



Controlling SO₃, Slag and Fouling Resulting in Improved Heat Rates, Better Efficiency and Allowing for Fuel Flexibility – Santee Cooper, Cross Station Case Study

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Abstract

A comprehensive approach to controlling opacity from SO₃ emissions has proven highly effective at Santee Cooper’s Cross Station. The plant also had problems with furnace slag and “popcorn ash” pluggage of the SCR which is used for NO_x control. Magnesium Hydroxide can neutralize SO₃ and the associated sulfuric acid mist that cause opacity issues. Beyond this, it can reduce slag deposits and back-end fouling that promotes the conversion of SO₂ to SO₃. Fly ash is rendered more friable and more easily cleaned from surfaces. A combination of opportunities was harvested to improve plant performance. As a result, substantial economic benefits were realized on top of the resolution of an emissions problem.

Santee Cooper and Fuel Tech, Inc. have cooperated over the past 18 months to demonstrate the capabilities of the TIFI™ Targeted In-Furnace Injection™ program. The program incorporates a highly visible service component to assist the plant in assessing opportunities and identifying solutions to problems. Thus far, the effort has shown greater than 4 to 1 Return on Investment (ROI), in synergy with resolving the problem with opacity.

Introduction

Regulatory factors and economic considerations continue to drive the Industry toward more cost effective technologies to help satisfy increasing electrical demand while lowering emissions from coal fired plants. This paper is focused on the results obtained from a chemical treatment program currently ongoing at Santee Cooper, Cross Station. The primary objectives of the program were slag/fouling control and SO₃ mitigation.

Although it is common to consider only a backend treatment program for SO₃ control and the resulting opacity, a backend approach disregards several key factors that increase SO₃ generation in the furnace. While it is possible to remove SO₃ by applying chemistry in the backend, constant variation in the levels of SO₃ is consistently noted from furnaces which may be burning fuels with increased slag characteristics. Higher slag concentrations on the water walls, superheat pendants, reheat pendants, and backend surfaces increase both SO₃ generation, and the difficulties maintaining good combustion air flow. Generally, a cleaner furnace can operate more efficiently and generate less SO₃.

This paper, which is a joint effort between Santee Cooper and Fuel Tech, Inc., will discuss the advantages of a front end solution for opacity issues. The TIFI™ Targeted In-Furnace Injection™ program has been operational for more than 1½ years and provides a significant payback in both operational benefits and fuel flexibility. This is done by demonstrating that a front end approach provides for less formation of SO₃ by reducing SO₂ to SO₃ conversion and allowing greater consistency in control. Ultimately, while pursuing an environmental solution for opacity control, Santee Cooper was able to generate very significant savings. TIFI technology successfully contributed greater than 4 to 1 Return on Investment (ROI) from improved unit performance and additional savings from increased fuel flexibility.

SO₃ mitigation, slag/fouling control, improved heat rate, boiler efficiency, favorable impact to ash characteristics and fuel flexibility will be discussed and analyzed. The key technologies necessary for accomplishing the program objectives will also be discussed as well as the test methodology for measuring SO₃.

Program Objectives and Background

Santee Cooper's Cross Unit 1 is a 600 MW opposed wall fired unit that started commercial operation in January 1995. Cross 1 was equipped with staged combustion low NO_x burners. The unit had issues with "popcorn ash" formation from the time of initial operation. The unit also had issues with tube thinning in areas of the furnace adjacent to the burners due to a reducing atmosphere. There were persistent problems with burner eyebrows, burner fires, furnace imbalance, and air-heater pluggage. The air-heater pluggage was attributed to popcorn ash formation. Unit 1 was subsequently modified by the addition of an SCR in 2003. Subsequently, popcorn ash also blinded the SCR and protective screens. Year round SCR operation began June 2004.

Cross Unit 2 is a 600 MW T-Fired unit that began commercial operation in 1983. Unit 2 is equipped with close-coupled over-fired air and was modified by the addition of an SCR in 2003. The SCR went into full year operation in 2004. Cross 2 has seen increased slag and performance related issues since burning lower fusion coals.

Until 2004 Cross Units 1&2 burned Eastern Kentucky Bituminous coal. Around that time, Cross began burning coal from a source outside the normal supply area. The coal was contracted due to supply issues. The coal was higher in BTU, sulfur and iron content. Cross Station also has 100% wet FGD scrubbers and sells gypsum to local cement plants. Cross markets type F flyash for sale to cement plants as well as the ready mix market.

The new coal had fusion temperatures under reducing conditions in the range of 2000-2100°F. This compared with corresponding fusion temperatures of 2300°F for the previously fired coal. This boiler was designed to burn fuel with an iron content of 0.56 lb iron/10⁶ BTU and a minimum fusion temperature under reducing conditions of 2500°F (softening). The most significant difference in the coal burned during the baseline and treated periods was that the fuel had an average iron content of approximately 1.0 lb iron/10⁶ BTU.

Cross 1 furnace exit gas temperatures (FEGT) are very high, in the range of 2300-2400°F at full load. The results of this coal supply change were marked increases in slag formation on the super heater pendants, eyebrow formation at the burners and wall slag formation. The bottom ash slag was hard and dense due to high iron content. This caused numerous clinker grinder problems and resulted in broken clinker grinders. High pressure washing was used to break the slag into manageable pieces which could be removed from the boiler ash pit. The slag had to be dumped to the deck underneath the boiler on numerous occasions.

Slag formation on the water walls and pendants required removal with explosives. This sometimes delayed the start of outage work by 24-36 hours. Also, much of the hard fly ash carried over as popcorn ash causing pluggage and high pressure drop across the SCR. Santee Cooper resorted to SCR on-line cleaning with contract personnel in 'Hot Suits' within weeks of the SCR startup.

During this time, Cross 1 & Cross 2 also began experiencing opacity issues due to sulfuric acid mist emissions. Although the SCR used the lowest conversion catalyst formula available at the time, SO₂ to SO₃ conversion was also occurring in the furnace and resulted in visible emissions. This was particularly problematic for Unit 2. The emissions seemed to increase with high iron in the ash.

The following objectives for the Unit 1 TIFI (highly reactive magnesium hydroxide Mg(OH)₂) technology evaluation were set:

- Reduce SO₃ related Opacity issues.
- Reduce popcorn ash and SCR fouling
- Provide a significant reduction of the coal-related slag and fouling issues.
- Increase fuel flexibility

After approximately four months, early success prompted the initiation of the same program on Unit 2.

TIFI™ Targeted In-Furnace Injection™ Technology

The TIFI process was designed as a slag and fouling control program that specifically targets areas of the radiant and convection sections of a boiler. Targeting the problem areas of the furnace, instead of simply applying chemical to the fuel, produces performance and cost effectiveness that exceeds the less sophisticated approach. Recent developments include the use of this technology to control SO₃ formation and the resulting issues of high stack opacity (caused by sulfuric acid), and air pre-heater fouling related to these conditions.

Treatment 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) to ensure maximum coverage where the problem areas are known to exist. The chemical is added to the flue gas and targeted at either the problem heat transfer surfaces or at regions favoring chemical reactions for SO₃ formation. This assures that the injected material reaches the problem areas and is utilized efficiently. The additive then inter-reacts with slag as it is forming and penetrates existing deposits to affect their physical crystal characteristics.

Computational Fluid Dynamics (CFD) Modeling

TIFI technology utilizes multiple computational fluid dynamics (CFD) models coupled with a proprietary virtual reality based visualization software system. Advanced visualization brings these simulation methods to life and creates a detailed running duplicate of the furnace. Injection overlays and dosage maps are used to predict where the chemical is going and to ensure effective coverage of the targeted zones. The immersive and interactive nature of the simulation enables the designers to intuitively discern problems and to improve the design. Moreover, the customer can also enter the visualization and provide input for years or decades of experience with the real unit. Treatment programs are designed and a customized injection scenario is built virtually and evaluated.

Injection Technology

Injection is simulated with proprietary models that evaluate the distribution of the reagent in the flue gas. An interactive injector model enables quick optimization of the needed droplet trajectories and resulting penetration. A rigorous model is then used in the CFD solution to precisely determine the distribution of the chemical treatment. The TIFI injection strategy utilizes a variety of injection developments to provide treatment on the walls, in the convective pass and in very large furnaces, see Figure 1.

