Thermal Cycling, Air In-Leakage & Impact On Heat Rate, Emissions and Cost of Compliance

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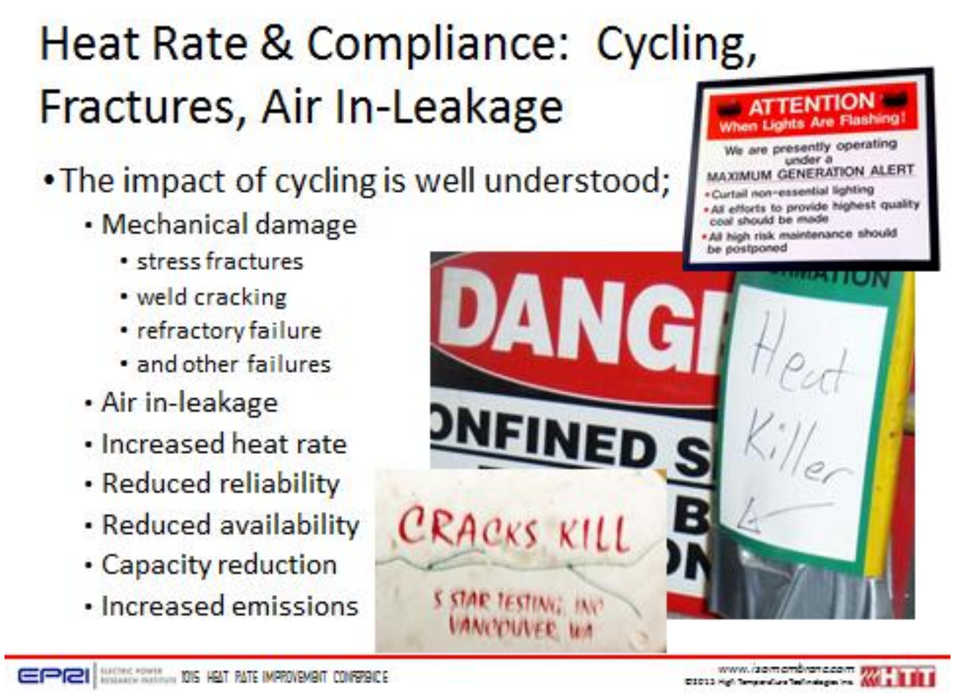
Heat Rate & Compliance: Cycling, Fractures, Air In-Leakage
The low price of gas and increased role of renewables in the energy mix has relegated many formerly base load plants to intermediate and peak load operation, contributing significantly to air in-leakage issues. These plants are experiencing increased cycling…cycling they were not designed for. The impact of this cycling is well understood:

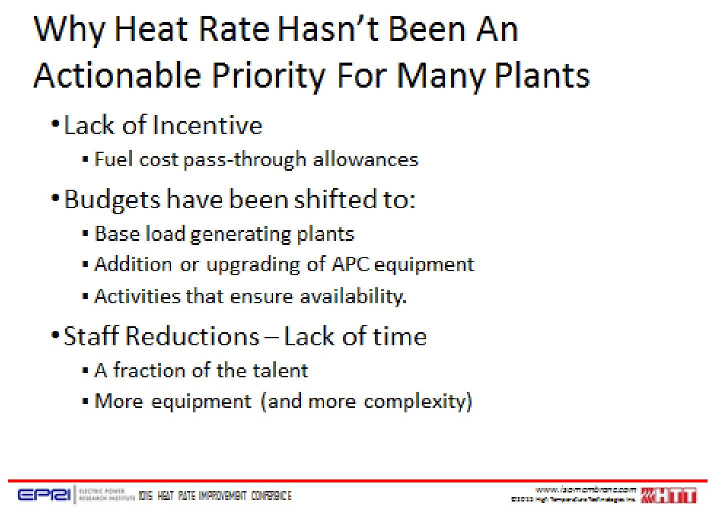
- Increased air in-leakage,
- Poor efficiency,
- Increased emissions and
- Mechanical damage (stress fractures, weld cracking, refractory failure, etc.)

The scope of this paper is to discuss the mechanical damage on the boiler and ductwork caused by cycling and its impact on air in-leakage, problems with current remedial tactics and alternative solution options that have proven to provide cost-effective, long-term reliable service-life.



