization Technology*[6]. The capital and fixed and variable O&M costs were then converted into and combined as 20-year levelized costs using the traditional EPRI *Levelized Cost* or *Uniform Annual Cost* analysis typical of historical EPRI studies and as used in Reference 6. This methodology provides a suitable first-cut approximation and comparison of the time-value of money over the 20-year estimated life of the trona injection system options considered.

Different scenarios of equipment set-up and injection rates were priced and compared. These scenarios and the economic analysis results are summarized below. A more-detailed description of the analysis is presented in Appendix A.

Capital Costs

The costs of equipment and installation for the trona injection system and balance-of-plant systems are shown in Table 4. This table compares the capital cost elements for the one-silo vs. three-silo systems. Capital costs for a permanent trona injection system include the storage silo(s), blowers, conveyor piping, dehumidifiers, and modifications to the ash handling system. Bulk Conveyor Specialist, Inc provided the cost estimates for the trona storage and injection equipment and installation. The required capital equipment is summarized below. A more-detailed description of these capital cost elements is presented in Appendix A.

- **Storage Silo**: Skirted, carbon steel shell with cone. Storage capacity of 75 tons. Includes bin vent collector, bin discharger, discharge valve, bin indicators, weigh hopper, rotary valves, control panel, blowers, dehumidifiers.
- **Blowers**.
- **Conveyor Piping**.
- **Lances**.
- **Housing for Redundant Blowers and Dehumidifiers**.
- **Mechanical Exhauster Package**
- **Larger Capacity Filter/Separator**

Table 4: Summary of Equipment, Balance-of-Plant, and Engineering Costs

Trona Injection System and Balance-of-Plant Equipment and Installation Costs Presque Isle Power Plant Units 7, 8, and 9		
CAPITAL COST ELEMENT DESCRIPTION	**COST**	
	1 Silo	**3 Silos**
Trona Storage/Injection System (Equipment Cost)		
• Silo (s) - Including: 75 ton Capacity Storage Silo, 1 Hopper Below Silo, 1 Blower, 1 Dehumidifier Pkg, Conveyor Piping (300 ft)	$ 595,000	$ 1,785,000
• Lances (*Injection lances from test can be used in permanent system; additional lances are optional at $5,000 per lance)	$ 5,000*	$ 5,000*
• Redundancy (equipment added for 3 injection lines per 1 silo), Including: Splitter Valve, 2 Hoppers, 2 Rotary Valves, 2 Blowers, 2 Dehumidifier Packages, Housing for Blowers and dehumidifiers	$ 98,500	$ -
Installation of Trona Storage/Injection Equipment Includes civil, electrical, mechanical and piping	$ 580,000	$ 580,000
TOTAL PROCESS EQUIPMENT	$ 1,273,500	$ 2,365,000
Increase In Ash Handling Capabilities		
• 2 Mechanical Exhauster Packages	$ 15,000	$ 15,000
• Larger Capacity Filter/Separator (Design and Supply)	$ 200,000	$ 200,000
TOTAL ASH HANDLING EQUIPMENT UPGRADES	$ 215,000	$ 215,000
TOTAL EQUIPMENT COSTS (Installed Cost, TEC)	**$ 1,488,500**	**$ 2,580,000**
General Facilities **(10% of TEC)**	$148,850	$258,000
Engineering and Home office Fees **(12.5% of TEC)**	$186,062	$322,500
Project Contingency **(25% of Process Equip. + 20% of Ash Handling Equip.)**	$361,375	$634,250
Process Contingency **(7.5% of Process Equip. + 5% of Ash Handling Equip.)**	$106,262	$188,125
TOTAL PLANT COST (TPC)	**$2,291,050**	**$3,982,875**
Preproduction Costs **(=(1/12)*(Fixed O&M + Var O&M)+.02*TPC)**	$397,921	$431,757
TOTAL CAPITAL REQUIREMENT (TCR)	**$2,688,971**	**$4,414,632**

As shown in Table 4, the total capital requirement (TCR) for a project includes not only the capital cost estimates provided by the vendor, but also such factored estimates as funds for general facilities, engineering and home office fees, project and process contingencies, and preproduction costs. These factored estimates were calculated in accordance with EPRI guidelines and are consistent with those factors used in the analysis in Reference 6 as shown in the table. The TCR for a three-silo system is about 1.6 times that for a one-silo system.

Operating and Maintenance Costs

The operating and maintenance (O&M) costs associated with trona injection for SO_2 control include fixed and variable costs. Fixed O&M costs include labor, maintenance materials, and administrative and support labor. The variable O&M costs vary depending on unit and other capacity factors and include sorbent, power, and waste disposal.

Fixed O&M Costs

The fixed O&M costs include:

- labor costs for ash handling
- operating and maintenance labor costs for the silo and injection equipment
- maintenance materials
- administrative and support labor

The maintenance labor, materials and support labor are estimated using known costs for the TOXECON system installed and operating at Presque Isle.

Applicable labor rates, maintenance, and operating materials costs were determined for three SO_2 removal rates (45%, 64%, and 70%). For example, the ash handling system labor costs increase as SO_2 removal rates increase due to the need for more frequent ash unloading and disposal because of the increased sorbent injection rates. Operating labor costs also vary slightly depending on the type of PAC used due to slight differences in injection rate.

The operating labor costs for the silo and injection equipment are constant for different SO_2 removal rates as well as constant with either one-silo or three-silo systems. The operating, maintenance and project overhead costs are estimated from the annual costs associated with the TOXECON system currently at Presque Isle. The maintenance materials are estimated in the same manner.

Table 5 summarizes the first-year fixed O&M costs calculated for this analysis. As seen, the Fixed O&M costs do not vary depending on whether a one- or three-silo system is used. However, costs do vary depending upon the type of sorbent used and on the SO_2 removal rate. Table 5 shows the total first year fixed O&M costs comparing costs at different SO_2 removal rates.

Note that these first-year O&M costs in Table 5 can also be expressed in terms of $/yr, although such numbers do not reflect the application of levelization factors to reflect the time-value of money. Levelized O&M and capital costs are discussed below. The development of these fixed O&M costs and the assumptions made are described in more detail in Appendix A.

Table 5. Total First-Year Fixed Operating & Maintenance Costs

Total First Year Fixed O&M Cost			
1 or 3 Silos	**SO_2 Removal Rate**		
O&M Labor & Material Costs*	**45%**	**64%**	**70%**
• Labor Costs for Ash Handling			
Trona + DARCO® Hg + Ash	$132,740	$265,880	$357,860
Trona + DARCO® Hg-LH + Ash	$126,470	$256,800	$345,500
• O&M Labor & Materials & Support Labor for Silo & Injection Equipment			
O&M Labor Costs	$360,000	$360,000	$360,000
Maintenance Materials	$108,000	$108,000	$108,000
Total First Year Operating, Maintenance, & Support Costs (Silo & Injection)	$468,000	$468,000	$468,000
TOTAL O&M COSTS, 1 or 3 SILOS (Trona + DARCO® Hg + Ash)	**$600,740**	**$733,880**	**$825,860**
TOTAL O&M COSTS, 1 or 3 SILOS (Trona + DARCO® Hg-LH + Ash)	**$594,470**	**$724,800**	**$813,500**

*PAC injection rate varied for each SO2 removal rate.

