

## **DEMONSTRATED PERFORMANCE IMPROVEMENTS ON LARGE LIGNITE-FIRED BOILER WITH TARGETED IN-FURNACE INJECTION TECHNOLOGY™**

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### **ABSTRACT**

The Leland Olds Station (LOS) comprises two lignite-fired units with a combined generating capacity of 669 megawatts (MW). When Unit 1 went on-line in January 1966, it was the largest lignite power plant in the Western Hemisphere. Unit 2 began commercial operation in 1975 and is based on a Babcock & Wilcox cyclone furnace design. Even though the cyclone burner configuration removes approximately 70% of total coal ash through the bottom slag taps, the high sodium, low fusion temperature properties of the local lignite coal has created ongoing slagging and fouling problems. Throughout much of the plant's operating history, these issues have required cleaning outages at least twice per year to deslag waterwalls and remove deposits in the convective sections which were frequently bridged over, creating large flow blockages. Between these outages, key performance indicators such as superheat and reheat steam temperatures, exit gas temperatures, and fan power would rapidly deteriorate until the next cleaning cycle. Over the years, LOS operators have tried various on-line cleaning enhancements including optimized soot blowing, water lancing, shot gunning, load drops, and injection of vermiculite. In January 2009, Fuel Tech started up its innovative TIFI® Targeted In-Furnace Injection™ program on Unit 2. The TIFI process involves the use of two different forms of computational fluid dynamics modeling coupled with a virtual reality engine. Together, these simulation methods create a running duplicate of a given furnace with injection overlays and dosage maps to predict the precise trajectory of an injected chemical, helping to ensure as close to 100% coverage of the targeted zones as possible. In addition to specific targeting and biasing of injected reagents in the furnace, chemical feed rates are adjusted in real time in response to incoming coal quality fluctuations. From initial implementation until the present day, the TIFI program has significantly improved key performance indicators as evidenced by year over year comparisons. New retrofit overfire air ports were installed and started up in the fall of 2009, providing a NO<sub>x</sub> reduction of about 40 percent. TIFI has proved even more valuable in reducing slag deposits normally expected in the main furnace with deeper air staging. Enhancements in unit efficiencies, increased generation, and reduction of forced outages have substantially improved financial performance at LOS.

### **INTRODUCTION**

The Basin Electric Power Cooperative (BEPC) Leland Olds Station has been proactively evaluating viable options to increase their bottom line goal of producing un-interrupted, base-load power at the lowest possible cost. A key goal was the elimination of a previously used fuel additive (vermiculite), and reduction of challenges associated with burning poorer quality coals, all while

maintaining MW production. Most of the challenges with utilization of low quality coals are commonly encountered at other plants and include:

- Slagging and clinker formation in the radiant zone of the furnace
- Fouling of superheat and reheat surfaces leading to lost steam production
- Flue gas flow restrictions and increased ID fan power
- Increased soot blowing and potential for pressure part damage

Vermiculite was used for 24 years at LOS Unit 2 prior to TIFI and was an essential aid in keeping the convection pass clean. However, heavy slagging and fouling became increasingly problematic in 2007 and 2008 with periods of reduced coal quality (primarily high sodium and ash). Even with higher vermiculite injection rates, boiler conditions could not recover from these excursions and would often continue to deteriorate at an accelerated rate, ultimately requiring an unplanned cleaning outage. Finally, the vermiculite transport system was becoming increasingly maintenance intensive and the rail car unloading system was not conducive to safe handling practice.

To address these issues and achieve the goals set by management and operations, LOS worked with Fuel Tech to design a Fuel Chem<sup>®</sup> TIFI program to reduce or eliminate slagging and fouling so that the station could take full advantage of available low cost coals. The LOS/Fuel Tech project team defined the following success criteria for the program:

- Annual generation gains (net MWh)
- Unit heat rate gains resulting from increased boiler efficiency and reduced auxiliary power
- Improved slagging and fouling management and the ability to recover from periods of reduced coal quality
- Increase operator safety due to reduced manual cleaning
- Reduction of cleaning outage frequency, effort, and duration
- Contribute to NOx control efforts
- Reduce/Eliminate maintenance, delivery, reliability costs of the vermiculite unloading and transport system

## FUELS AT LELAND OLDS STATION

The Leland Olds Station has been fueled with lignite from North Dakota since start-up. In addition to this cost effective and locally sourced coal, LOS blends Powder River Basin (PRB) coal in order to control maximum as-fired sulfur, ash, and sodium content. Increasing percentages of PRB coal in the blend brings another set of problems however. Average coal analysis shown in Table 1 indicates that PRB has lower ash fusion temperatures under both oxidizing and reducing conditions. Evaluation of slagging indices also indicates the potential for heat transfer surface fouling. Calculation of slagging and fouling indices is based on classification of the ash (Babcock & Wilcox Company 1992). Both the lignite and PRB coals contain more (CaO + MgO) than Fe<sub>2</sub>O<sub>3</sub> and therefore can be classified as having lignitic ash. The slagging index for lignitic ash is based on ASTM ash fusion temperatures. The index is a weighted average of the maximum hemispherical temperature (HT) and the minimum initial deformation temperature (IT), as given by:

$$R_s = \frac{(\text{Max HT}) + 4(\text{Min IT})}{5}$$

Where: Max HT = higher of the reducing or oxidizing hemispherical softening temperatures (°F)

Min IT = lower of the reducing or oxidizing initial deformation temperatures (°F)

For the two fuels, the slagging indices ( $R_s$ ) are calculated as 2,160 for lignite and 2,126 for PRB. Based on the Babcock & Wilcox ranking of slagging potential, these indices would rank both coals as having high slagging potentials, with the PRB coal being slightly worse.