Why Heat Rate Hasn't Been An Actionable Priority For Many Plants

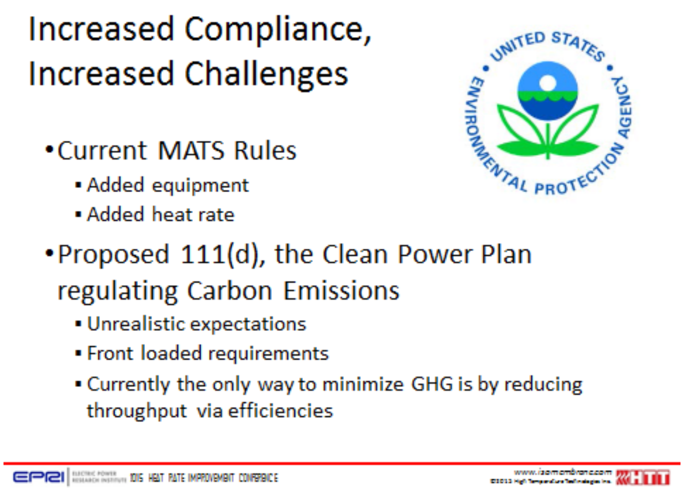
For years we've talked about heat rate, but let's be honest, in reality it hasn't driven maintenance and operational activities to a great degree. For many utilities, the reasons are simple: lack of resources and a lack of meaningful incentives.



The people who want to improve it are committed, but they are hindered by:

- **Lack of Incentive** – <u>Fuel cost pass-through allowances</u>
  - There hasn't been real incentive to operate more efficiently because fuel cost pass-through allowances cover the added cost of inefficient fuel consumption. And as the last 3-4 years have shown us, competitive survival hasn't been much of a motivator either. I have seen plants switch to a lower cost coal to be more competitive, with the trade-off being lower BTU's or higher sulfur which increases corrosion and tube failure potential. Yet the maintenance budget doesn't increase to negate the negative side-effects associated with the fuel savings.
- **Budgets** –
  - Budgets have been curtailed significantly over the years as money has been diverted to new gas plants, air pollution control equipment (APC), to urgent issues that ensure immediate availability, and corporate financial priorities are more concerned with quarterly reports than long-term efficiencies.
  - The <u>plant</u> is incentivized for dispatchability, and <u>corporate</u> for cutting costs, whereas long-term efficiency (and true savings) are overshadowed in the metrics, because they are not as immediate and dramatic enough for quarterly reports to Wall Street. (Much of this equipment has been in place for 30-50 years. Maintenance decisions/restrictions based on short-term goals is penny-wise and pound foolish and will jeopardize the survival of a plant and associated jobs and reliable availability.)
  - It is critical that those running the equipment at the plant are allowed to the make engineering and maintenance decisions that ensure real and lasting efficiencies (…not the accountants.)
  - I've been to numerous plants with leakage issues that in their words were "*<u>urgent</u>*," but they couldn't get the money. Unfortunately, two of the plants finally got the money. I say unfortunately, because it was only after each unit was taken offline due to leakage issues, one that caused a fire and had the unit offline for three months (during the polar vortex!), and the other unit kept tripping. In the end they both spent the money, but not until they experienced equipment damage and extensive opportunity costs.
  - Publically traded industrial companies get the value of long-term efficiencies because they understand it reduces their cost of doing business and improves margins (Wall Street loves that). One client's maintenance budget is increased in accordance with improved efficiency. It's how they continually reduce overall costs. Perhaps plants could be rewarded in bonuses and increased budgets for every 100 Btu/kWh improvement in heat rate with a share of the savings in fuel costs. For instance, if a plant reduces their heat rate from 10,400 Btu/kWh to 10,100 Btu/kWh. Realizing a 2.75% improvement in fuel consumption, the plant would cut their fuel costs by $3,535,231 (at $75/ton delivered). What would be the impact if the plant was allowed to reinvest half of that savings?
- **Time** -
  - The number of the people required to get the job done has been cut in half over the years, while the equipment (and complexity) they have to manage and maintain, has multiplied. They've been forced to operate in a reactionary mode. These constraints make it difficult to address the details and get the all the required work done as needed.