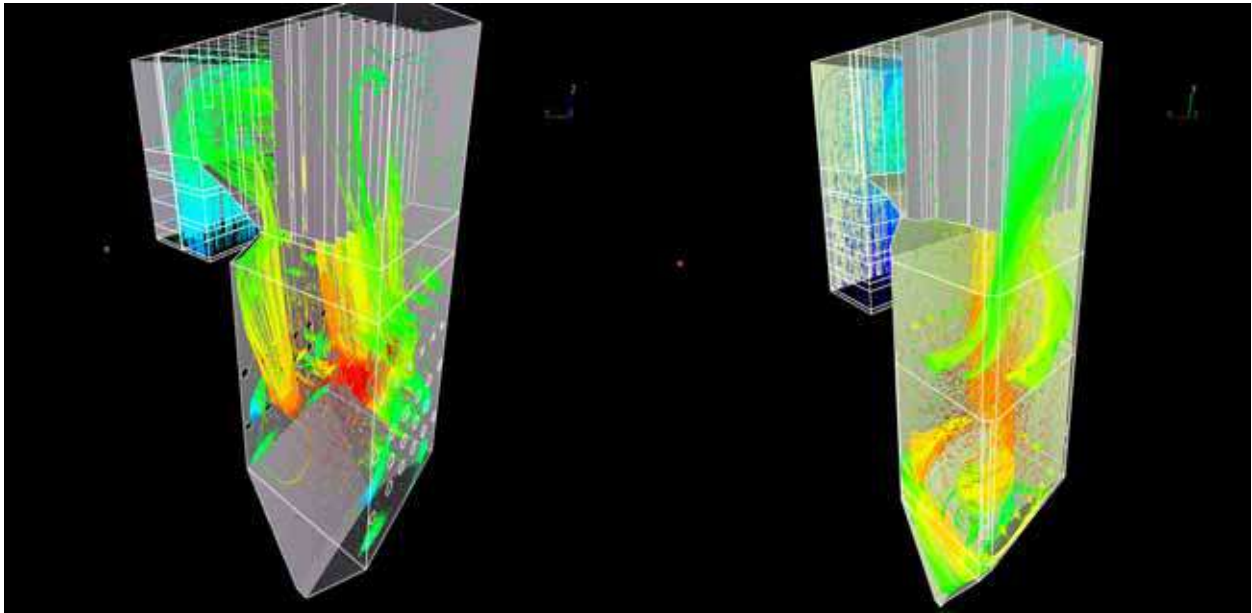


Figure 1 Fuel Tech Visualizations of Droplet Trajectories

The visualization tools are also used to illustrate the likely slag and fouling fronts in the furnace. In this example (Figure 2), the translucent red iso-surface has been created to visualize a potential ash fusion temperature of 2,150°F. It shows the operators and designers quite clearly where slag and fouling are likely to first occur. When targeted with the chemical injection, a unique and powerful tool is formed that can be used to control the slag and fouling to a degree not possible before.

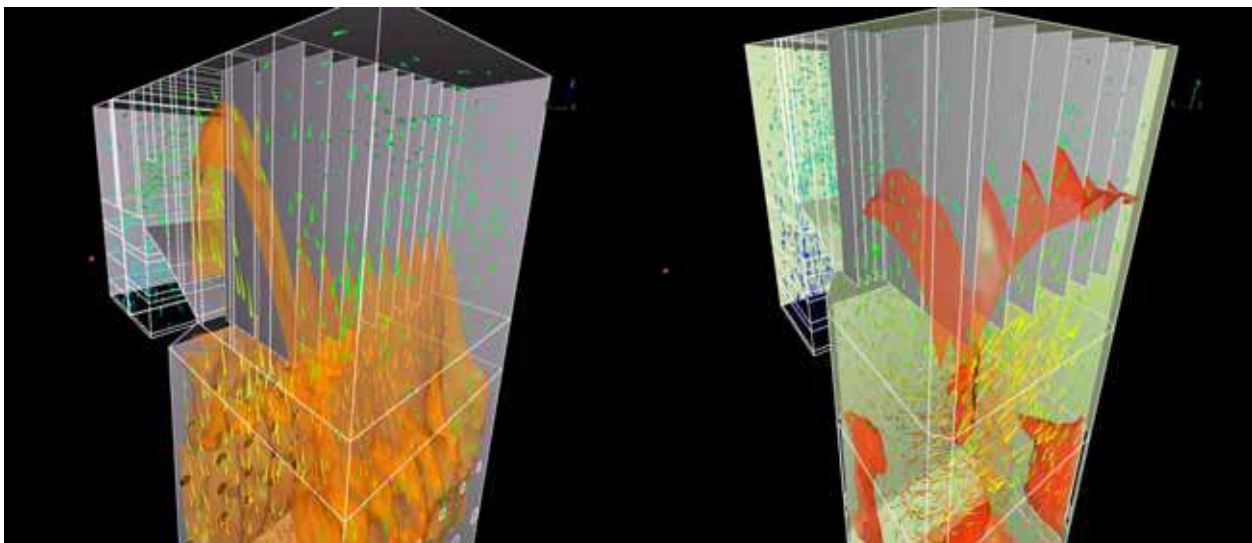


Figure 2 Fuel Tech Visualizations of Temperature Surfaces

Reagent Chemistry

The TIFI reagent is a stable chemical slurry with high reactivity due to its high relative surface area. The high activity results in better performance at recommended treatment dosages while its high stability eliminates many of the handling and feeding problems associated with un-stabilized compounds.

The chemical reagent arrives at the customer site in the form of suspended slurry of 5–8 micron sized particles. Atomization and chemical distribution systems, guided by the CFD and injection model results, provide the desired reagent coverage of the walls, the convective pass, and the furnace gases.

The TIFI process uses Magnesium Hydroxide to change slag characteristics and also to mitigate SO₃ formation. As Magnesium Hydroxide, in the form of a slurry, travels into the furnace it becomes superheated and ultimately forms nanometer size particles of Magnesium Oxide (MgO). These very small particles behave almost like a gas and travel with the flue gas stream. This becomes an important aspect regarding not only slag control, but also SO₃ mitigation.

The reagent, enhanced by the rapid heating, quickly begins to interact with the existing deposits and the deposit formation mechanisms (through crystal morphology) to control the slag accumulation and downstream fouling. This slag control leads to a decrease in SO₃ formation. In addition, the gas stream treatment, through acid-base neutralization reactions, reduces much of the SO₃ that is formed. Control of the SO₃ reduces sulfuric acid concentrations, stack opacity issues, and pre-heater fouling.

Chemistry of SO₃ Formation

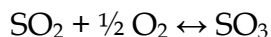
The formation of Sulfur oxides (SO_x) is dependent on reaction kinetics, combustion temperatures, fuel sulfur content, ash composition and the level of excess air. Most fuel bound sulfur oxidizes to SO₂ in the combustion zone.

The further oxidation of SO₂ to SO₃ is brought on by three mechanisms.

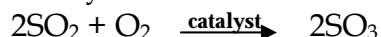
1. Oxidation of SO₂ in flame by atomic oxygen.



2. Oxidation of SO₂ by molecular oxygen.



3. Catalytic oxidation via molecular oxygen.



The third mechanism is significant and is the result of metal-catalytic oxidation by iron oxides and vanadium, among others. These metals are found in the ash particles, on slagged or fouled metal heat transfer surfaces, or in an SCR catalyst.

SO₃ in the post-combustion gases will react with the moisture in these gases to form sulfuric acid in the air pre-heater (APH).



The sulfuric acid condenses on the cold metal surfaces of the APH or downstream equipment. This condensed acid can cause corrosive damage or simply provide a site for ash buildup and eventual APH pluggage that may cause a very expensive forced outage.

In units equipped with ammonia or urea-based NO_x reduction systems, interaction between residual ammonia and SO₃ is an important factor in determining system performance. For all of these systems, a high concentration of SO₃ at the APH limits the available NO_x reduction. This is because residual NH₃ reacts with SO₃ to produce ammonium bisulfate in the APH at approximately 400°F.

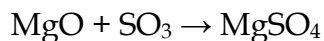


Ammonium bisulfate deposits are sticky and difficult to remove, accelerate corrosion and create significant air heater fouling.

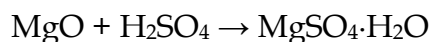
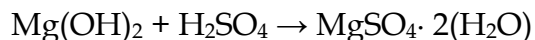
Chemistry of TIFI SO₃ Control

The TIFI reagent treatment strategy controls SO₃ formation by both limiting the catalytic opportunities for oxidation and by providing a clean and efficient furnace that can function well at lower levels of excess oxygen. In addition, the TIFI technologies provide SO₃ capture to limit or eliminate the effects of sulfuric acid impacts downstream at the APH.

Magnesium oxide reacts with SO₃ to form Magnesium Sulfate as:



In addition, the same environment that causes the formation of sulfuric acid also allows for a classic acid-base reaction between magnesium hydroxide and magnesium oxide with sulfuric acid.

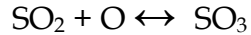


Case Study: Results and Observations

There are several observations that seem to be common for utility operators that are having trouble controlling SO₃ emissions. A good example is opacity caused by sulfuric acid emissions. Often this opacity is most notable during power ramp up. Although this is a common observation, the underlying mechanisms, the best control strategies and the best measurement criteria are not easily devised. Inspection of the air heater,

although accurate, is an after-the-fact observation. It makes more sense to devise a preventative solution to the problems before they occur.

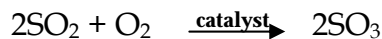
TIFI technology reduces SO₃ and H₂SO₄ by addressing the following mechanisms:



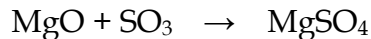
A cooler furnace, the result of more efficient heat transfer, lowers SO₂ to SO₃ conversion.



A cleaner furnace and convective pass allows for reduced excess oxygen.



Reduced slag, fouling, and iron based deposits reduces the catalytic conversion of SO₂.



Magnesium Oxide is extremely reactive and will readily combine with SO₃ and H₂SO₄ to form Magnesium Sulfate.