**Table 1 – LOS Unit 2 Coal Options**

<b>Proximate Analysis (As Received)</b>			<b>Lignite</b>	<b>PRB</b>	<b>Mineral Analysis of Ash</b>			<b>Lignite</b>	<b>PRB</b>	
Moisture	H <sub>2</sub> O	(%)	35.36	33.71	Silicon Dioxide	SiO <sub>2</sub>	(%)	25.66	27.9	
Ash	Ash	(%)	8.01	4.74	Aluminum Oxide	Al <sub>2</sub> O <sub>3</sub>	(%)	11.64	13.49	
Volatile Matter	VM	(%)	28.16	30.32	Titanium Dioxide	TiO <sub>2</sub>	(%)	0.45	0.98	
Fixed Carbon	FC	(%)	28.47	31.23	Iron Oxide	Fe <sub>2</sub> O <sub>3</sub>	(%)	8.53	6.49	
Total		(%)	100.00	100.00	Calcium Oxide	CaO	(%)	22.95	25.94	
					Magnesium Oxide	MgO	(%)	6.77	6.65	
					Potassium Oxide	K <sub>2</sub> O	(%)	0.73	0.28	
					Sodium Oxide	Na <sub>2</sub> O	(%)	2.94	1.65	
					Sulfur Trioxide	SO <sub>3</sub>	(%)	18.68	14.6	
					Phosphorus Pentoxide	P <sub>2</sub> O <sub>5</sub>	(%)	0.18	0.74	
					Strontium Oxide	SrO	(%)	0.53	0.52	
					Barium Oxide	BaO	(%)	0.86	0.73	
					Manganese Dioxide	MnO <sub>2</sub>	(%)	0.08	0.03	
<b>Ultimate Analysis (As Received)</b>					<b>Alkalies as N<sub>2</sub>O</b>			(%)	3.42	1.83
Moisture	H <sub>2</sub> O	(%)	35.36	33.71	Base to Acid Ratio			1.11	0.97	
Carbon	C	(%)	42.40	46.05	Silica Ratio			0.4	0.42	
Hydrogen	H	(%)	1.92	2.55	T250	(°F)	2274		2306	
Nitrogen	N	(%)	0.76	0.68						
Sulfur	S	(%)	0.81	0.37						
Ash	Ash	(%)	8.01	4.74						
Oxygen	O	(%)	10.74	11.90						
Total		(%)	100.00	100.00						
Higher Heating Value	HHV	(Btu/lb)	6,905	7,706						
Higher Heating Value (MAF)		(Btu/lb)	12,194	12,520						
<b>Ash Fusion Temperatures - Oxidizing</b>					<b>Ash Fusion Temperatures - Reducing</b>					
Initial Deformation	IT	(°F)	2218	2142	Initial Deformation	IT	(°F)	2140	2106	
Softening	ST	(°F)	2224	2165	Softening	ST	(°F)	2207	2152	
Hemispherical	HT	(°F)	2235	2206	Hemispherical	HT	(°F)	2238	2200	
Fluid	FT	(°F)	2259	2217	Fluid	FT	(°F)	2330	2206	

**TARGETED IN-FURNACE INJECTION™**

Fuel Tech has been applying and optimizing the Fuel Chem® TIFI program since the early 1990s. Details of TIFI technology, ash deposit chemistry, and modification of slag crystalline structure have been presented previously (Smyrniotis 2003, Schulz and Smyrniotis 2006). TIFI systems are currently installed on over 100 combustion units burning a wide variety of fuels including coal, heavy oil, biomass, and municipal waste. Identified benefits fall into five broad categories: availability and reliability gains, efficiency gains, maintenance benefits, fuel flexibility, and environmental improvements.

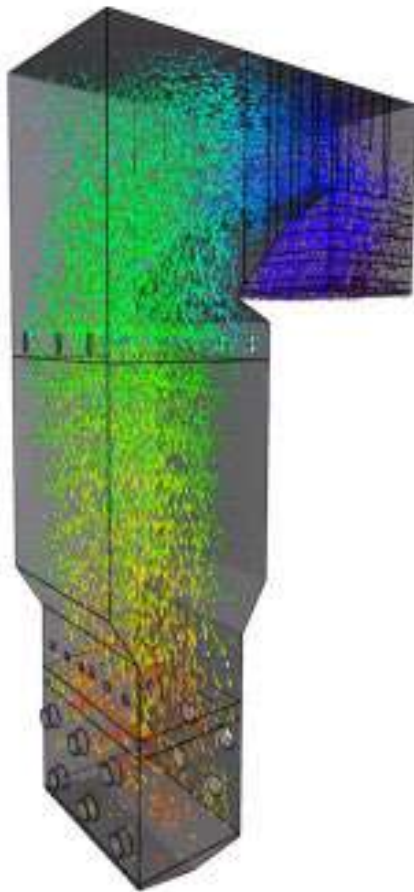
The TIFI slag and fouling control program involves targeting areas of the radiant and convection sections of a boiler with chemicals designed to control these problems. By targeting the problem areas of the furnace instead of simply putting additives in the fuel, performance and cost effectiveness are significantly improved. Chemicals are mixed with air and water and then injected into the flue gas stream. The areas that are targeted are based on Computational Fluid Dynamics (CFD) models to ensure maximum coverage where the problem areas are known to exist.