Variable O&M Costs

The variable O&M costs vary depending on unit and other capacity factors and include estimates for:

- Power Costs
- Sorbent Costs
- Landfill Costs

The sorbent costs include trona as well as the increased PAC needed to keep the mercury removal at 90%. Power costs were estimated from the equipment power requirements and the current busbar cost of power production as obtained from the utility.

Power Costs

The electrical requirements for the trona injection system include power for blowers, rotary valve motors, bin discharger, and dehumidifiers. Each injection system requires power for one blower, one dehumidifier, and one rotary valve. There is one bin discharger per silo. Therefore, for a one-silo system with one large silo, power for one discharger is needed. For a three-silo system, power for 3 dischargers is needed. The long-term running power required is roughly half of the power required for start-up (connected load). The system power in kW is calculated knowing the amperage and voltage needed for the different components, along with a power factor and knowledge of the estimated time that each component operates.

Table 6 summarizes the estimated variable first-year operating cost for power estimated for one- and three-silo injection systems by summing the power usage requirements for each component and using an assumed busbar cost to produce power of $0.03/kWh as estimated by the utility. The calculations and intermediate steps used to determine the power cost estimate are presented in more detail in Appendix A.

Table 6. Variable First-Year Operating & Maintenance Costs for Power

Variable O&M Costs: Power		
	1 –Silo System	3-Silo System
Power Usage, in kW	42.35	127.05
Unit Power Cost, in \$/kWh	\$0.03	\$0.03
Power Cost, in \$/yr	\$11,125	\$33,375

Sorbent Costs

Sorbent costs vary depending on the desired SO_2 removal percentage and on the delivery method. Costs for trona and PAC increase as SO_2 removal levels increase due to the need for higher sorbent injection rates; this includes the increased trona injection rate as well as the increased PAC injection rate to maintain mercury removal levels. The cost for trona to be railed directly to the plant is \$140/ton assuming the costs to install a rail spur is picked up under another project. If a rail spur is not installed to the plant, the trona can be railed to Ishpeming, then loaded into a truck from there and delivered to the plant by truck. Using a combination of rail and truck would cost \$155/ton.

The amount of PAC needed to maintain 90% mercury control increases as trona injection increases due to the interference of trona injection with the PAC's ability to capture mercury. Table 7 summarizes the sorbent costs for the two delivery methods for the three SO_2 removal rates of 45, 64 and 70%. Also reflected in the table are the effects on first-year sorbent costs of different unit costs, and injection rates for trona and the PAC mercury sorbent, whether DARCO® Hg or DARCO® Hg-LH. The unit costs and injection rates assumed for each sorbent, delivery method and for each SO_2 removal rate as well as the steps taken to arrive at the total values summarized in Table 7. Additional details are provided in Appendix A.

Table 7. First-Year Variable Operating & Maintenance Costs for Sorbent Delivered by Rail and by Rail/Truck Combination to the Plant

Variable O&M Costs: Sorbent Delivered By Rail* or Combination to Plant			
Sorbent Costs in \$/yr**	SO_2 Removal Rate		
	45%	64%	70%
Delivered by Rail* to Plant			
Trona + DARCO® Hg	\$1,405,651	\$2,836,597	\$3,887,797
Trona + DARCO® Hg-LH	\$1,460,182	\$2,934,162	\$3,920,647
Delivered by Rail† and Truck†			
Trona + DARCO® Hg	\$1,514,056	\$3,053,407	\$4,178,520
Trona + DARCO® Hg-LH	\$1,568,587	\$3,150,972	\$4,211,370

* Trona rail spur assumed to be installed under separate project
** Minus PAC that would already be injected
† Trona railed to Ishpeming and trucked to plant

Waste Disposal Costs

The variable O&M costs for waste disposal are the costs required to landfill the spent sorbent captured in the baghouse. The 2007 unit cost to landfill material was \$44.40. The unit cost for landfill along with the waste production rates for each sorbent was used to calculate the total cost to landfill the waste for both PAC sorbents for each of the three SO_2 reduction rates as summarized in Table 8. Since this is a differential cost estimate that considers only the effect of adding a trona injection system, the costs do not reflect the ash and PAC waste that is disposed of while running at full load with no trona injection. The waste production rates and steps used in calculating the waste disposal costs summarized in Table 8 are shown in more detail in Appendix A.

Table 8. First-Year Variable Operating & Maintenance Costs for Landfill Waste Disposal

Variable O&M Costs: Waste Disposal			
Waste Disposal Costs, in $/yr**	**SO_2 Removal Rate**		
	45%	**64%**	**70%**
Trona + DARCO® Hg	$336,780	$674,575	$907,940
Trona + DARCO® Hg-LH	$330,360	$661,010	$886,060
**minus PAC/Ash waste that would already be disposed of			

Total Variable O&M Costs

Table 9 shows the total variable O&M costs at the three different SO_2 removal rates and for the different delivery methods. The total O&M costs include costs for power, sorbent usage, and disposal costs.

Table 9. First-Year Total Variable Operating & Maintenance Costs

Total Variable O&M Costs			
Total Variable O&M Costs, $/yr	**SO_2 Removal Rate**		
	45%	**64%**	**70%**
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg	$1,775,800	$3,544,550	$4,829,115
Trona + DARCO® Hg-LH	$1,823,915	$3,628,550	$4,840,085
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg	$1,884,210	$3,761,360	$5,119,840
Trona + DARCO® Hg-LH	$1,932,320	$3,845,360	$5,130,810

Levelized Costs

Levelized costs were computed to represent a constant cost value for the operating and capital costs over the lifetime of the equipment and project. In other words, the levelized costs take the present value of the net costs and spread them evenly over a period of time. This makes it possible to compare costs looking into the future. For this assessment levelized costs are presented in units of mills/kWh, where a mill is 1/1000 of a dollar.

The key economic parameters and factors used in this analysis are summarized in Table 10. The calculations to determine levelized costs assumed a discount rate of 7.5% and a 20-year levelization factor was used. The capital costs are converted using a fixed charge rate of 15.0%

and the O&M costs are converted using levelization factors of 1.29 for all costs including power and consumables.