However there's a major game-changer in the mix, MATS. With emissions' allowances tied to BTU's generated, <u>reducing through-put is critical</u>. And with the restriction of greenhouse gases being proposed under Section 111(d) of the Clean Air Act, efficiency improvements will have a direct impact on CO_2 emissions. This is while every viable plant has been increasing their heat rate by adding air pollution control equipment (APC).



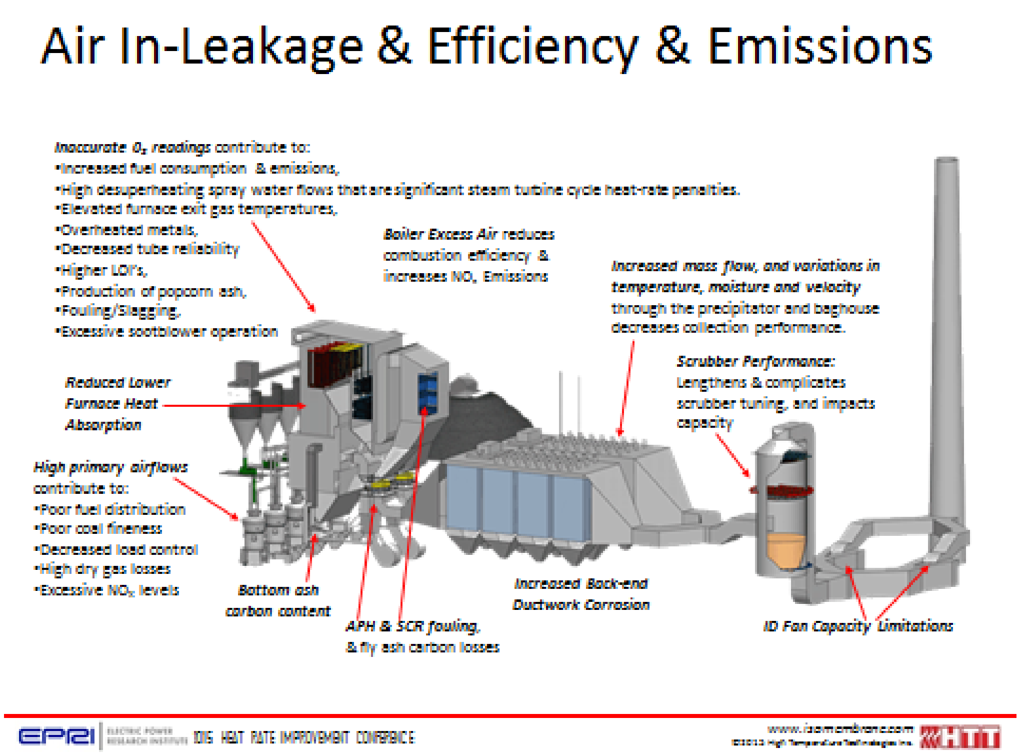
Increased Compliance, Increased Challenges

The EPA recently stated in reference to proposed rule under Section 111(d) of the Clean Air Act, that speculates total heat rate improvements in the range of 4% to 12% could be achieved. 12% is a huge stretch. 4% is achievable for many plants. The EPA said, "the total of the estimated potential heat rate improvements from adoption of best practices to reduce heat rate variability and implementation of equipment upgrades is 6%."

I was recently at conference where the COO of Midwest utility said, "If I had a plant in my system today, where I could get another 6% efficiency improvement, that Plant Manager would be fired because he should have already made those changes sooner." Well the problem with that is, as discussed earlier, many at the plants, due to limited budgets, are unable to address many of the issues that would improve heat rate.

Air In-Leakage & Efficiency & Emissions

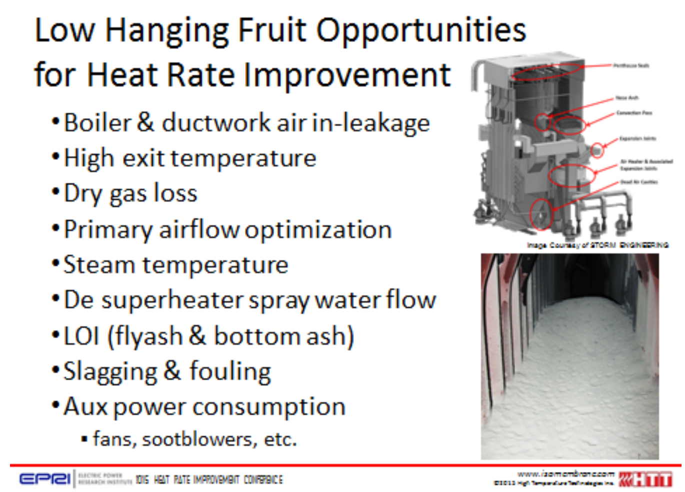
Air in-leakage will result in unit heat rate penalties.