When highly reactive magnesium hydroxide is injected using TIFI technology based on CFD modeling, the results are dramatic but not necessarily immediate. It takes approximately 30 days to season a boiler and neutralize acid based deposits located post-SCR. The initial time to season a boiler will vary based on SO₃/H₂SO₄ concentrations, and the amount of acid based deposits found in the components and ductwork. One of the goals in dealing with SO₃ mitigation is to ensure minimal impact to operations. TIFI technology is designed with that objective in mind.

SO₃ Measurements

SO₃ measurements on Unit 2, using a modified controlled condensation method, were used to obtain SO₃ data from three different locations in the boiler for this case study. Baseline and TIFI treated data were obtained at the economizer outlet, SCR outlet and air heater outlet, Figure 3. Significant reductions in SO₃ levels were observed with 46%, 66%, and 56% SO₃ reductions respectively at each testing location.

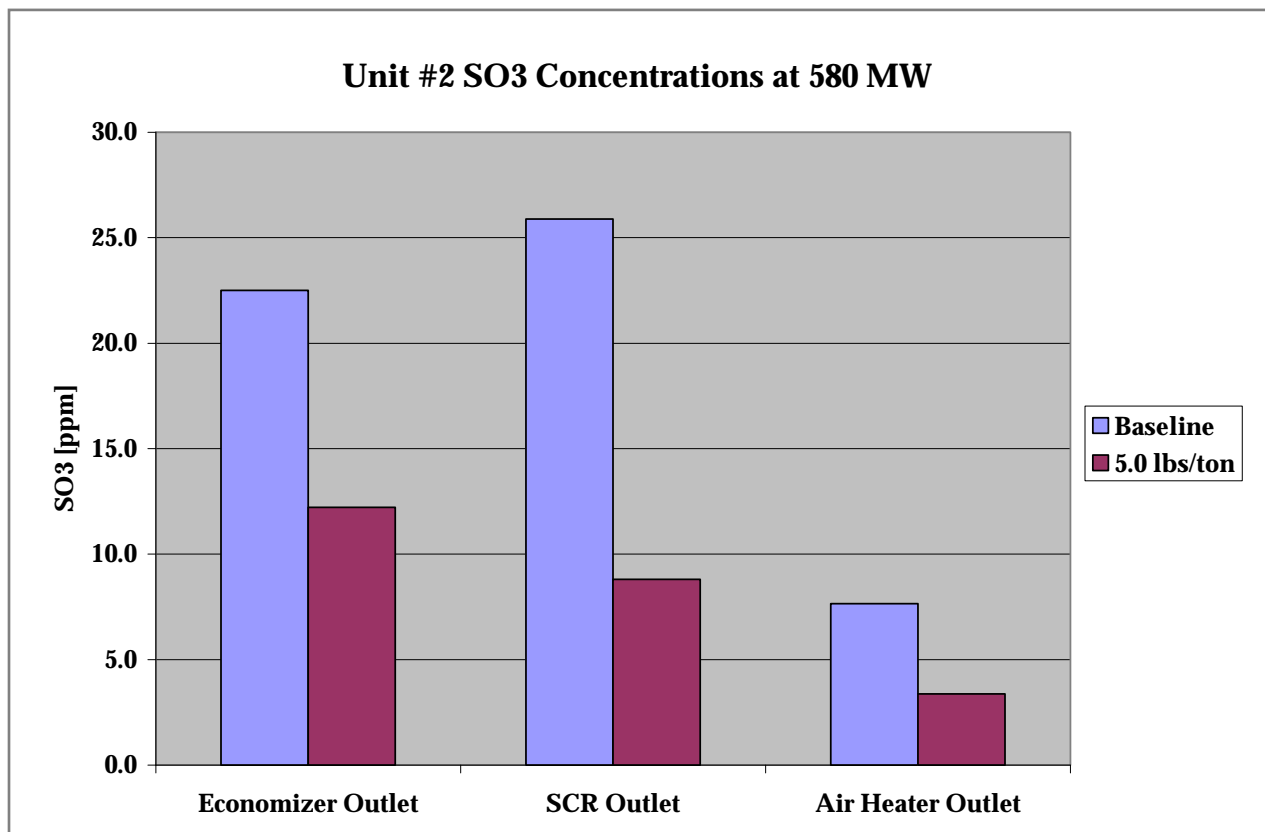


Figure 3 *SO₃ Concentrations at High Load*

The dramatic and consistent difference between the untreated and the treated SO₃ measurements indicate that the TIFI program is providing SO₃ mitigation from before the economizer and through the air pre-heater. The large decrease in SO₃ for both treated and untreated conditions between the SCR outlet and the APH outlet locations is an indicator of the acid condensation in the APH. The treated flue gases had 66% less SO₃ available to influence opacity emissions.

Similar results are seen in the data taken at the reduced load of 430 MW, Figure 4. A 69% decrease in SO₃ was seen at the SCR outlet.

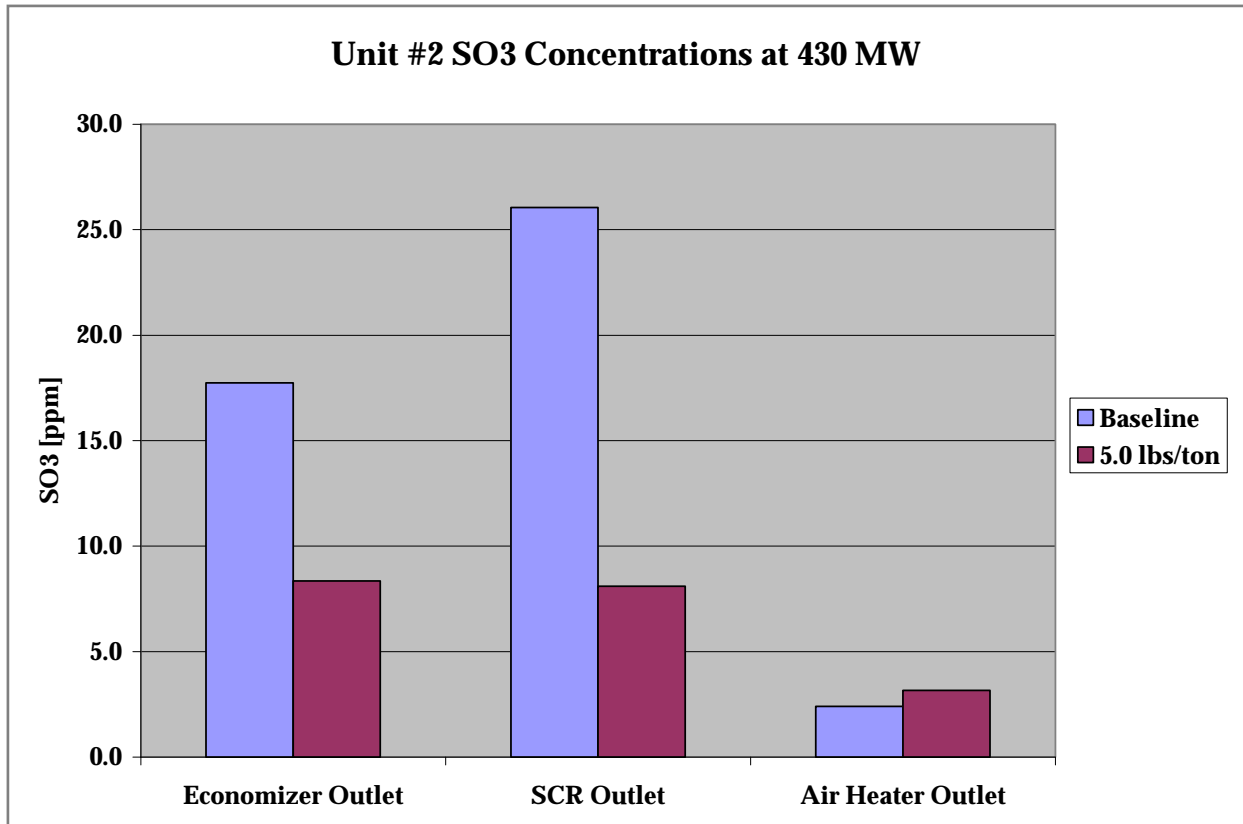


Figure 4 *SO₃ Concentrations at 430MW*

Opacity

The SO₃-related opacity has been controlled. Figure 5 shows two photos of Unit 2 with and without TIFI treatment. The plume has, in fact, been controlled regardless of fuel characteristics and sulfur content. In general, a TIFI program is very effective with SO₃ and H₂SO₄ allowing the unit to remain cleaner with improved slag and fouling control. Less SO₃ is generated throughout the unit. This allows consistently lower levels of SO₃ related opacity.



Figure 5 No Visible Opacity issues with TIFI treatment on the right photo with both stack inlets at an SO₂ concentration of 2.9#/10⁶ BTU

Slag and Fouling Control

Prior to the application of the TIFI treatment program, it was very difficult to remove bottom ash and maintain clean water walls. In fact, the removal of the bottom ash required high pressure blasting regularly to aid in ash removal. The clinker grinder system required daily maintenance quite often, and it was very difficult to overcome the performance problems associated with the inability to remove this ash. With reducing fusion temperatures being 200-300°F below the bull-nose temperatures, there was a very significant and consistent buildup of slag on the water walls, the superheat pendants, the reheats, and the bull nose.