TIFI technology involves using two different forms of fluid dynamics modeling and a virtual reality engine. Together, these create a running duplicate of a given furnace with injection overlays and dosage maps to analyze where chemical distribution and to achieve maximum possible coverage of the targeted areas. The most common application of TIFI technology utilizes brine derived magnesium hydroxide slurry diluted with water and then atomized with air. This mixture is injected into the furnace at optimized port locations as determined by the CFD models.

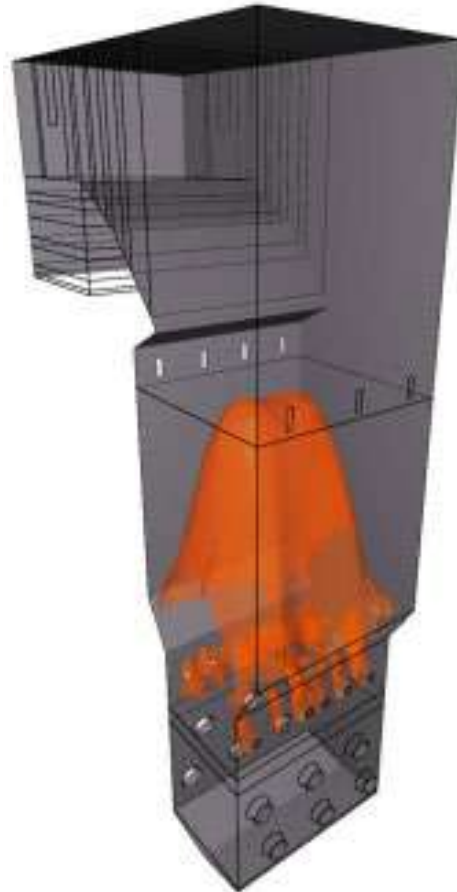
The first step with CFD process is to create a geometrically correct, three-dimensional model based on all internal boiler dimensions and structures. Burner and overfire air configurations, tube spacing, locations, and materials are taken into account to provide an accurate representation of the combustion zone and convective passes. Combustion air flows, fuel flows, and fuel properties are then included to build a mass and energy balanced model. Field measurements of furnace temperatures and

combustion gas concentration profiles are usually taken to verify and calibrate the model. Figure 1 shows an image taken from the virtual reality model and details the gas flow dynamics using vectors that are coded for velocity (length), temperature (color), and direction.

Once the fluid dynamic model is constructed, a very useful visualization tool is an isosurface to show where ash softening temperatures are expected to occur in the unit. Generally, temperatures are hotter upstream of the surface and cooler downstream. The ash will tend to stick to surfaces that are encountered in regions where the gas temperature is hotter than the softening temperature. Figure 2 shows an isosurface for baseline lignite coal at 2,207°F, which is the ash softening temperature under reducing conditions (see Table 1). As long as waterwall slagging can be effectively managed, and efficient heat transfer is maintained in the radiant zone, the impact of semi-molten or sticky ash on the superheat pendants above the bull nose of the furnace can be controlled. TIFI slag management helps substantially by interfering with the crystalline structure of the deposits, creating shear planes and reducing tensile strength of the deposit so that routine soot blowing is sufficient to keep waterwall surfaces relatively clean. TIFI also increases effective ash fusion temperatures, to slow the build-up of fouling deposits in the first place.