Table 10. Economic Factors and Parameters

Economic Factors & Parameters	
Year of Estimate	2007
Plant Life	20 Years
Capital Recovery Factor	0.15
Fixed Charge Rate	15%
O&M Levelization Factor	1.29
Normal Capacity Factor	0.75
Power Capacity Factor	0.85

This methodology is consistent with typical historical EPRI studies, and in particular, the factors used here reflect those used in Reference 6. The use of a 15% *Fixed Charge Rate* is consistent with using a *Capital Recovery Factor* of 0.15, a typical approximation currently used by EPRI and utilities today for levelizing capital costs. Although the factors used here are generalizations, their use is a reasonable approximation for a first-cut economic evaluation for the rough comparison of these similar options. Should any utility desire to pursue these options more seriously for a given plant, a detailed economic analysis using economic factors and a methodology specific to the utility's current normal practice would be advised to confirm the economic viability of each option.

Levelized Capital Costs

The calculations used to determine levelized capital costs are shown in detail in Appendix A. Table 11 summarizes the levelized total capital requirement for the one- and three-silo options. The total capital requirement for three silos is less than double the requirement for one silo.

Table 11. Levelized Capital Costs

Levelized Capital Costs (20 yr, Current $ Basis)		
LEVELIZED TOTAL CAPITAL REQUIREMENT	1-Silo System	3-Silo System
Levelized $/yr	$403,345	$662,195
Levelized $/kW	$1.49	$2.45
mills/kWh	0.23	0.37

By comparison, the total capital requirement for a green-field installation of a pulse-jet baghouse on a 250 MW unit might cost approximately 50 $/kW as suggested by an EPRI study published in 1992.[7]

Levelized O&M Costs

The detailed steps in calculating levelized fixed and variable O&M costs are discussed in Appendix A. Tables 12 and 13 summarize the levelized fixed and variable O&M costs, respectively, resulting from this analysis. These tables summarize the levelized costs for the two PAC sorbents versus the three SO_2 removal rates.

Table 12. Total Levelized Fixed Operating & Maintenance Costs

Levelized Total Fixed O&M Cost			
Levelized Total Fixed O&M Costs	**SO_2 Removal Rates**		
	45%	**64%**	**70%**
Trona + DARCO® Hg + Ash			
Levelized $/yr	$774,950	$946,705	$1,065,360
Levelized mills/kWh	0.44	0.53	0.60
Trona + DARCO® Hg-LH + Ash			
Levelized $/yr	$766,870	$934,990	$1,049,415
Levelized mills/kWh	0.43	0.53	0.59

Recall that the variable O&M costs are dependent not only on the SO_2 removal rate and type of PAC sorbent used, but also on the transportation mode to the plant; i.e., whether the sorbent is taken to the plant directly by rail or whether the Rail/Truck combination is used. This is reflected in the levelized total variable O&M costs given in Table 13.

Table 13. Levelized Total Variable Operating & Maintenance Costs

Levelized Total Variable O&M Costs			
Levelized Total Variable O&M Cost	**SO_2 Removal Rate**		
	45%	**64%**	**70%**
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg			
Levelized $/yr	$2,290,786	$4,572,466	$6,229,557
Levelized mills/kWh	1.29	2.58	3.51
Trona + DARCO® Hg-LH			
Levelized $/yr	$2,352,853	$4,680,826	$6,243,710
Levelized mills/kWh	1.33	2.64	3.52
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg			
Levelized $/yr	$2,430,629	$4,852,150	$6,604,588
Levelized mills/kWh	1.37	2.74	3.72
Trona + DARCO® Hg-LH			
Levelized $/yr	$2,492,695	$4,960,510	$6,618,742
Levelized mills/kWh	1.41	2.80	3.72

Total Levelized Costs

Table 14 shows the total levelized costs, which includes the total variable O&M costs, total fixed O&M costs and total capital costs at three removal rates and for the two PAC sorbents for the two sorbent delivery methods. This is presented for the both the one- and three-silo systems.

Table 14. Total Levelized Costs (Capital and Fixed & Variable O&M Costs)

TOTAL Levelized Costs			
Total Levelized Cost (Capital and Fixed & Variable O&M Costs)	SO_2 Removal Rate		
	45%	64%	70%
1-SILO SYSTEM			
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg			
mills/kWh	1.96	3.34	4.34
Trona + DARCO® Hg-LH			
mills/kWh	1.99	3.39	4.34
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg			
mills/kWh	2.03	3.50	4.55
Trona + DARCO® Hg-LH			
mills/kWh	2.06	3.55	4.55
3-SILO SYSTEM			
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg			
mills/kWh	2.10	3.48	4.49
Trona + DARCO® Hg-LH			
mills/kWh	2.13	3.54	4.48
Trona Delivered by Rail/Truck			
mills/kWh	2.18	3.64	4.70
Trona + DARCO® Hg-LH			
mills/kWh	2.21	3.70	4.70

Removal Cost per Ton of SO_2 Removed

The best way to compare SO_2 removal technologies is on the basis of $/ton of SO_2 removed. Table 15 shows the cost per ton of SO_2 removed using trona at full scale for the three SO_2 removal rates considered as compared for the two PAC sorbent options and the two sorbent delivery options. These values are levelized over 20 years.

Table 15. Removal Cost per Ton of SO_2

Levelized Total Cost per Ton of SO_2 Removed ($/ton)			
No. of Silos, Delivery Method, and Sorbent	**SO_2 Removal Rate**		
	45%	**64%**	**70%**
1 SILO			
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg	$1,483	$1,780	$2,116
Trona + DARCO® Hg-LH	$1,506	$1,809	$2,115
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg	$1,543	$1,864	$2,219
Trona + DARCO® Hg-LH	$1,566	$1,893	$2,218
3 SILOS			
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg	$1,594	$1,858	$2,187
Trona + DARCO® Hg-LH	$1,617	$1,887	$2,186
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg	$1,654	$1,942	$2,290
Trona + DARCO® Hg-LH	$1,677	$1,971	$2,290

Inspection of Table 15 reveals that the greatest impact on the cost per ton of SO_2 removal is primarily due to the rate of sorbent injection. Note that in a one-silo system for both sorbents and both delivery methods, the cost typically increases by a factor of about 1.4 to increase SO_2 removal from 45% to 70%. For a three-silo system, the capital required for the larger system becomes a more significant in total cost. However, the sorbent cost still dominates and the total cost per ton of SO_2 removed increases by a factor of about 1.35.

Conclusions

The goal of 70% SO_2 removal was achieved during this two week test period when injecting 5926 lb/hr of trona. This corresponds to an average NSR of 1.02. The inlet concentration of SO_2 varied from 0.48-0.64 lb/MBtu. The highest removal was 74.1% with PAC injection at 3.8 lb/MMacf.