After TIFI start up, there was a significant improvement in water wall cleanliness and bottom ash handling. The walls, superheat pendants, reheat pendants and bull nose were much easier to keep clean with soot blowing.

The first noticeable improvements in unit operation were with the clinker grinders. Removing the bottom ash became much easier as the ash became more friable. Clinker grinder maintenance requirements dropped from daily problems to routine. The current slag is friable, lighter and more easily controlled. The pictures in Figure 6 (A&B) capture the dramatic change in the slag. The untreated slag, shown in Figure 6A, is smooth, strong and dense. The treated slag sample in Figure 6B, however, is clearly porous and less dense.

Slag formation has been controlled. With regular soot blowing, the slag is efficiently removed and the unit is kept clean. Cross Unit 2 is adding some soot blowers at several locations to control slag. These areas currently do not have soot blowers.



Figure 6A Before TIFI slag



Figure 6B After TIFI treatment slag

Effects on Popcorn Ash

As previously noted, this unit has had issues with popcorn ash since initial operation. Since the 2003 installation of the SCR, the economizer hoppers and the SCR have routinely become fouled with popcorn ash. Constant maintenance of the economizer hoppers was needed to allow ash removal to occur. On line cleanings, which included a load drop, was a common practice. During the outage prior to treatment, two areas were improved to help address boiler performance.

- The economizer outlet screens and SCR rectifier screens were replaced with a slightly larger mesh size.
- The burners were upgraded to improve primary air flow velocities and combustion.

Upon startup after the outage in April 2006, there were several burner tuning requirements that took several months to complete. The initial goal was to first improve mill fineness so that burner tuning could be performed successfully. Mill fineness and burner issues were improved by October 2006. During the period from April 2006 through October 2006, there were many periods where significant reducing conditions occurred, with furnace O₂ at 1.0% or less, and gas temperatures at the bull nose above 2450°F. It is important to observe from the data presented later in this paper that, during this period, the typical fuel variability continued with reducing fusion temperatures at approximately 2000 - 2100°F.

To illustrate the effectiveness of the TIFI program on popcorn ash production, the pressure drop across the SCR reactor has been graphed, Figure 7. After the initiation of TIFI treatment, the pressure drop simply no longer increased.

Prior to the start of treatment (from April 2005 to April 2006) the pressure drop can be seen to increase regularly on both the A and B side reactors, the blue and red symbols,

respectively. After the start of treatment, there are no more pressure drop spikes. The popcorn ash has been minimized.

Unit availability and heat rate improved immediately due to improved furnace cleanliness, a reduction in load sheds, and the elimination of SCR cleanings. Moreover, all issues related to economizer hopper pluggage also ended immediately after startup of treatment.

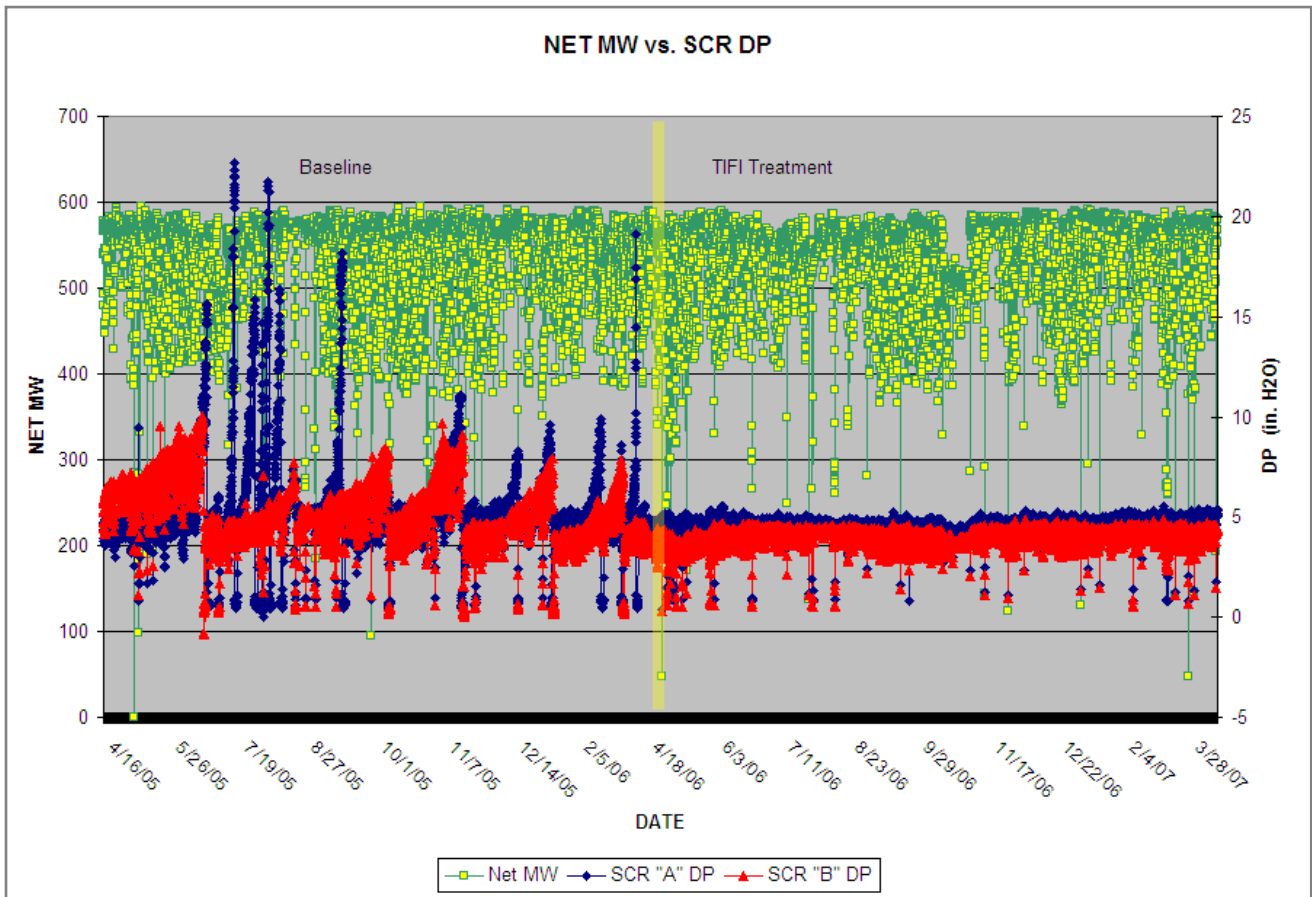


Figure 7 SCR pressure drop indicates the end of “pop-corn” ash

Boiler Efficiency & Heat Rate: Unit 1

TIFI treatment has led to improved unit operational stability, an increase in the furnace efficiency and an improved net heat rate. Although some of the gains may be due to burner modifications and mill adjustments, much of the data reflects improved heat transfer and a dramatic decrease in slag and fouling consistent with TIFI treatment.

Most dramatically, the maximum load capability was seen to increase by an average of 44.5 MW(net) during treatment as compared to the previous year. This was determined by an analysis of the daily maximum load over two years, based on hourly averages. This increase is indicative of better heat transfer in the furnace and convective pass as well as decreased resistance to flow through the downstream equipment.

Reduction of the upsets due to popcorn ash formation and SCR on-line cleaning led to improved heat rate through the elimination of frequent load drops. In addition, load sheds (load drops to encourage shedding of slag and fouling deposits) were not required as often, further affecting the net heat rate.

As you can see from the data in the following graphs, boiler efficiency and heat rate continued to improve while fuel characteristics changed continuously. At the same time ash flow characteristics improved clinker grinder operations, allowing for easier removal of large clinkers in the ash hoppers.

A chart has been constructed that shows the unit efficiency and load, as provided by the plant, over the time of the evaluation, Figure 8. This data has been roughly divided into two year-long evaluation periods. The first is from April 16, 2005 to April 15, 2006, and represents a full year of operation without TIFI treatment. The second time period is from April 16, 2006 to April 15, 2007, and represents operation with TIFI treatment.

An outage occurred in the spring of 2006, in which the burner modifications were made to address coal flow and wind box operations and in which the TIFI system was installed. The unit was cleaned and was returned to service with TIFI treatment. An immediate modest efficiency gain was realized. During the first few months, burner tuning and mill adjustments were required. Furnace operation was unsteady as numerous combustion issues were resolved. Most of the tuning and combustion optimization was completed by August of 2006.