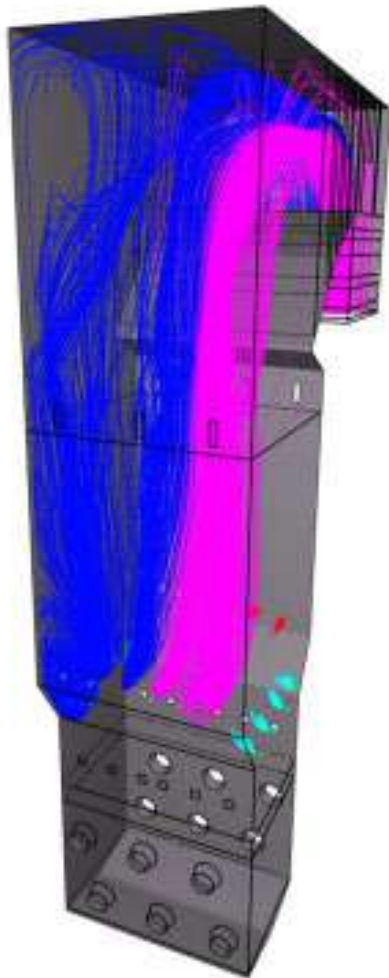


**Figure 1 – LOS Unit 2 Gas Flow Vectors**

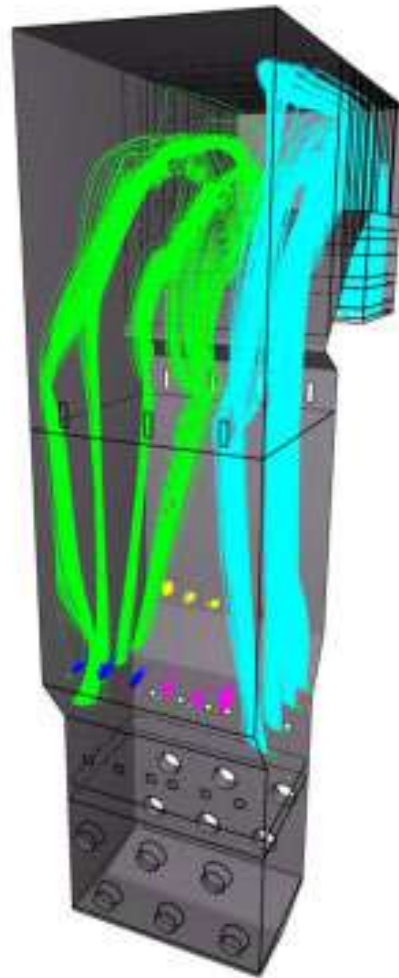


**Figure 2 – Temperature Isosurface Showing Lignite Coal Ash Softening Temperature Location (2,207°F – Reducing)**

Following the completion of the CFD model and operating case studies, an injection design model is then developed to simulate and optimize the TIFI injector array. The model allows the design team to test various combinations of injector locations along with variable droplet size, distribution, and velocity. Best candidate solutions are then modeled with CFD coupled with injector placement and flows. Concentration contours showing chemical distribution are used to evaluate the effectiveness of possible injector arrays. Figures 3 and 4 show the optimized injector placement and predicted chemical streamlines for LOS Unit 2. There are 22 injectors distributed over two levels and six feed manifolds. Chemical streamlines from injectors located on the front wall are shown in Figure 3. Figure 4 shows chemical streamlines from the injectors on the side walls.

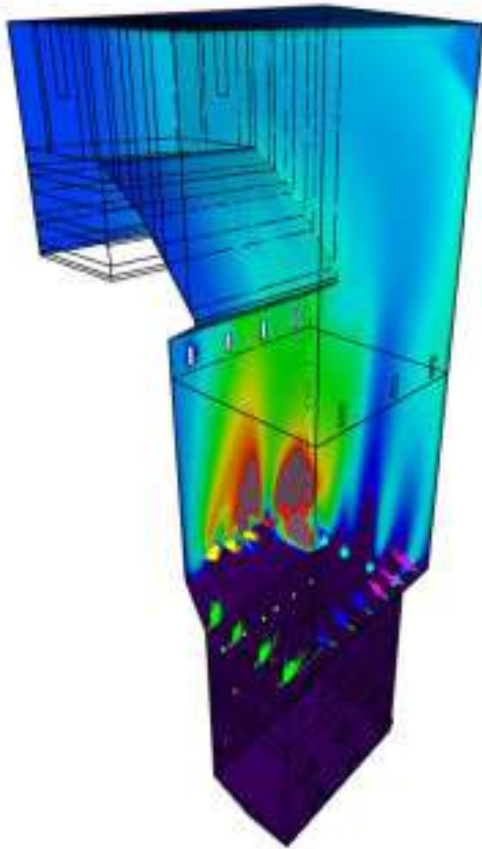


**Figure 3 – LOS Unit 2 TIFI Injector Placement Showing Predicted Chemical Streamlines From Front Wall Manifolds**

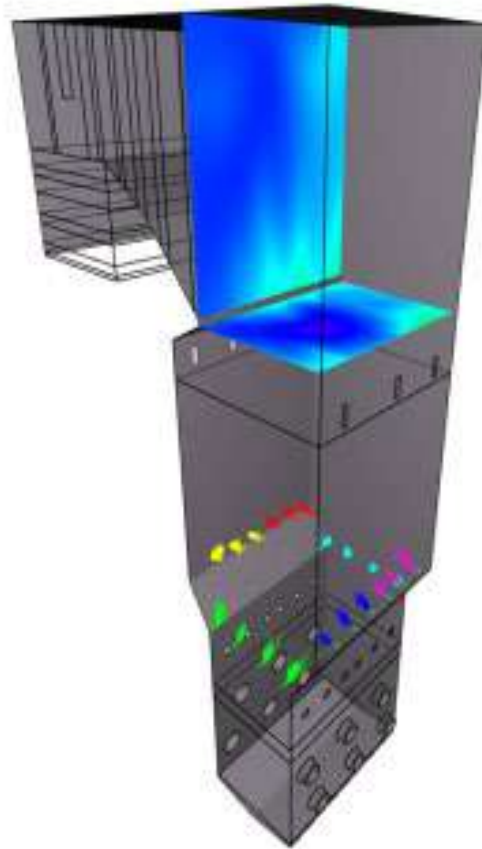


**Figure 4 – LOS Unit 2 TIFI Injector Placement Showing Predicted Chemical Streamlines From Side Wall Manifolds**

TIFI chemical coverage over the walls of the radiant and convective zones of the unit are illustrated in Figure 5. Figure 6 shows a cross-sectional concentration profiles exiting the furnace and entering the superheat pendants. Green and light blue shades indicate more concentrated coverage of the targeted surfaces. The primary targeted areas include all of the waterwall surface area and the leading edge of the secondary superheat pendants – where fouling deposits have been problematic in the past.