There was very little reduction in NO_x during the test period. In addition, the effect of a side reaction, where NO is oxidized to produce NO_2, was observed on one test day when PAC injection was turned off. This indicates that there is some conversion of NO to NO_2, but not enough to measure on the stack NO_x CEMs and considerably below the target of 30% reduction. The NO_2 level was high enough to be visible and cause an increase in opacity of almost 3%. On days when PAC injection was occurring, the opacity increased by a maximum of 0.75% but there was no visible plume.

Injection of trona for SO_2 control resulted in a decrease in mercury removal using activated carbon. This effect was seen every day that trona was injected. The mercury removal slowly recovered overnight to the pre-test level of >90%. On the last two days of testing, PAC injection was increased to regain the >90% removal rate. Test conditions did not allow sufficient time to achieve this target rate while injecting trona. An estimate of the required PAC is 3X the pre-trona test rate.

Baghouse and tube sheet pressure drop increased during trona injection, causing an increase in cleaning frequency from 0.18 p/b/hr to 0.22 p/b/hr.

Plant operators kept the three units at full, steady load during testing. The boiler soot blowers were used every hour on a staggered schedule to keep the flue gas temperature from fluctuating during testing. Trona was injected near the PAC injection port, which should have resulted in excellent mixing with the flue gas before reaching the baghouse. The trona injection had no effect on boiler operations.

The reacted trona, PAC, and ash were unloaded from the ash silo using a wet unloading system. Because sodium carbonate will react with water to form solid hydrates, an anti-setup chemical was initially used with the water during unloading. No setup of the baghouse mixture was seen either in the mixer or in the transport truck. During the first week, an unloading during the morning occurred without the chemical, also resulting in no setup in the mixer or truck. The material may have been forming hydrates during mixing, preventing a hard setup. The use of the anti-setup chemical should be considered in future tests unless it can be shown that the mixing system prevents a solid setup in the mixer or truck.

An economic assessment of a full-scale trona injection system included equipment and other capital costs along with sorbent cost (trona and increased amount of PAC to maintain 90% removal) and O&M costs. The cost to remove SO_2 varied from $1,483/ton at 45% removal and one silo to $2,290/ton SO_2 at 70% removal with 3 silos.

References

1. EPRI Project Report number ADA4352002F01, March 1994.

2. EPRI Project RP 3083-05 Final Report (Mohave Pilot Tests), April 1996.

3. EPRI Project #TR-110867, "Assessing Air Pollution Control Options at the Hudson Station of Public Service Electric and Gas," August 1998.

4. Standards of Performance for New Stationary Sources National Emission Standards for Hazardous Air Pollutants Addition of Method 29 to Appendix A of Part 60 and Amendments to Method 101A of Appendix B of Part 61 | Federal Register | USEPA03-08-2007
    a. Federal Register document
    b. **URL:**http://www.epa.gov/EPA-AIR/1996/April/Day-25/pr-23270.html

5. Mirant Corporation, "Trona Injection Tests Mirant Potomac River Station Unit 1 November 12 to December 23, 2005", January 16, 2006.

6. *Economic Evaluation of Dry-Injection Flue gas Desulfurization Technology*, EPRI CS-4373, EPRI Project 1682-1, January 1986.

7. *Economic Evaluation of Particulate Control Technologies, Volume 1: New Units*, EPRI TR-100748, EPRI Project 3083-04-1, September 1992.

APPENDIX A – Cost Estimates and Results – Details

Costs for capital equipment, operations, maintenance, and power were provided by vendors as well as estimated using the economic basis provided in EPRI's "Economic Evaluation of Dry-Injection Flue Gas Desulfurization Technology." The costs are broken into sections of capital costs, operating and maintenance costs, and all are converted to 20-year levelized costs. Different scenarios of equipment set-up and injection rates were priced and compared.

The capital costs assumed an availability of 100% until these costs were levelized where a capacity factor of 75% was used. The fixed and variable operating and maintenance costs used a capacity factor of 75% throughout both the first year and levelized estimations with an exception of power which used an 85% capacity factor.

Capital Costs

The costs of equipment and installation for the trona injection system and balance-of-plant systems are shown in Table 16. This table compares the cost for one-silo and three-silo systems. Capital costs for a permanent trona injection system include the storage silo(s), blowers, conveyor piping, dehumidifiers, and modifications to the ash handling system. Cost estimates for the trona storage and injection equipment and installation costs were provided by Bulk Conveyor Specialist, Inc. A description of capital equipment is shown below.

- **Storage Silo**: Skirted, carbon steel shell with cone. Storage capacity of 75 tons. Includes bin vent collector, bin discharger, discharge valve, bin indicators, weigh hopper, rotary valves, control panel, blowers, dehumidifiers. Bin Vent Collector: Shaker type, 280 sq. ft. cloth, air-to-cloth ratio of 3:1.
    - Bin Discharger: 8 in. diameter, 1 Hp motor.
    - Discharge Valve: pneumatic knife gate.
    - Bin Indicators: (3) paddle type.
    - Weigh Hopper: 2000 lb capacity with load cells, 1.5 Hp rotary valve feeders, and one level indicator.
    - Control Panel: Allen Bradley, PLC Logic.

- **Blowers**: 350 CFM, 8-10 psi with in-and-out silencers.

- **Conveyor Piping**: 3" schedule 80, estimated length of 300'.

- **Lances**: 2" schedule 80 pipe, 304 stainless steel, 5'2" in length from flange to tip with 45 degree beveled tip.

- **Housing for Redundant Blowers and Dehumidifiers**: Skirted silo does not have sufficient space available for redundant blowers and dehumidifiers, a small building would be required.

- **Mechanical Exhauster Package**: Exhauster motor size increased from 10 Hp to 20-25 Hp, capable of pulling 15 inHg (14 inHg at full load).

- **Larger Capacity Filter/Separator**: Two larger, continuous operating filter/separators. Modifications to bin roof by extending 14' and bin structure by modifying support steel frame across bin roof to accept higher loads.