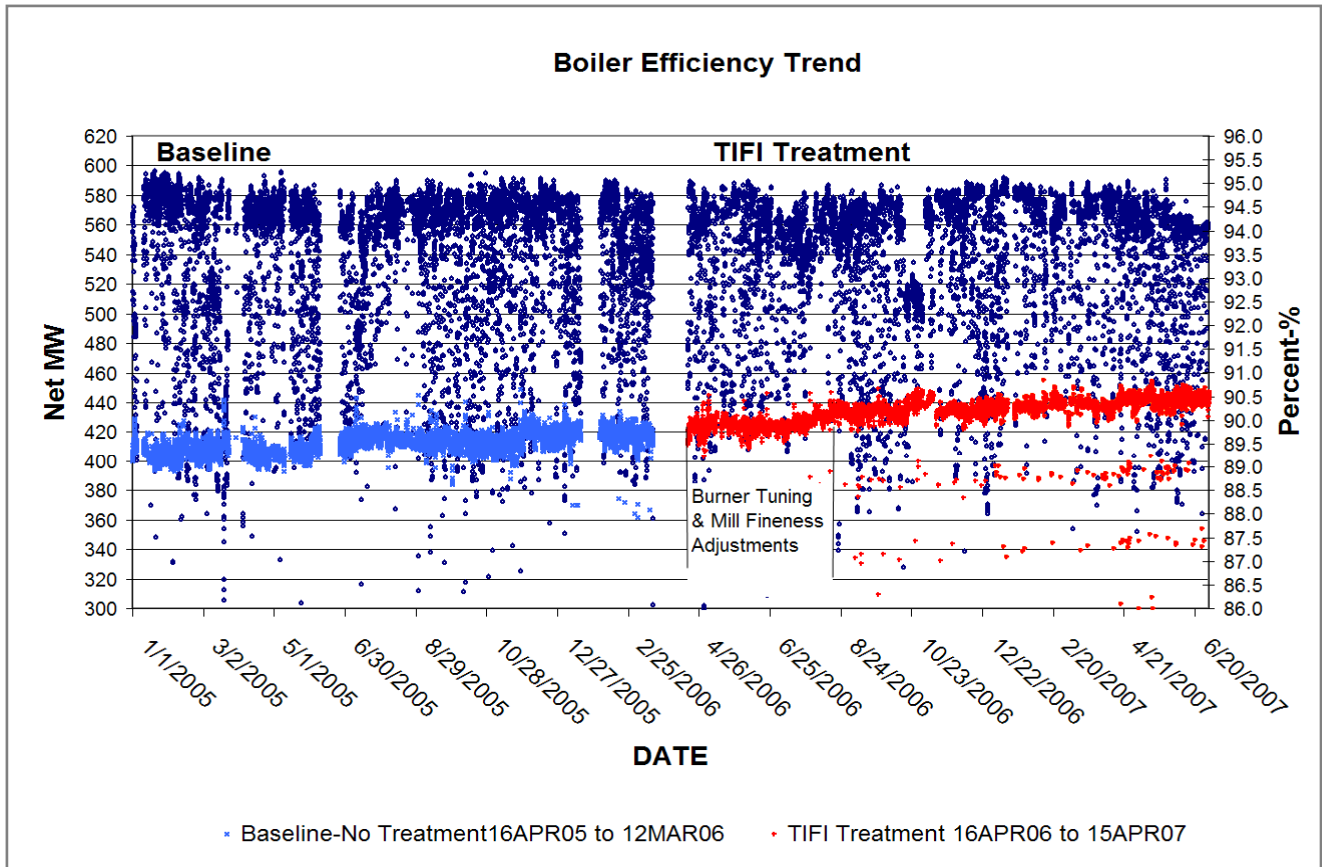


Figure 8 Unit 1 Boiler Efficiency Trend

A direct comparison of the unit efficiency data from the untreated and the treated test periods is shown in Figure 9. The blue data points represent the untreated operation while the red data points represent the subsequent treated operation. This chart shows quite clearly the improved boiler efficiency across the entire load range. Simple arithmetic averaging across the data yields a 0.51% efficiency improvement for the TIFI treatment period.

A similar calculation performed using only the data after the combustion upsets (during burner tuning) reveals a larger net increase in efficiency of 0.65%. Incidentally, an average of four months of data subsequent to the second period produces an overall efficiency gain of 0.77%.

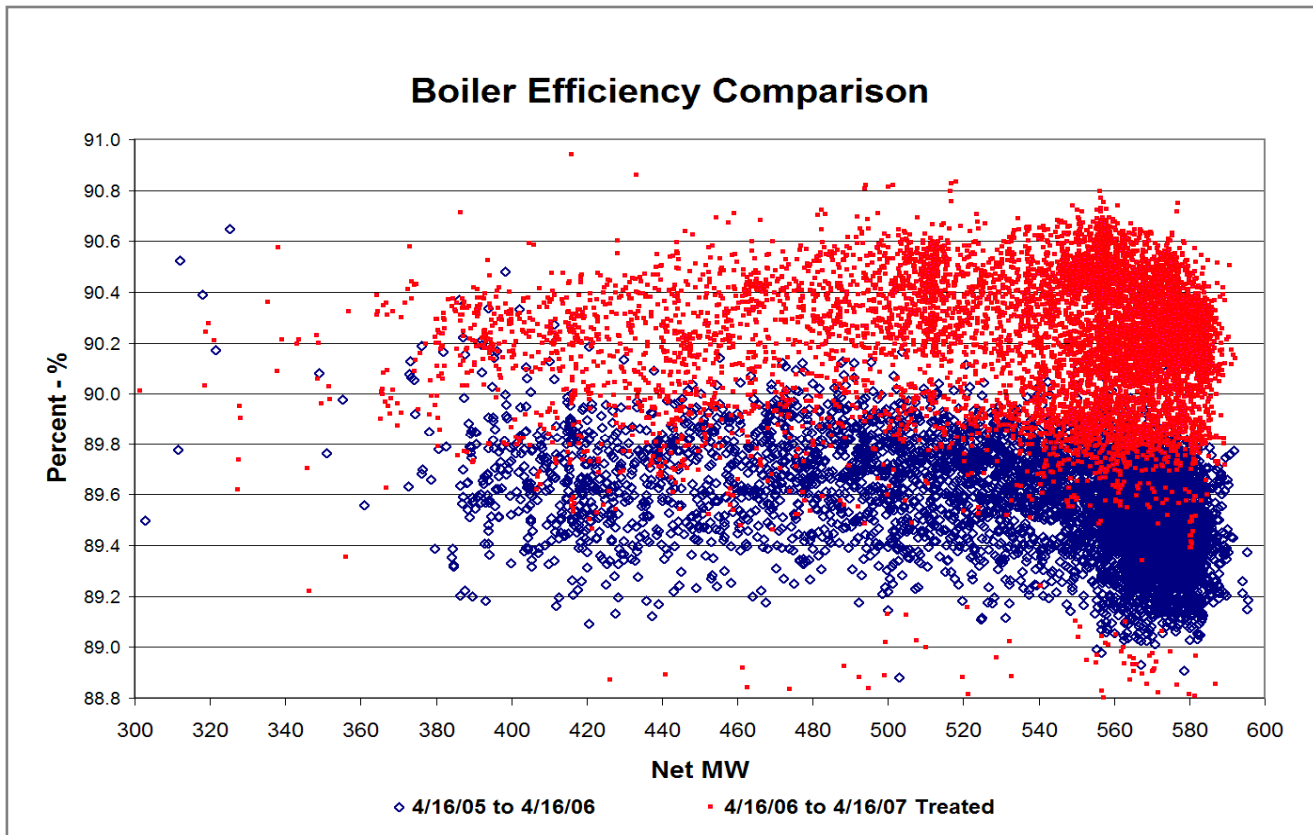


Figure 9 Unit 1 Boiler Efficiency Improvement with TIFI Treatment

A similar measure of unit performance can be obtained by comparing the Unit 1 Net Heat Rate, as provided by the plant, between the untreated and treated time periods, Figure 10. Again, the blue data points represent the untreated operation while the red data points represent the subsequent treated operation.

The average Net Heat Rate over the load range improved by 120 BTU/kW-hr for the period with TIFI treatment. This occurred even though the average fuel heat content was reduced by 225 BTU/lb during treatment compared to the baseline. The improvement is about 1.25%, and represents a much greater effect than boiler efficiency alone.

Cleaner furnace and convective pass heat transfer surfaces produce improved turbine performance through efficient and balanced superheat and reheat utilization. In fact, there was a significant drop in average steam attemperation sprays during the TIFI treatment period. In addition, due to both reduced slag and increased furnace performance, there is a reduction in the parasitic demand for the ID and FD fans as the flue gas flow and the flue gas path pressure drop decrease.