**Figure 5 – LOS Unit 2 TIFI Chemical Coverage on Rear and Right Side Walls**

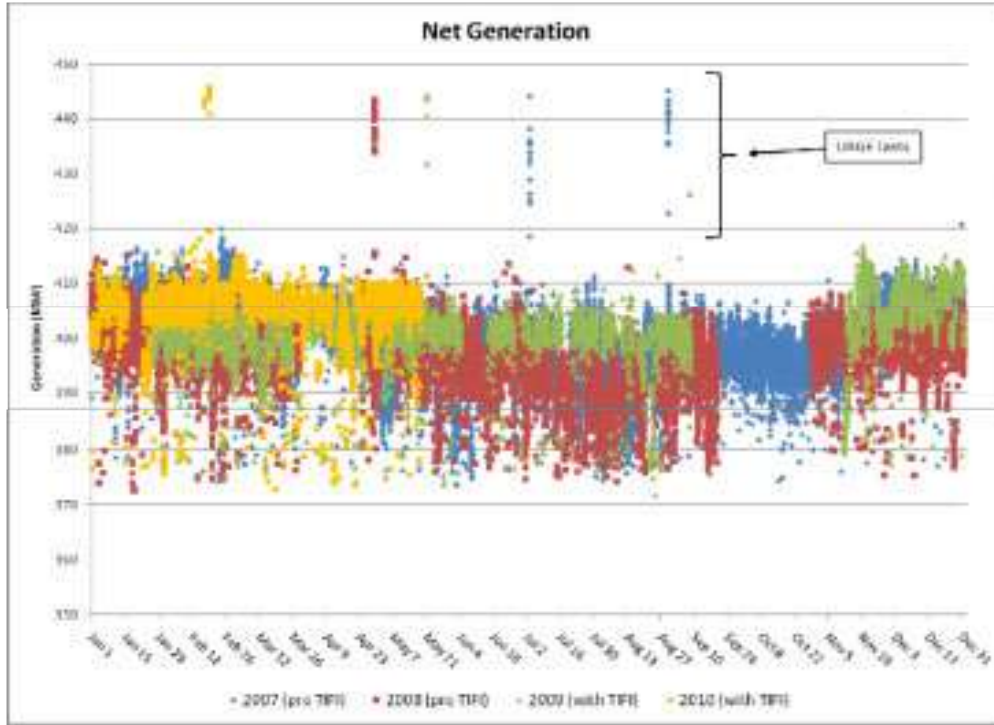


**Figure 6 – LOS Unit 2 TIFI Chemical Concentration Contours**

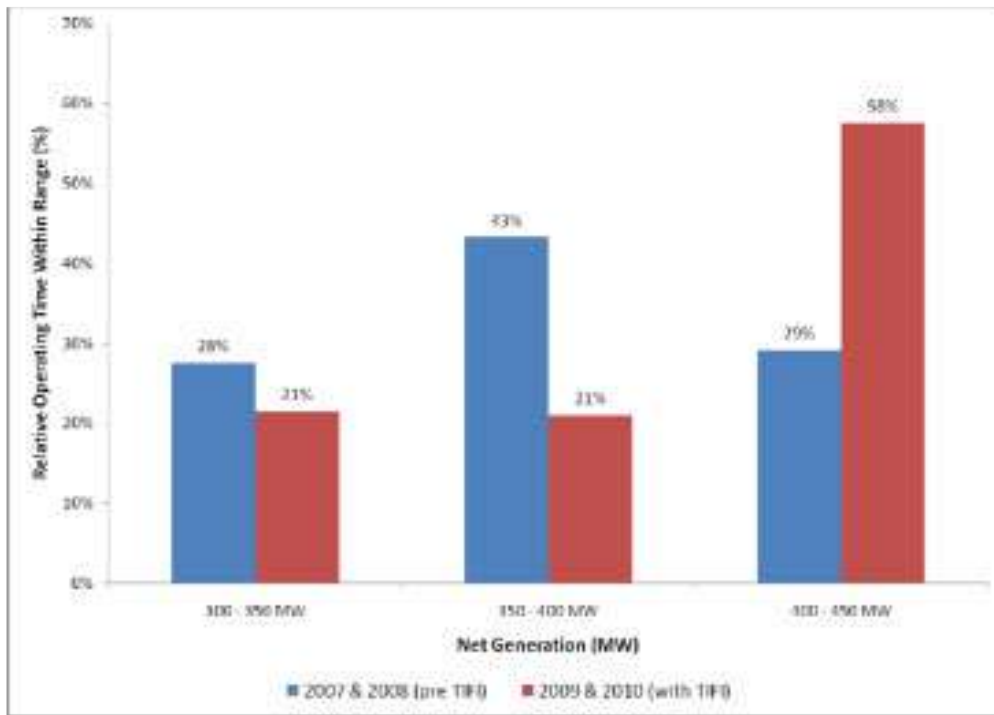
## UNIT 2 PERFORMANCE ANALYSIS

In addition to spatially targeting or biasing TIFI chemical to problem areas of the boiler as described above, Fuel Tech has implemented a procedure at LOS to continuously adjust chemical injection rates according to changes in coal properties. This ensures that the slag control program proactively responds to varying potential for slagging and fouling without over-dosing during periods of improved coal quality. As described in the Fuels section above, LOS operators frequently adjust PRB blend ratios from 0% to as high as 50% in order to maintain maximum levels of as-fired sulfur, ash, and sodium content. Fuel Tech's on-site personnel monitoring LOS Unit 2 receive coal quality information on incoming lignite 12 – 24 hours before the fuel reaches the burner tips. If this lignite exceeds plant established limits for sodium, ash, and sulfur levels, a specified PRB blend will be implemented by LOS operators. At the same time, the TIFI targeted dose rate is adjusted based on established parameters. The new injection rates are then maintained until the next 24-hour coal report, or until a combination of slag surveys and analysis of key performance parameters indicate that it is safe to reduce TIFI injection back to nominal levels. This procedure, developed jointly with LOS operations and Fuel Tech team members has been highly successful in maximizing unit performance in a very cost effective manner. The LOS/Fuel Tech team has also developed a 10 point boiler grading scale to better quantify and record visual slag surveys. Finally, LOS and Fuel Tech have formed a Soot Blower Optimization Team to build best practices around the operation and management of the soot blowing systems.