1. Excess oxygen measured at the O_2 sensors, contributes to;
   - Higher fuel consumption
   - An oxygen starved furnace
   - Increased flyash carbon loss
   - Reducing environment which can cause accelerated tube wastage and reduced reliability
   - High desuperheating spray water flows
   - Overheated metals
   - Slagging
   - Production of popcorn ash
   - Higher furnace exit gas temperatures
2. Dry gas loss of heated excess air that provides no benefit to combustion
3. Parasitic power consumption
   - Increased I.D. fan horsepower to move tramp air, potential capacity limitations
   - Increased sootblowing requirements
4. Emissions performance
   - Boiler excess air increases NOx emissions
   - SCR & APH fouling
   - Increased mass flow, and variations in temperature, moisture and velocity through the precipitator and baghouse decreases collection performance
   - Scrubber performance; lengthens & complicates scrubber tuning, and impacts capacity

Low Hanging Fruit Opportunities for Heat Rate Improvement
(but not limited to the following)

- Boiler & ductwork air in-leakage
- High exit temperature
- Dry gas loss
- Primary airflow optimization
- Steam temperature
- De superheater spray water flow
- LOI (flyash & bottom ash)
- Slagging & fouling
- Aux power consumption (fans, sootblowers, etc.)



There are a wealth of articles and resources that discuss a number of "low hanging fruit" fundamental tactics that have resulted in heat rate improvements upwards of 5%, about 500 Btu/kWh for an average plant. (See Appendix: Reference Materials) Based on our experience, most plants have about 250-350 Btu/kWh sitting on the table that could be addressed by resolving air in-leakage issues alone.

As Sam Korellis covers in his paper, "Range & Applicability of Heat Rate Improvements" (EPRI Document: 3002003457), a meaningful improvement in heat rate can be accomplished, often without need for huge capital expenditure on new technologies, with a recommitment to best operating practices…the fundamentals.

Applying the fundamentals is not just about heat rate. It's about;

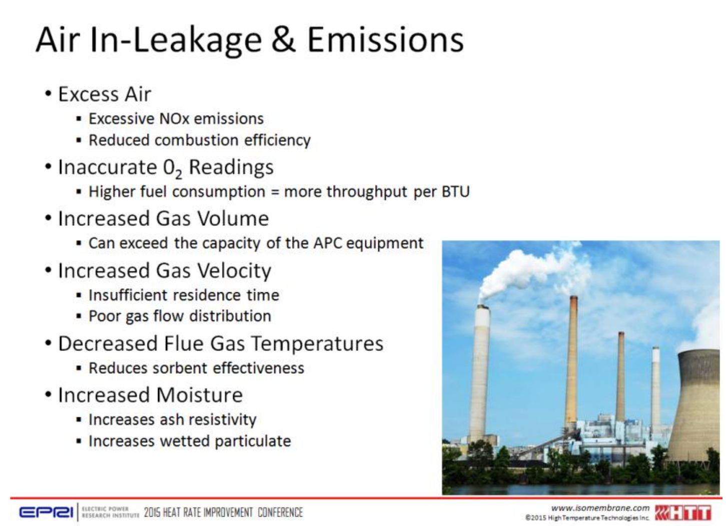
- **Availability via emissions control and reliability.**
- **And ultimately, a specific plant's dispatchability via competiveness.**

There are so many variables that can impact heat rate and emissions, and many that are out of our control. So it is important to control what you can. Controlling air in-leakage is one of the few tactics that can address many, if not all of the listed areas, and as a result can improve heat rate emissions control and operating efficiency. And it is relatively easily, quickly and inexpensively controlled, and in doing so you can improve the stability of 4 of the most volatile emissions variables; gas volume, velocity, temperature & moisture.

It would have been an appropriate first line of defense before engaging in costly large scale projects. Unfortunately many plants have bypassed this step and spent a lot of money on upgrades. However it's not too late. Tightening up can provide added buffer to ensure uninterrupted compliance.