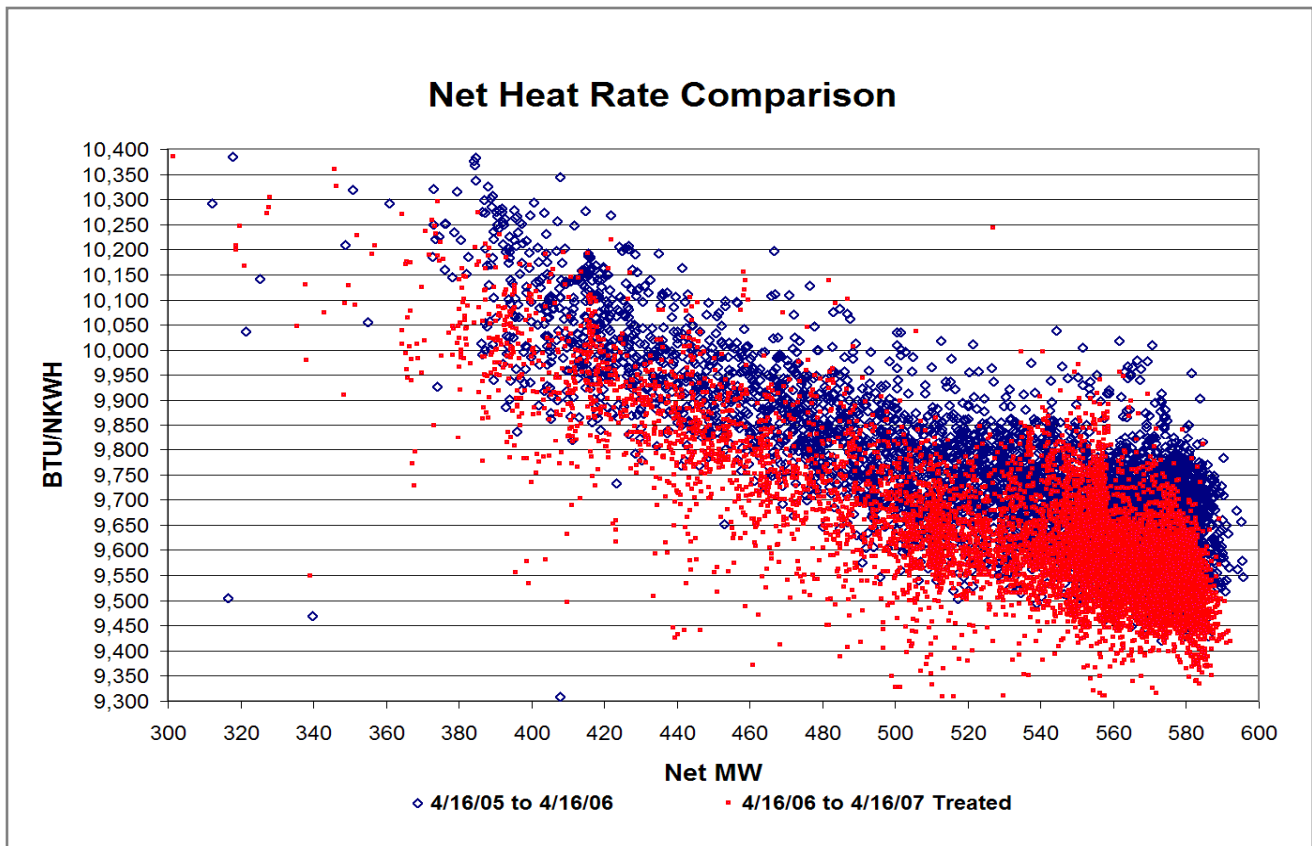


Figure 10 Improvement in Unit 1 Net Heat Rate

Air Heater Inlet Temperature Trends

The boiler efficiency gains are corroborated by the reduction in economizer exit gas temperatures or, in this case, air heater inlet gas temperatures. The following trends demonstrate the reduction in temperatures at the inlet to the A and B air heaters.

Trended temperatures over the period of the study show more efficient and stable operation, Figure 11. The unit load during this period shows some variability, but it is generally consistent between the baseline and treated time periods. Due to the fact that the boiler was cleaned during the outage in the spring of 2006, it is not surprising to see lower initial air heater inlet temperatures.

The effect of TIFI treatment becomes evident in the fact that the temperatures do not increase with time. The furnace, convective and back pass heat transfer surfaces remain relatively clean and continue to remove heat effectively. Furthermore, the average temperatures decrease.

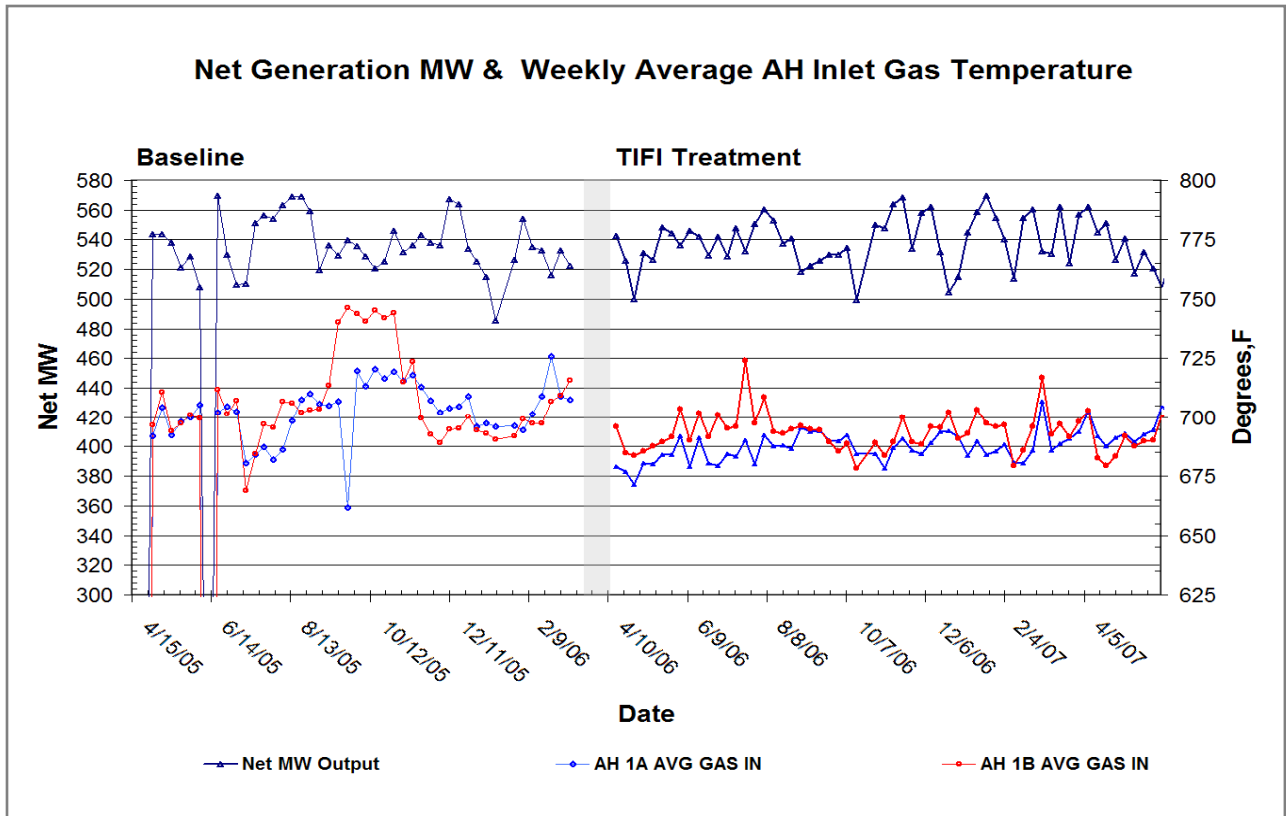


Figure 11 Air Heater Gas Inlet Temperatures Are Decreased and More Stable.

Scatter plots of air heater inlet temperatures for both the A and B side illustrate the effect across the load range, Figure 12. The blue data points represent the untreated operation while the red data points represent the treated operation.

The effect of slag and fouling is readily apparent in the large scatter in the untreated data. In particular, the treated data at high load (>500 MWe) forms a coherent mass representing normal boiler variations in O₂ and fuel heating value. The untreated data, in comparison, overlaps the coherent data set and extends well above. The B-side temperature plot, in particular shows a particularly large variation.

These effects are indicative of the improved heat transfer and boiler efficiency with TIFI treatment.