The programs described above have met the goals and success criteria outlined in the Introduction. The improvement in net generation can easily be seen in a year over year comparison from 2007 to the present time, as shown in Figure 7. The URGE (Utility Rating of Generating Equipment) tests conducted once or twice a year are evident in the chart. The net generation increase of 5 – 8 MW following the September – October 2009 outage can be attributed to offline cleaning as well as steam turbine upgrades installed during the outage. This increased generation is holding up through 2010 without the deterioration seen in prior years. A histogram showing relative operation across three ranges (or “bins”) of generation is shown in Figure 8. This graph reveals that with all of the operating measures and slag management tools employed during the TIFI program, the station was able to increase generation on Unit 2 over the 2007 – 2008 run periods. Looking at the top bin range, we see that 2009 – 2010 run periods with optimized cleanliness management and other upgrades have achieved an operating time of 58% at or above 400 MW, whereas the pre-TIFI run periods only achieved 29% of operating time at or above 400 MW. If the increased generation from the turbine upgrades is removed from this analysis, the 2009 – 2010 run periods still attain run time percentages of over 45% above 400 MW.

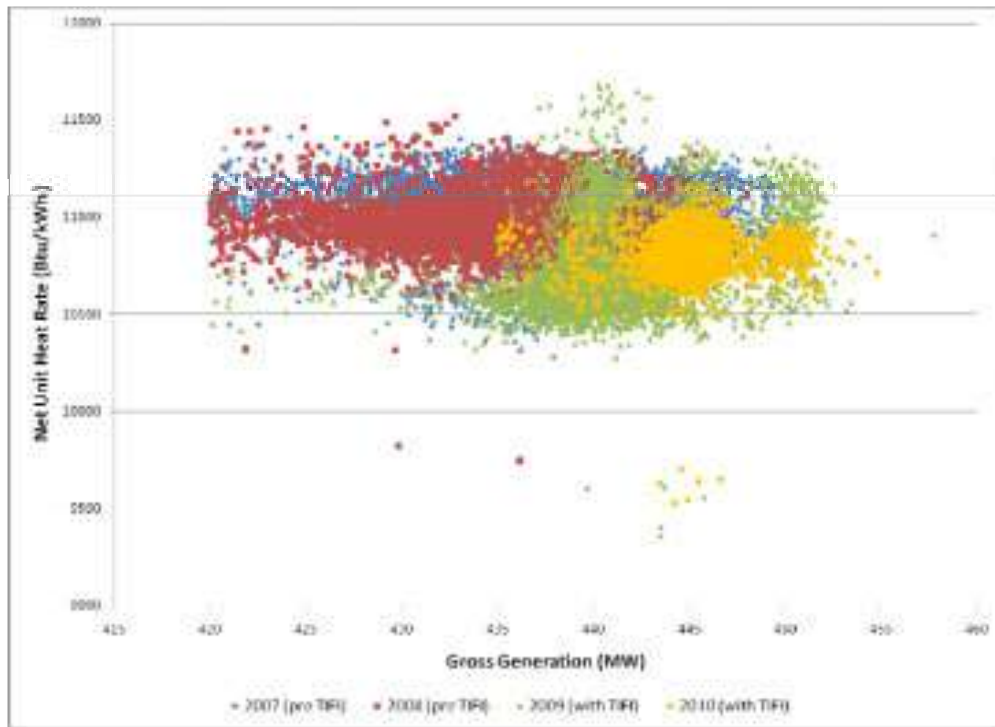


**Figure 7 – Unit 2 Net Generation**

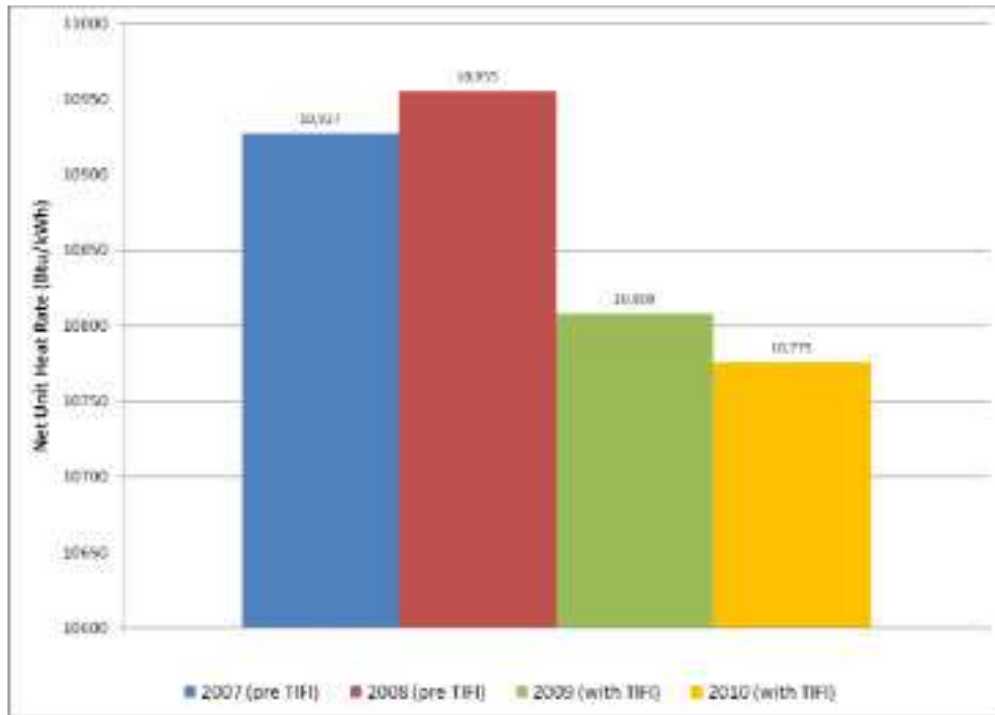


**Figure 8 – Unit 2 Net Generation Histogram**

With improved waterwall and secondary superheat absorptions in 2009 and 2010, Unit 2 has been able to maintain design steam temperatures for significantly longer time periods following each annual outage. This improvement, together with reduced reheat attemperator spray flows, reduced economizer and air heater exit gas temperatures, and lower boiler O<sub>2</sub> have all contributed to increased boiler efficiencies. Along with reduced flue gas flow restrictions and corresponding ID fan power, these boiler efficiency improvements have led to reductions in net unit heat rate. Figure 9 shows net heat rate for each run period for gross generation between 420 MW and 460 MW. Heat