Table 16. Summary of Equipment, Balance-of-Plant, and Engineering Costs

Trona Injection System and Balance-of-Plant Equipment and Installation Costs		
Presque Isle Power Plant Units 7, 8, and 9		
Budget Item Description	**Cost**	
	1 SILO	**3 SILOS**
Trona Storage/Injection System		
Silo	$ 595,000	$ 1,785,000
Equipment Included		
75 ton Capacity Storage Silo		
1 Hopper Below Silo		
1 Blower		
1 Dehumidifier Package		
Conveyor Piping (300 ft)		
Lances (*Injection lances from test can be used in permanent system; additional lances are optional at $5,000 per lance)	$ 5,000*	$ 5,000*
Redundancy (equipment added for 3 injection lines per 1 silo)	$ 98,500	$ -
Splitter Valve		
2 Hoppers		
2 Rotary Valves		
2 Blowers		
2 Dehumidifier Packages		
Housing for Blowers and dehumidifiers		
Installation of Trona Storage/Injection Equipment	$ 580,000	$ 580,000
Includes civil, electrical, mechanical and piping		
TOTAL PROCESS EQUIPMENT	$ 1,273,500	$ 2,365,000
Increase In Ash Handling Capabilities		
2 Mechanical Exhauster Packages	$ 15,000	$ 15,000
Exhauster motor size increase (10 Hp to 20-25 Hp)		
Larger Capacity Filter/Separator	$ 200,000	$ 200,000
Design and Supply		
TOTAL ASH HANDLING EQUIPMENT UPGRADES	$ 215,000	$ 215,000
TOTAL EQUIPMENT COSTS (TEC)	$ 1,488,500	$ 2,580,000
General Facilities **(10% of TEC)**	$148,850	$258,000
Engineering and Home office Fees **(12.5% of TEC)**	$186,062	$322,500
Project Contingency **(25% of Process Equip. + 20% of Ash Handling Equip.)**	$361,375	$634,250
Process Contingency **(7.5% of Process Equip. + 5% of Ash Handling Equip.)**	$106,262	$188,125
TOTAL PLANT COST (TPC)	$2,291,050	$3,982,875
Preproduction Costs **(=(1/12)*(Fixed O&M + Var O&M)+.02*TPC)**	$397,921	$431,757
TOTAL CAPITAL REQUIREMENT (TCR)	$2,688,971	$4,414,632

Operating and Maintenance Costs

The operating and maintenance (O&M) costs associated with trona injection for SO_2 control include fixed and variable costs. Fixed O&M costs include labor, maintenance materials, and administrative and support labor. The variable O&M costs vary depending on unit and other capacity factors and include sorbent, power, and waste disposal.

Fixed O&M Costs

The fixed O&M costs include estimates of labor costs for ash handling and costs for operating and maintenance of the silo and injection equipment. It also includes estimates for maintenance materials and for administrative and support labor. The maintenance labor, materials and support labor are estimated using known costs for the TOXECON system installed and operating at Presque Isle.

Table 17 shows the operating labor cost parameters assumed for this cost analysis.

Table 17. Fixed O & M Costs – Ash Handling Labor Cost Parameters

Ash Handling Operating Labor Cost Parameters	
Operating Labor Cost Parameter	
Ash Handling	
rate $/hr (truck+ driver)	$70
ton/load (tons)	20
time/load (hrs)	5
Normal Capacity Factor	0.75

Table 18 indicates how the Ash Handling Labor cost estimates were determined using the labor parameters indicated in Table 17 along with the number of loads of trona/ash/PAC required for the three SO_2 removal rates of 45%, 64% and 70%. The labor costs increase as SO_2 removal rates increase due to the need for more frequent ash unloading and disposal. The 2007 rate for an ash truck and driver is about $70/hr with each truck-load capable of hauling 40,000 lbs or 20 tons. It takes roughly 5 hours to unload the ash and dispose of it in the landfill.

The number of loads of trona/ash/PAC to be disposed of assumes 100% material injected will be captured and disposed of and also incorporates a capacity factor of 75%. The equation below was used to determine the number of loads per year:

$$\text{\# Loads/Year} = (((WPR_{trona} + WPR_{PAC})*NCF)-((WPR_{PAC,\text{no trona inj.}})*NCF)) / (\text{Tons per load})$$

WPR: Waste Production Rate (tons/hour)
NCF: Normal Capacity Factor

Table 18. Fixed O & M Costs – Ash Handling Labor Costs for Three SO_2 Removal Rates

Fixed O&M Cost: Ash Handling Operating Labor			
	SO_2 Removal Rate		
	45%	**64%**	**70%**
# of Loads Per Year			
Trona + DARCO® Hg + Ash	379	760	1022
Trona + DARCO® Hg-LH + Ash	361	734	987
Man-hours Per Year			
Trona + DARCO® Hg + Ash	1896	3798	5112
Trona + DARCO® Hg-LH + Ash	1807	3669	4936
Labor Costs for Ash Handling ($/yr)			
Trona + DARCO® Hg + Ash	$132,739	$265,880	$357,860
Trona + DARCO® Hg-LH + Ash	$126,473	$256,797	$345,500

The operating labor costs for the silo and injection equipment are constant for different SO_2 removal rates as well as constant with either one-silo or three-silo systems. The operating, maintenance and project overhead costs are estimated from the annual costs associated with the TOXECON system currently at Presque Isle. The maintenance materials are estimated in the same manner. The first year labor costs on projects such as this are usually higher than the following years due to the first year start-up issues and optimization of long-term operation. Table 19 shows the fixed costs of equipment operating, maintenance and support labor.

Table 19. Fixed Operating & Maintenance Costs for Equipment Operating, Maintenance and Support Labor

Fixed O&M Cost: Equipment Operating, Maintenance, and Support Labor		
	1st Year	
Operating Labor Costs	**1 SILO**	**3 SILOS**
Operating & Maintenance Labor Costs, in $/yr*	$360,000	$360,000
*Includes operating labor, maintenance labor, project overhead costs		
Maintenance Materials, in $/yr	$108,000	$108,000
TOTAL FIRST YEAR OPERATING, MAINTENANCE, AND SUPPORT COSTS	$468,000	$468,000

.

Table 20. Total First Year Fixed Operating & Maintenance Costs

Total First Year Fixed O&M Cost			
1 or 3 Silos	**SO_2 Removal Rate**		
O&M Labor & Material Costs*	**45%**	**64%**	**70%**
Labor Costs for Ash Handling			
Trona + DARCO® Hg + Ash	$132,740	$265,880	$357,860
Trona + DARCO® Hg-LH + Ash	$126,470	$256,800	$345,500
Labor Costs for Silo and Injection Equipment			
Total First Year Operating, Maintenance, & Support Costs	$468,000	$468,000	$468,000
TOTAL O&M COSTS, 1 or 3 SILOS (Trona + DARCO® Hg + Ash)	**$600,740**	**$733,880**	**$825,860**
TOTAL O&M COSTS, 1 or 3 SILOS (Trona + DARCO® Hg-LH + Ash)	**$594,470**	**$724,800**	**$813,500**

Variable O&M Costs

The variable O&M costs include estimates for sorbent costs, landfill costs and power costs. The sorbent costs include trona as well as the increased PAC needed to keep the mercury removal at 90%. Power costs were estimated from the equipment's power requirements and the current cost of power production.