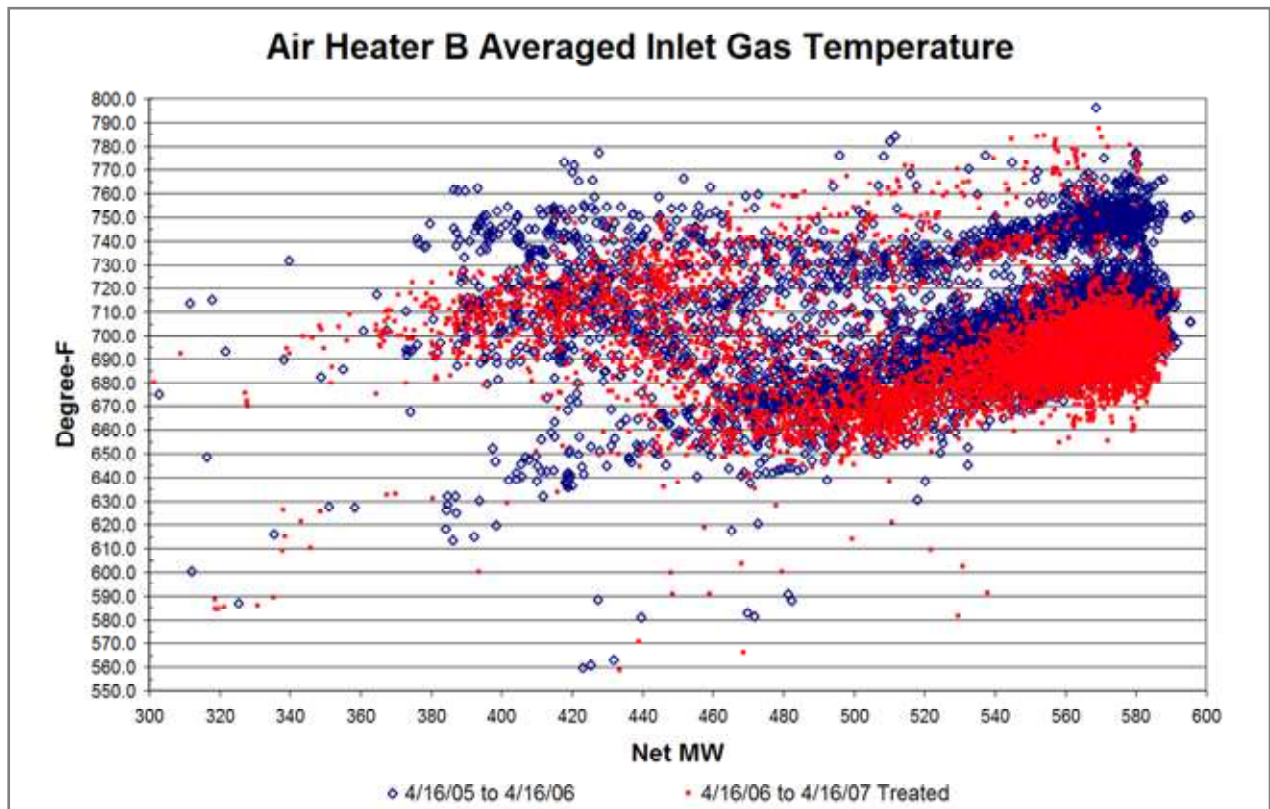
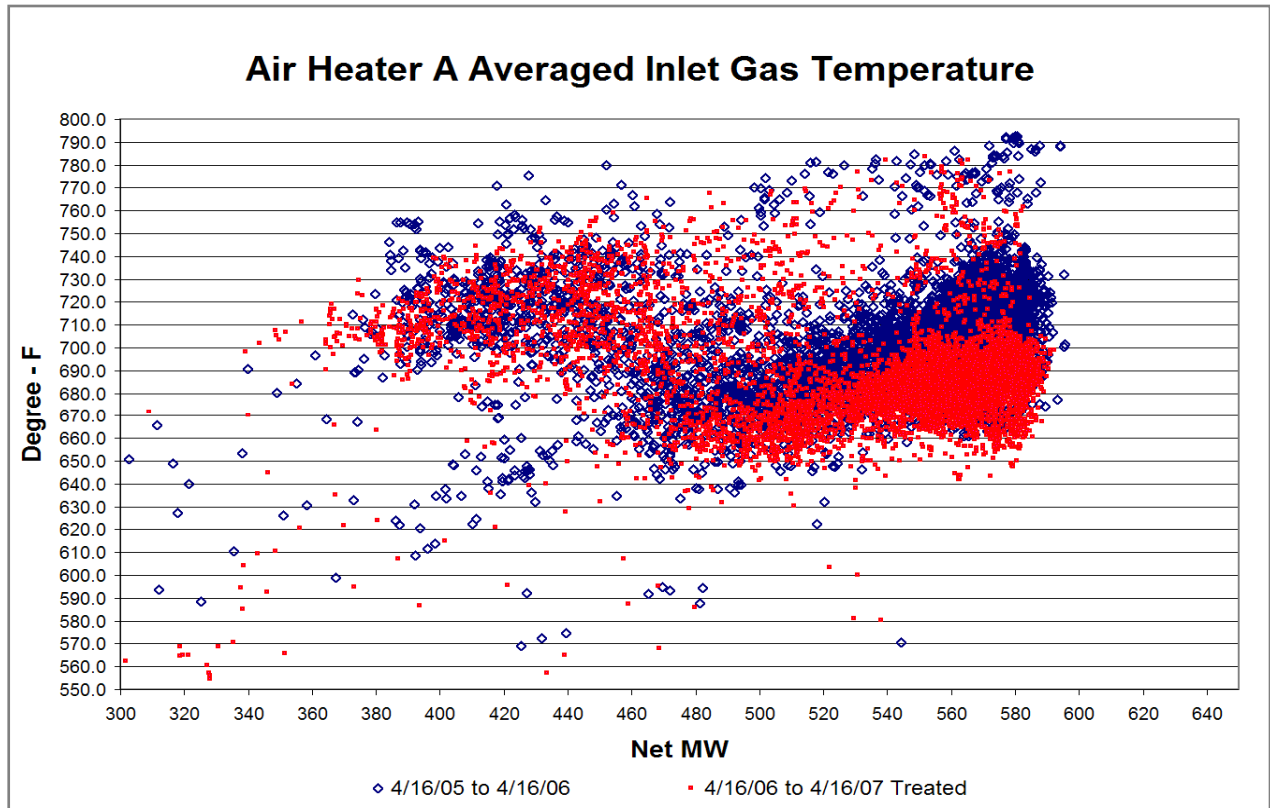


Figure 12 Air Heater Inlet Gas Temperatures Decrease with TIFI Treatment

Furnace Percent Loss on Ignition (%LOI)

Another benefit to the cleaner and more efficient furnace is the effect on %LOI. It is certain that the burner modifications and eventual tuning had a great effect on the ability to control %LOI. A summary of the weekly averaged %LOI over the course of the two year baseline and evaluation periods, Figure 13, reveals an obvious stabilization after the burner tuning was completed.

It is important to note that stable and efficient furnace operation is critical to stable combustion. The TIFI treatment program reduced slag formation and fouling and therefore provided a consistent gas path behavior that helped to eliminate fluctuations in furnace O₂. In fact, this is generally an opportunity to reduce the furnace O₂. In addition, a more efficient boiler also reduces the need to over-fire the unit to compensate for furnace performance.

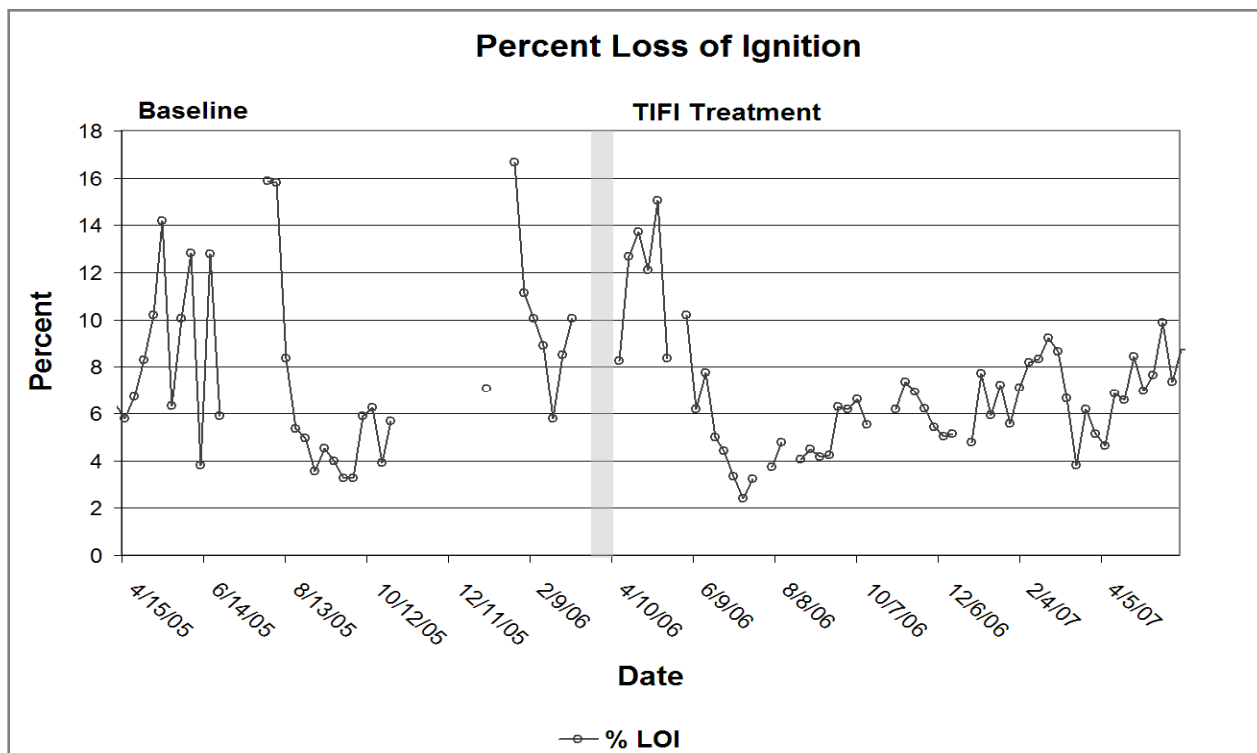


Figure 13 Stable Unit Operations and %LOI with Treatment

Fuel Flexibility

The plant goal is to have an unrestricted ability to utilize higher slagging coals without negatively impacting either SO₃ related opacity control or unit performance. The charts in this section describe a wide variability in fuel heat capacity, iron content, slagging factor, and base to acid ratio.

Figure 14 contains three charts comparing boiler efficiency to the variable qualities of the fuel fired during this evaluation.

The weekly averaged fuel heat content is shown in the center chart. The heat content of the coal varied by as much as 9% during the baseline period and by about 6% during the treated period. The average fuel heat content was also about 225 BTU/lb (2%) lower during the treated period. This variation had no significant effect on the performance of the TIFI treatment.