Air In-Leakage & the Flue Gas Path & Emissions
MATS is here, even if you have an extension to 2016. With the regulations establishing specific emissions limits for mercury, particulate matter (PM), acid gases, per BTU generated, it is critical to operate as efficiently as possible. And given the current state of applicable technology, it is the only way to minimize greenhouse gas emissions.

A significant number of facilities have closed or are slated to close because the cost to comply with these regulations is more than they are able, or willing, to bear.



Going forward, compliance will be a critical variable in dispatchability. Non-compliance will result in a $25,000 fine per day until the plant has returned to compliance. Non-compliance may result in a forced outage for many plants. Some utilities have set the guidelines that if a plant goes out of compliance they have 2 hours to identify and correct the problem, or they will be shut down. Some utilities have stated plants that go out of compliance have to come offline immediately. It's mighty hard to identify and correct a problem when you are offline. And those plants' EFOR numbers aren't going to look so great either.

Here are just some of the impacts air in-leakage has on emissions:

Air In-Leakage, the Flue Gas Path & Emissions

Excess Air

- Excessive NOx emissions
- Reduced combustion efficiency

Inaccurate 0_2 Readings

- Higher fuel consumption = more throughput per BTU

Increased Gas Volume

- Can exceed the capacity of the APC equipment
- ESP collection efficiency is exponentially related to gas volume. A small change in gas volume results in a large reduction in collection efficiency
- Baghouse: increases the air/gas to cloth ratio reducing collection efficiency

Increased Gas Velocity

- Insufficient residence time required by the APC equipment
- Poor gas flow distribution
- Baghouse: can decrease bag service life, increase probability of bag failure, and/or allow flue gas blow-by.

Decreased Flue Gas Temperatures

- ESP: Changes the resistivity of the ash and ash resistivity impacts rapping which increases PM emissions
- Reduces sorbent effectiveness, alters the ability of activated carbon or other additives to mitigate Hg
- Increase the potential for dew point corrosion throughout the back-end

Increased Moisture

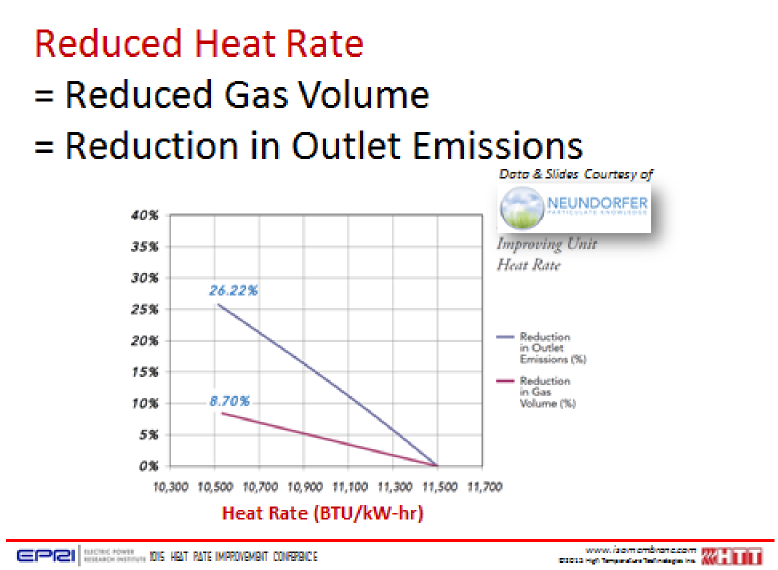
- ESP: Increases ash resistivity, reducing particle collection efficiency
- Baghouse: Increases wetted particulate, increasing adhesion and reducing particulate releasability increasing blockage forcing flow to bypass collection
- Baghouse: Increases weight and stress on bags impacting service life

Improving thermal efficiency, air heater performance, and minimizing air in-leakage, are fundamental to optimizing the plant and ensuring regulatory compliance. These factors play a significant role in the gas volume, velocity, distribution, temperature and moisture in the flue gas stream, which in turn has significant impact on air pollution control performance.