rate data in this analysis have been corrected back to the design steam turbine exhaust pressure of 1.5 in. Hg to remove effects of seasonal temperatures and condenser cooling water temperature swings. The steam turbine upgrades installed during the September – October 2009 outage further contributed to the heat rate improvements. This is evident in Figure 10 where heat rate data have been averaged at 440 MW for each run period and plotted in a side by side comparison. The column for 2009 does not include heat rate data after the installation of the turbine upgrades, however they are included in the 2010 average. Overall, Figure 10 shows heat rate reductions of 120 – 180 Btu/kWh over the previous 2007 – 2008 run periods.



**Figure 9 – Unit 2 Net Unit Heat Rate versus Generation**



**Figure 10 – Unit 2 Average Net Unit Heat at 440 MW for Each Run Period**

Figure 11 shows a timeline of economizer O<sub>2</sub> and stack NO<sub>x</sub> emissions starting immediately after the September – October 2009 outage when the overfire air (OFA) ports were installed. The OFA ports were put into service on November 30. After about 1 week of tuning and adjustment, the average O<sub>2</sub> levels have settled at 2.8 – 3% and NO<sub>x</sub> emissions have stabilized at 0.3 lb/MMBtu. This is about 30 – 40% below previous NO<sub>x</sub> levels without OFA, and 12 – 14% below the new limit of 0.35 lb/MMBtu. Figure 12 gives a dramatic illustration of NO<sub>x</sub> emissions versus economizer O<sub>2</sub> for the three significant run periods (2008 without TIFI, 2009 with TIFI but before OFA operation, and 2010 with TIFI and OFA). Comparing 2008 and 2009 at the same O<sub>2</sub> levels, average NO<sub>x</sub> emissions dropped by 15 – 18% with TIFI. This decrease can be directly attributed to improved furnace cleanliness, radiant zone heat transfer, and corresponding reductions in peak flame temperature. Similar reductions in NO<sub>x</sub> emissions resulting from active cleanliness management have been reported elsewhere (Carter and Larson 1993, Booher 1995). A further 30 – 40% NO<sub>x</sub> reduction to an average of 0.3 lb/MMBtu (at 3% O<sub>2</sub>) has been achieved with the start-up and optimization of the OFA system.