The bottom chart shows the fuel iron content, slagging factor, and base to acid ratio. Each of these slag-related factors showed considerable variability during the treatment program, consistent with the fuel being fired the year before. In particular, the fuel iron spiked quite high in the spring of 2007. On average, the iron content was approximately 1.0 lb iron/10⁶ BTU (minimum reducing ash fusion temperature of 2000°-2100°F), as compared to the design coal iron content of 0.56 lb iron/10⁶ BTU (minimum reducing ash fusion temperature of 2500°F).

The TIFI treatment program successfully provided slag and fouling control with these challenging fuel specifications. A comparison of boiler performance from baseline to treatment with TIFI treatment concluded that boiler efficiencies improved even though fuel properties remained difficult with higher slagging coals.

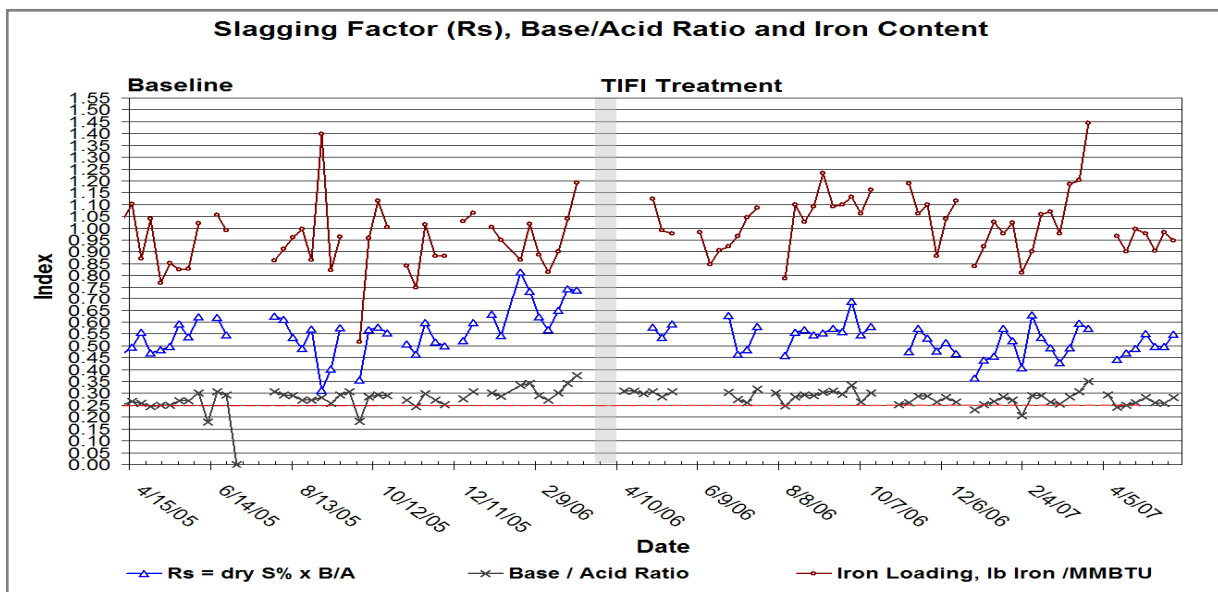
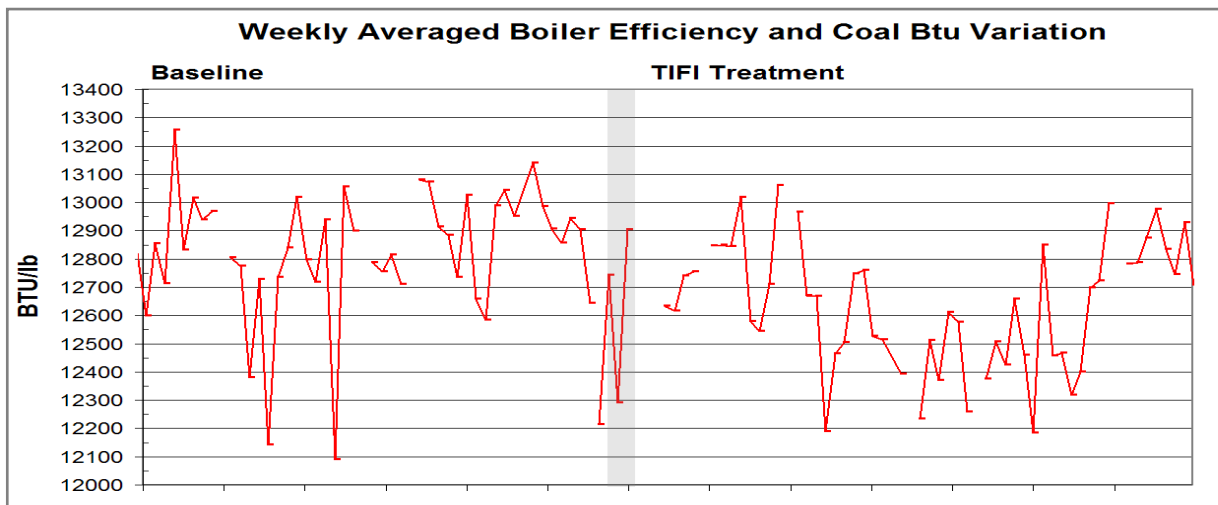
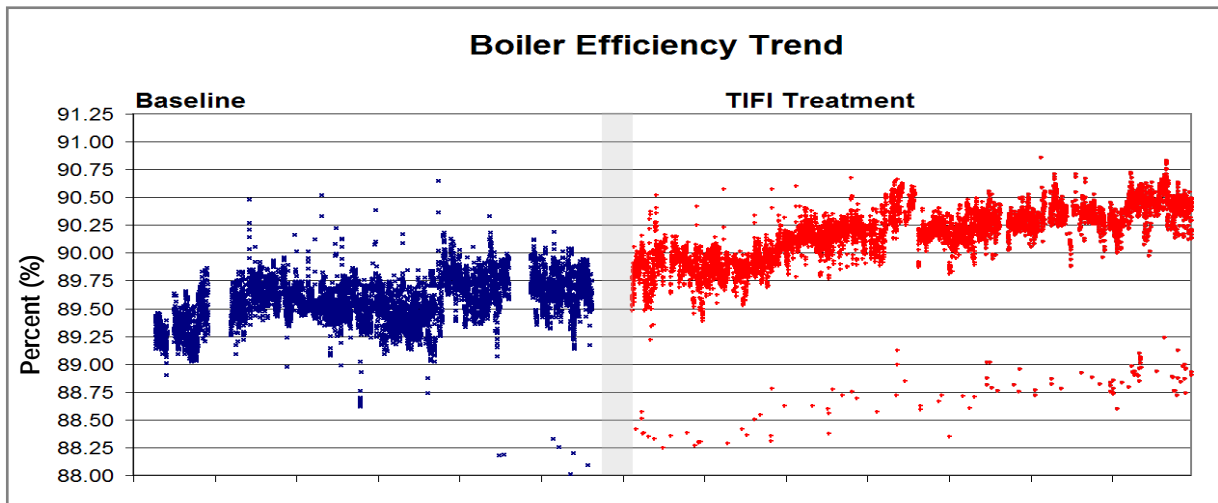


Figure 14 Three plots showing Fuel Flexibility during the evaluation period

Impact on Ash Sales

Ash sales were not affected by this program. The plant continues to sell its ash to the cement industry and the ready mix market. There have been no issues related to ash customers.

Reduction of Total Toxic Releases (TRR)

Toxic Release Inventory reporting for 2006 showed a reduction of 20% in total air emissions. This is due to a 35% reduction in sulfuric acid mist emissions compared to 2005. The reduction in estimated emissions was in spite of an 8% increase in gross generation at Cross. The only difference noted was the inclusion of Magnesium Oxide furnace injection in the boilers. The estimates were based on EPRI's Lark Tripp program. This was based on the TIFI program being in operation for 9 months and we would expect further reductions for a full year of operation.

Conclusions

Choosing to control SO₃/Opacity issues by injecting in the furnace has many advantages over the typical backend treatment programs that exist. As demonstrated at Santee Cooper, a front end approach provides significant performance improvements in heat rate, boiler efficiency, and fuel flexibility. The program more than pays for itself.

- The TIFI approach was very successful at reducing SO₃ related Opacity in the furnace and Post SCR, ultimately removing all related opacity.
- Reduced SO₃ at the Air Heater Inlet by 66%.
- Contributed to the reduction of popcorn ash on Unit 1.
- Increased MW capability by 44.5 MWe.
- Increased boiler efficiency by 0.65%.
- Improved Heat Rate by 120 BTU/kW-h while utilizing coals that had an average heat content decreased by 225 BTU/lb
- Allowed Fuel Blending with lower fusion coals having nearly twice the Iron.
- Reduced outage cleaning times by more than 50%.
- Reduced clinker growth.
- Clinker Grinder maintenance dramatically reduced.
- Greatly improved ash handling characteristics.
- A reduction in Total Toxic Release (TTR) of 20% with a 35% reduction in H₂SO₄ for a 9 month period of operation.
- Significantly reduced slag and with higher slag forming coals.

While pursuing the environmental concern of opacity control, this program was able to generate very significant savings. A TIFI program successfully contributed greater than 4 to 1 Return on Investment (ROI) from improved unit performance and additional savings from increased fuel flexibility.