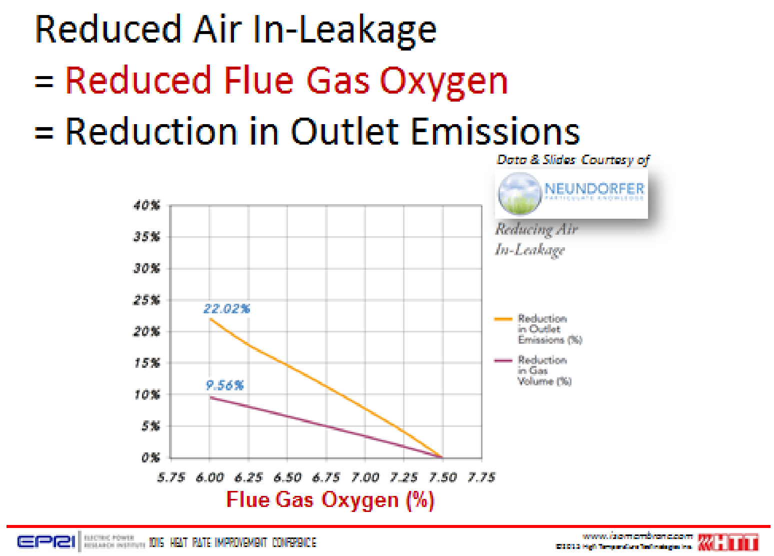
Impact of Heat Rate on Emissions

When evaluating the impact of boiler thermal efficiency or unit heat rate on emissions it is critical to understand that improved heat rate reduces throughput and the total volume of gas that needs to be treated. This is a critical first step in reducing emissions. As the graph demonstrates, the purple line shows an example where a unit's heat rate is reduced from 11,500 to 10,500, reducing the treated gas volume by 8.7%. With the resulting reduced throughput and improvement to ESP performance, a 26% reduction in outlet emissions was realized.

A heat rate improvement that significant today would be very difficult. However, extrapolating from the data one could expect, in this case, a ~16.5% emission reduction for a 600 Btu/kWh (5%) improvement, or a ~11% emissions reduction for a 400 Btu/kWh (~3.5%) improvement

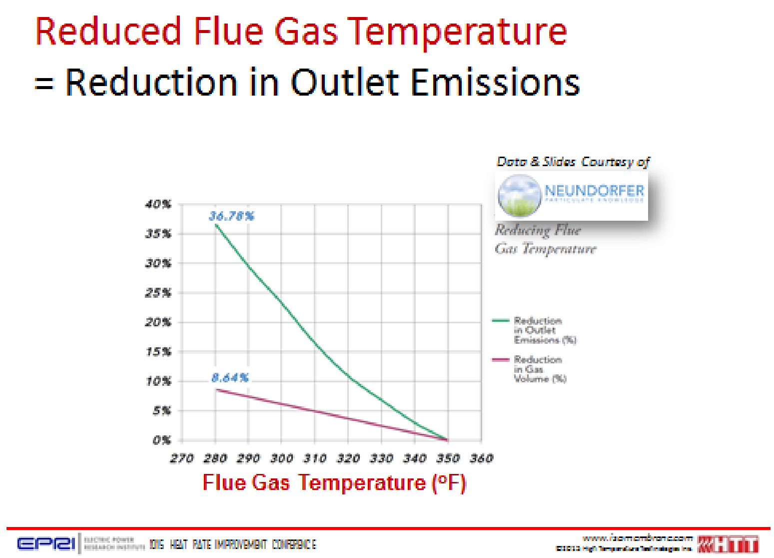


Impact of Air In-Leakage on O_2 & Emissions
Next let's look at air in-leakage and its effect on oxygen levels. As the graph demonstrates, the purple line shows an example where reducing the O_2 concentration to the stack from 7.5% to 6% reduces the treated gas volume by 9.5%, resulting in a 22% reduction in outlet emissions.