Power Costs

The electrical requirements for the trona injection system include power for blowers, rotary valve motors, bin discharger, and dehumidifiers. Each injection system requires power for one blower, one dehumidifier, and one rotary valve. There is one bin discharger per silo, therefore, if there is one large silo power for one discharger is needed, but with 3 silos power for 3 dischargers is needed. The long-term running power required is roughly half of the power required for start-up. Table 21 shows the amperage needed for the different components and the conversion to kilowatts. Table 22 shows the estimated costs required for long-term running of the injection system using an assumed cost to produce power of $0.03/kWh. The power cost estimations use a Power Capacity Factor of 85%.

Table 21. Power Requirements to Run Trona Injection System

Power Requirements, 1 Injection System (Amps)		
Item	**Motor Description**	**Amps Required**
Blowers:	30 Hp, 480 Vac, 3 phase	40 amps at full load
Rotary Valve:	1 Hp each (2)	1.6 amps each (2)
Bin Discharger:	1.5 Hp	3.0 amps
TOTAL AMPS AT FULL LOAD		46.2 amps
TOTAL AMPS WHILE RUNNING (~1/2 Full Load)		20 amps
Dehumidifiers:		40 amps
TOTAL (amps)		60 amps
Power Requirements, 1 Injection System (kW)		
TOTAL in kW, 3 phase (kW=(1.73*Volts*Current*Power Factor)/1000)		42.35
Power Capacity Factor		0.85
Volts		480
Power Requirements, 3 Injection Systems (kW)		
TOTAL in kW, 3 phase		127.05

Table 22. Variable Operating & Maintenance Costs for Power

Variable O&M Costs: Power		
	1 Injection System	**3 Injection Systems**
Power Usage, in kW	42.35	127.05
Unit Power Cost, in $/kWh	$0.03	$0.03
Power Cost, in $/yr	$11,125	$33,375

Sorbent Costs

Sorbent costs vary depending on the SO_2 removal percentage desired and on the delivery method. Cost for both trona and PAC increase as SO_2 removal percentages increase. The cost for trona to be railed directly to the plant is $140/ton assuming the costs to install a rail spur is picked up under another project. If a rail spur is not installed to the plant the trona can be railed to Ishpeming then loaded into a truck from there and delivered to the plant by truck. Using a combination of rail and truck would cost $155/ton.

The amount of PAC needed to maintain 90% mercury control increases as trona injection increases due to trona interfering with the PAC's ability to capture mercury. Table 23 shows the sorbent costs for trona being delivered directly to the plant by rail and Table 24 shows the sorbent costs for trona being delivered by a combination of rail and truck. Both tables have unit costs for trona, DARCO® Hg, and DARCO® Hg-LH and display the injection rates required for different SO_2 removals. The sorbent cost estimations use a capacity factor of 75%

Table 23. Variable Operating & Maintenance Costs for Sorbent Delivered by Rail to the Plant

Variable O&M Costs: Sorbent Delivered By Rail to Plant			
Sorbent Unit Cost, FOB PIPP , in $/ton	Rail*		
Trona	$140		
DARCO® Hg	$1,100		
DARCO® Hg-LH	$2,100		
*Trona rail spur assumed to be installed under separate project			
	Injection Rates (ton/hr)		
Sorbent	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Trona	1.1	2.2	2.95
DARCO® Hg	0.142	0.20	0.25
DARCO® Hg-LH	0.085	0.1185	0.14
Sorbent Costs, in $/yr**			
Trona + DARCO® Hg	$1,405,651	$2,836,597	$3,887,797
Trona + DARCO® Hg-LH	$1,460,182	$2,934,162	$3,920,647
**minus PAC that would already be injected			

Table 24. Variable Operating & Maintenance Costs for Sorbent Delivered by a Combination of Rail and Truck to the Plant

Variable O&M Costs: Sorbent Delivered By Rail and Trucked To Plant			
Sorbent Unit Cost, FOB PIPP , in $/ton	Rail + Truck*		
Trona	$155		
DARCO® Hg	$1,100		
DARCO® Hg-LH	$2,100		
*Trona railed to Ishpeming and trucked to plant			
	Injection Rates (ton/hr)		
Sorbent	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Trona	1.1	2.2	2.95
DARCO® Hg	0.142	0.20	0.25
DARCO® Hg-LH	0.085	0.1185	0.14
Sorbent Costs, in $/yr**			
Trona + DARCO® Hg	$1,514,056	$3,053,407	$4,178,520
Trona + DARCO® Hg-LH	$1,568,587	$3,150,972	$4,211,370
**minus PAC that would already be injected			

Waste Disposal Costs

The variable O&M costs for waste disposal are the costs required to landfill the spent sorbent captured in the baghouse. The 2007 unit cost to landfill material was $44.40. Table 25 shows the waste produced for the different SO_2 removal rates and the costs required to landfill the waste. The costs do not include the ash and PAC waste that is disposed of while running at full load with no trona injected. The waste disposal cost estimations use a capacity factor of 75%.

Table 25. Variable Operating & Maintenance Costs for Disposing the Waste to the Landfill

Variable O&M Costs: Waste Disposal			
Landfill Cost, in $/ton	$ 44.40		
Waste Product	**Waste Production Rates (ton/hr)**		
	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Trona	1.1	2.2	2.95
Hg	0.142	0.20	0.25
Hg-LH	0.085	0.1185	0.14
Ash (110 lb/hr)	0.055	0.055	0.055
Waste Disposal Costs, in $/yr**			
Trona + DARCO® Hg	$336,777	$674,575	$907,941
Trona + DARCO® Hg-LH	$330,560	$661,010	$886,063
**minus PAC/Ash waste that would already be disposed of			

Table 26 shows the total variable O&M costs at different SO_2 removal rates and at different delivery methods. The total O&M costs include costs for power, sorbent usage, and disposal costs.

Table 26. Total Variable Operating & Maintenance Costs

Total Variable O&M Costs			
	Removal Rates		
Total Variable O&M Costs, in $/yr	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg	$1,775,803	$3,544,547	$4,829,114
Trona + DARCO® Hg-LH	$1,823,917	$3,628,547	$4,840,085
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg	$1,884,208	$3,761,357	$5,119,836
Trona + DARCO® Hg-LH	$1,932,322	$3,845,357	$5,130,808

Levelized Costs

Levelized costs were computed to represent a constant cost value for the operating and capital costs over the lifetime of the equipment and project. In other words, the levelized costs take the present value of the net costs and spread them evenly over a period of time. This makes it possible to compare costs looking into the future. For this assessment levelized costs are presented in units of mills/kWh, where a mill is 1/1000 of a dollar.

The calculations to determine levelized costs assumed a discount rate of 7.5% and a 20-year levelization factor was used. The capital costs are converted using a fixed charge rate of 15.0% and the O&M costs are converted using levelization factors of 1.29 for all costs including power and consumables.