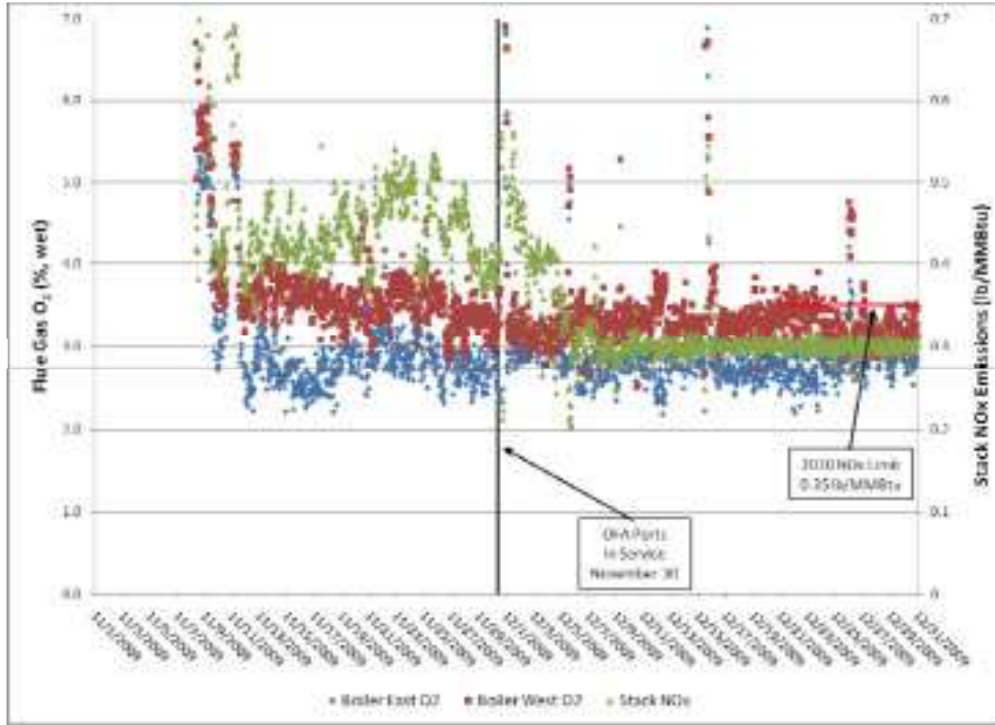


Figure 11 – Effect of OFA on Unit 2 NOx Emissions

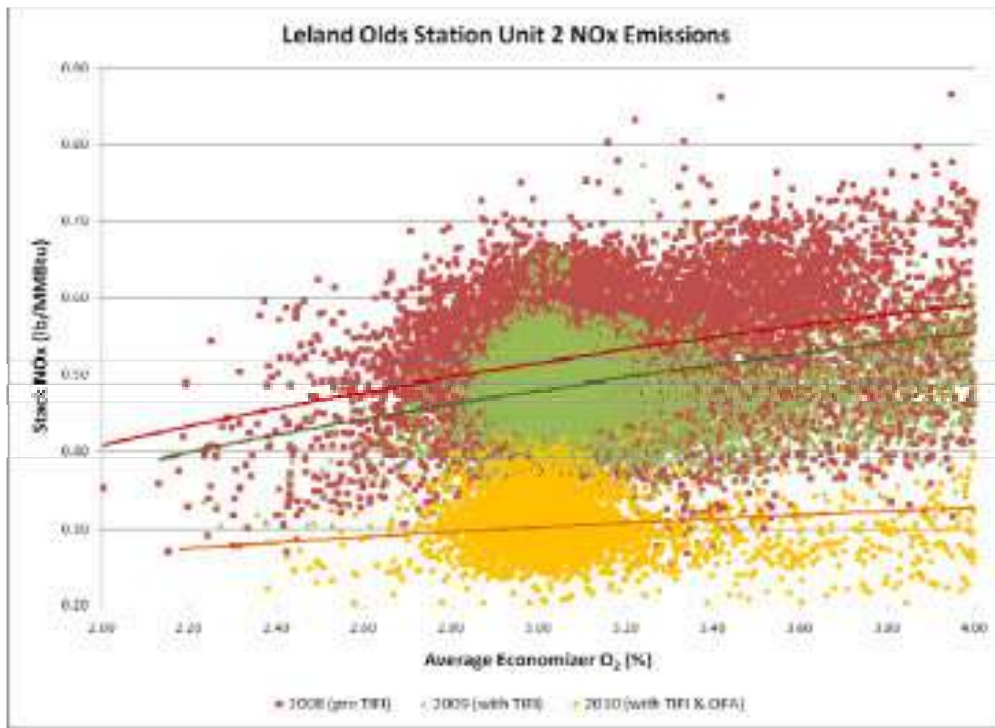


Figure 12 – Unit 2 NOx Emissions versus O<sub>2</sub>

## CONCLUSIONS

With continued performance monitoring and optimized slag management, the LOS/Fuel Tech team have successfully met the goals and improvement criteria outlined in the initial project scope. TIFI does not eliminate slagging and fouling, but it has proven to be an extremely valuable tool in active cleanliness management. The TIFI program enhances slag “consistency” to make the slag removal process easier. This has resulted in less sootblowing, shot gunning, and rodding. By reducing the “face time” requirement for operator manual cleaning, they have a safer working environment and have more time to focus on unit performance improvements. The TIFI slag control program continues at LOS Unit 2 with the addition of further features, including real-time targeting and flow biasing adjustments, numerical boiler grading scale, and the Soot Blower Optimization Team. The program has demonstrated the following enhancements:

- Overall net generation for 2009 and 2010 has achieved an operating time of 58% at or above 400 MW, whereas the pre-TIFI run periods only achieved 29% of operating time at or above 400 MW. If the increased generation from the turbine upgrades are removed from this analysis, the 2009 – 2010 run periods still attain run times over 400 MW of well over 45%.
- Waterwall slagging and convective pass fouling has been effectively controlled. This has resulted in:
  - A 40 – 60°F reduction in economizer exit gas temperature.
  - An average 5% decrease in ID fan power.
  - The ability to sustain main steam temperatures at maximum design value of 1,005°F for a greater percentage of time between annual outages.
  - TIFI and associated operational improvements have achieved reductions of 120 – 180 Btu/kWh over the previous 2007 – 2008 run periods.
  - Optimized soot blowing with associated reduction in pressure part damage.
  - With TIFI and optimized slag management, LOS Unit 2 has been able to avoid the annual cleaning outages taken in 2007 and 2008. Total cleaning time by blasting and other aggressive measures during the scheduled annual outage has been reduced by 4 days.
  - A 15 – 18% decrease in NOx emissions as a result of increased furnace cleanliness and improved heat transfer, plus a further 30 – 40% reduction in NOx with the commissioning of the overfire air ports.

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