Levelized Capital Costs

The capital costs are converted to levelized capital costs using a fixed charge rate of 15.0%. The levelized capital costs for $/year are calculated by multiplying the capital costs by the fixed charge rate of 15.0%. The levelized capital costs in $/kW are calculated by dividing the $/year amount by the nominal kilowatts produced by the plant, 270000kW for Presque Isle Power Plant. The levelized costs represented by mills/kWh are calculated using the following formula and a capacity factor (NCF) of 75%.

LCC (mills/kWh) = ((1000) * (CC) * (LFCR)) / ((NCF) * (8760 hr/yr))

LCC: Levelized Capital Costs
CC: Capital Costs ($/kW)
LFCR: Levelized Fixed Charge Rate
NCF: Normalized Capacity Factor

Table 27 shows the levelized capital costs and compares costs for a one-silo system versus a three-silo system. The total capital requirement for three silos is less than double the requirement for one silo.

Table 27. Levelized Capital Costs

Levelized Capital Costs (20 yr, Current $ Basis)		
Levelized Fixed Charge Rate	**15%**	
	1 SILO	**3 SILOS**
TOTAL LEVELIZED EQUIPMENT COST (Installed)		
Levelized $/yr (TEC * LFCR)	$223,275	$387,000
Levelized $/kW (TEC * LFCR / 270000 kW)	$0.83	$1.43
mills/kWh (1000* TEC*LFCR)/(270000kW*(8760 hrs/yr)*NCF))	0.13	0.22
TOTAL LEVELIZED PLANT COST		
Levelized $/yr (TPC * LFCR)	$343,657	$597,431
Levelized $/kW (TPC * LFCR / 270000 kW)	$1.27	$2.21
mills/kWh (1000* TPC*LFCR)/(270000kW*(8760 hrs/yr)*NCF))	0.19	0.34
TOTAL LEVELIZED CAPITAL REQUIREMENT		
Levelized $/yr (TCR * LFCR)	**$403,345**	**$662,195**
Levelized $/kW (TCR * LFCR / 270000 kW)	**$1.49**	**$2.45**
mills/kWh (1000* TCR*LFCR)/(270000kW*(8760 hrs/yr)*NCF))	**0.23**	**0.37**

Levelized Fixed O&M Costs

Tables 28 and 29 show the fixed operating and maintenance levelized costs for ash handling labor and equipment operating, maintenance, and support labor. These tables are summarized in Table 30. The calculations for the levelized fixed O&M costs are done in the same manner as the levelized capital costs but use a levelization factor of 1.29 in accordance with the EPRI Economic Analysis rather than the 15% fixed charge rate.

Table 28. Levelized Fixed Operating & Maintenance Costs for Ash Handling Labor

Levelized Fixed O&M Cost: Ash Handling Operating Labor			
Operating Labor Levelization Factors			
Ash Handling			
Capacity Factor	75%		
O&M Levelization Factor	1.29		
	Removal Rates		
	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Levelized Labor Costs for Ash Handling			
Trona + DARCO® Hg + Ash			
$/yr	$171,233	$342,985	$461,639
$/kW	$0.63	$1.27	$1.71
mills/kWh	0.10	0.19	0.26
Trona + DARCO® Hg-LH + Ash			
$/yr	$163,150	$331,268	$445,695
$/kW	$0.60	$1.23	$1.65
mills/kWh	0.09	0.19	0.25

Table 29. Levelized Fixed Operating & Maintenance Costs for Equipment Operating, Maintenance, and Support Labor

Levelized Fixed O&M COST: Equipment Operating, Maintenance, and Support Labor	
Operating Labor Levelization Factors	
Equipment Operating, Maintenance, and Support Labor	
Capacity Factor	75%
O&M Levelization Factor	1.29
	1 or 3 Silo(s)
Levelized Operating & Maintenance Labor Costs *	
$/yr	$464,400
$/kW	$1.72
mills/kWh	0.26
*Includes operating labor, maintenance labor, project overhead costs	
Levelized Maintenance Materials	
$/yr	$139,320
$/kW	$0.52
mills/kWh	0.08
TOTAL LEVELIZED OPERATING, MAINTENANCE, AND SUPPORT COSTS	
$/yr	$603,720
$/kW	$2.24
mills/kWh	0.34

Table 30. Levelized Total Operating & Maintenance Costs

Levelized Total Fixed O&M Cost			
Operating Labor Levelization Factors			
Capacity Factor	75%		
O&M Levelization Factor	1.29		
	Removal Rates		
	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Levelized Total Fixed O&M Costs			
Trona + DARCO® Hg + Ash			
$/yr	$774,953	$946,705	$1,065,360
$/kW	$2.87	$3.51	$3.95
mills/kWh	0.44	0.53	0.60
Trona + DARCO® Hg-LH + Ash			
$/yr	$766,870	$934,990	$1,049,415
$/kW	$2.84	$3.46	$3.89
mills/kWh	0.43	0.53	0.59

Levelized Fixed O&M Costs

Tables 31 through 34 show the variable operating and maintenance levelized costs for power, sorbents, and waste disposal. These tables are summarized in Table 35. The calculations for the levelized variable O&M costs are done in the same manner as the levelized fixed O&M costs and use a levelization factor of 1.29 in accordance with the EPRI Economic Analysis.

Levelized Power Costs

Table 31 shows the levelized power costs. A capacity factor of 75% is assumed and a levelization factor of 1.29 is used for power in accordance with the EPRI Economic Analysis.

Table 31. Levelized Variable Operating & Maintenance Costs for Power

Levelized Variable O&M Costs: Power		
Capacity Factor	0.75	
Levelization Factor	1.29	
	1 Injection System	**3 Injection Systems**
Power Usage, in kW	42.35	127.05
Levelized Power Cost		
$/yr	$14,351	$43,054
$/kW	0.05	0.16
mills/kWh	0.008	0.024

Levelized Sorbent Costs

Table 32 shows the levelized costs for sorbent delivered to the plant by rail. Table 33 shows the levelized costs for sorbent delivered to the plant by rail/truck. The levelized costs for trona and DARCO® Hg are compared to the levelized costs of trona and DARCO® Hg-LH at three different SO_2 removal rates. A capacity factor of 75% is assumed and a levelization factor of 1.29 was used in accordance with the EPRI Economic Analysis.

Table 32. Levelized Variable Operating & Maintenance Costs for Sorbent Delivered by Rail to the Plant

Levelized Variable O&M Costs: Sorbent Delivered By Rail to Plant			
Capacity Factor	75%		
Levelization Factor	1.29		
	Removal Rates		
Levelized Sorbent Costs	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Trona + DARCO® Hg*			
$/yr	$1,813,290	$3,659,211	$5,015,259
$/kW	$6.72	$13.55	$18.58
mills/kWh	1.02	2.06	2.83
Trona + DARCO® Hg-LH*			
$/yr	$1,883,635	$3,785,069	$5,057,635
$/kW	$6.98	$14.02	$18.73
mills/kWh	1.06	2.13	2.85
*minus PAC that would already be injected			

Table 33. Levelized Variable Operating & Maintenance Costs for Sorbent Delivered by a Combination of Rail and Truck to the Plant

Levelized Variable O&M Costs: Sorbent Delivered By Rail and Trucked to Plant			
Capacity Factor	75%		
Levelization Factor	1.29		
	Removal Rates		
Levelized Sorbent Costs	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Trona + DARCO® Hg*			
$/yr	$1,953,133	$3,938,896	$5,390,291
$/kW	$7.23	$14.59	$19.96
mills/kWh	1.10	2.22	3.04
Trona + DARCO® Hg-LH*			
$/yr	$2,023,478	$4,064,754	$5,432,667
$/kW	$7.49	$15.05	$20.12
mills/kWh	1.14	2.29	3.06
*minus PAC that would already be injected			

Levelized Waste Disposal Costs

Table 34 shows the levelized waste disposal costs. The levelized costs for landfilling a combination of trona, DARCO® Hg and ash are compared to levelized costs for landfilling trona, DARCO® Hg-LH and ash at three different SO_2 removal rates. A capacity factor of 75% was assumed and a levelization factor of 1.29 was used in accordance with the EPRI Economic Analysis.

Table 34. Levelized Variable Operating & Maintenance Costs for Waste Disposal

Levelized Variable O&M Costs: Waste Disposal			
Capacity Factor	75%		
Levelization Factor	1.29		
	Removal Rates		
Levelized Waste Disposal Costs	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Trona + DARCO® Hg*			
$/yr	$434,422	$870,200	$1,171,244
$/kW	$1.61	$3.22	$4.34
mills/kWh	0.24	0.49	0.66
Trona + DARCO® Hg-LH*			
$/yr	$426,164	$852,703	$1,143,021
$/kW	$1.58	$3.16	$4.23
mills/kWh	0.24	0.48	0.64
*minus PAC that would already be injected			

Total Levelized Variable O&M Costs

Table 35 shows the total levelized variable operating and maintenance costs. The levelized costs for power, sorbent, and waste disposal are added up and can be compared as one silo versus three silos at three different SO_2 removal rates.

Table 35. Levelized Total Variable Operating & Maintenance Costs

Levelized Total Variable O&M Costs			
	Removal Rates		
Levelized Total Variable O&M Cost	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg			
$/yr	$2,290,786	$4,572,466	$6,229,557
$/kW	$8.48	$16.94	$23.07
mills/kWh	1.29	2.58	3.51
Trona + DARCO® Hg-LH			
$/yr	$2,352,853	$4,680,826	$6,243,710
$/kW	$8.71	$17.34	$23.12
mills/kWh	1.33	2.64	3.52
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg			
$/yr	$2,430,629	$4,852,150	$6,604,588
$/kW	$9.00	$17.97	$24.46
mills/kWh	1.37	2.74	3.72
Trona + DARCO® Hg-LH			
$/yr	$2,492,695	$4,960,510	$6,618,742
$/kW	$9.23	$18.37	$24.51
mills/kWh	1.41	2.80	3.72

Total Levelized Costs

Table 36 shows the total levelized costs, which includes the total variable O&M costs, total fixed O&M costs and total capital costs at three removal rates.

Table 36. Levelized Costs (Capital, Fixed, and Variable Levelized Costs)

Levelized Total Costs			
	Removal Rates		
Total Levelized Cost (Capital, Fixed, and Variable Costs)	SO2 Removal of 45%	SO2 Removal of 64%	SO2 Removal of 70%
1 SILO			
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg			
$/yr	$3,469,084.86	$5,922,516.40	$7,698,261.25
$/kW	$12.85	$21.94	$28.51
mills/kWh	1.96	3.34	4.34
Trona + DARCO® Hg -LH			
$/yr	$3,523,067.86	$6,019,159.39	$7,696,470.85
$/kW	$13.05	$22.29	$28.51
mills/kWh	1.99	3.39	4.34
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg			
$/yr	$3,608,927.31	$6,202,201.30	$8,073,293.28
$/kW	$13.37	$22.97	$29.90
mills/kWh	2.03	3.50	4.55
Trona + DARCO® Hg -LH			
$/yr	$3,662,910.31	$6,298,844.29	$8,071,502.87
$/kW	$13.57	$23.33	$29.89
mills/kWh	2.06	3.55	4.55
3 SILOS			
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg			
$/yr	$3,727,934.08	$6,181,365.62	$7,957,110.48
$/kW	$13.81	$22.89	$29.47
mills/kWh	2.10	3.48	4.49
Trona + DARCO® Hg -LH			
$/yr	$3,781,917.08	$6,278,008.62	$7,955,320.07
$/kW	$14.01	$23.25	$29.46
mills/kWh	2.13	3.54	4.48
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg			
$/yr	$3,867,776.53	$6,461,050.52	$8,332,142.50
$/kW	$14.33	$23.93	$30.86
mills/kWh	2.18	3.64	4.70
Trona + DARCO® Hg -LH			
$/yr	$3,921,759.53	$6,557,693.52	$8,330,352.10
$/kW	$14.53	$24.29	$30.85
mills/kWh	2.21	3.70	4.70

Removal Cost per Ton of SO_2 Removed

Table 37 shows the cost per ton of SO_2 removed using trona at full scale. These values are levelized over 20 years. The amount of SO_2 removed is based on the baseline emission rate of 5,200 tons per year for all three units combined. The cost per ton of SO_2 removed is calculated by dividing the levelized total costs ($/yr) given in table 36 by the amount removed from the baseline for each removal rate. The cost per ton of SO_2 removed varied from $1,483 to $2,290.

Table 37. Removal Costs per Ton SO_2 Removed

Levelized Total Cost per Ton of SO_2 Removed ($/ton)			
No. of Silos, Delivery Method, and Sorbent	**SO_2 Removal Rate**		
*	**45%**	**64%**	**70%**
1 SILO			
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg	$1,483	$1,780	$2,116
Trona + DARCO® Hg-LH	$1,506	$1,809	$2,115
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg	$1,543	$1,864	$2,219
Trona + DARCO® Hg-LH	$1,566	$1,893	$2,218
3 SILOS			
Trona Delivered by Rail to Plant			
Trona + DARCO® Hg	$1,594	$1,858	$2,187
Trona + DARCO® Hg-LH	$1,617	$1,887	$2,186
Trona Delivered by Rail/Truck			
Trona + DARCO® Hg	$1,654	$1,942	$2,290
Trona + DARCO® Hg-LH	$1,677	$1,971	$2,290