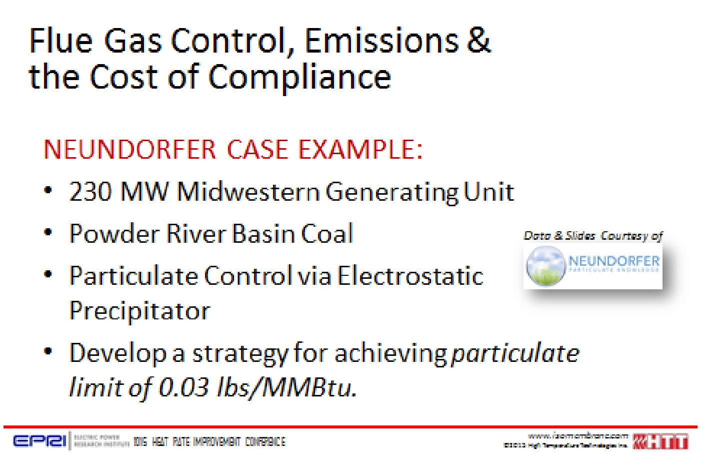


Impact of Flue Gas Temperature on Emissions
Reducing flue gas temperature can have significant impact on emissions. As the graph demonstrates, the purple line shows an example as flue gas temperature is reduced from 350˚ to 280˚, the gas volume is reduced by about 8.6%. In addition to reducing the gas volume, ash resistivity and ESP performance are very sensitive to flue gas temperature. So by controlling flue gas temperature, in this case, outlet emissions are reduced by over 36%.

Additionally, any reduction in gas volume, should also reduce the volume of sorbent, and other additives required, reducing consumable costs.



Flue Gas Control, Emissions & the Cost of Compliance
An interesting project was completed by Neundorfer, Inc., the precipitator and baghouse experts that demonstrates the value of a holistic approach, instead of focusing on just the air pollution control equipment. They were tasked by a Midwestern plant to develop a strategy to ensure the plant would maintain MATS compliance with a safe particulate limit margin. The boiler is a 230 MW unit, burning powder River Basin (PRB) coal, with particulate control via an electrostatic precipitator (ESP). Their particulate emissions were 0.0578 (lbs/MMBtu), almost twice the allowable limit under MATS.



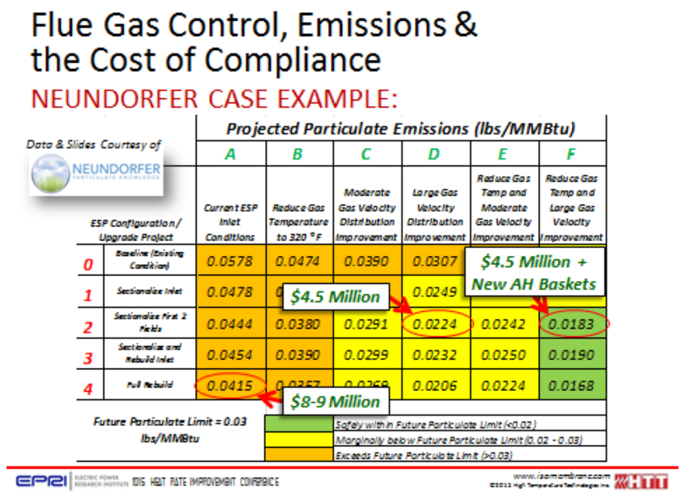
They considered a number of tactics to achieve this goal, from upgrading the ESP to optimizing the ESP flue gas conditions. (see chart)
First, several stages of ESP upgrades were considered:

1. Sectionalize the inlet
2. Sectionalize the first 2 fields
3. Sectionalize and rebuild Inlet
4. Full Rebuild

However, none of these ESP tactics would bring them into compliance; much less give them a safety margin that would ensure uninterrupted availability. The best particulate emission rate they were projected to achieve was 0.0415 lbs/MMBtu with a full rebuild, and the cost of a rebuild was estimated at $8-9 million.

By optimizing the flue gas conditions, by managing gas volume, distribution, velocity and temperature, they knew they could meet the compliance target, with room to spare.
Several stages of flue gas optimizations were considered (reference the chart): ("A" being baseline conditions)

B. Reduce gas temperature to 320°F
C. Moderate improvement in gas velocity distribution
D. Large improvement in gas velocity distribution
E. Reduce gas temperature and moderate improvement in gas velocity
F. Reduce gas temperature and large improvement in gas velocity



A combination of sectionalizing the first 2 fields and making a large improvement to the gas velocity yielded the highest return on investment, with a projected particulate emissions rate of 0.0224 lbs/MMBtu at a cost of approximately $4.5 million. It was identified the PM emissions could be reduced even further to 0.0183 lbs/MMBtu by reducing the temperature with new air heater baskets.

Clearly, managing the flue gas, in combination with making sure the equipment is in good operating condition provides a strategy that saves money, ensures availability, and the greatest ROI.

Cycling, Fractures, Air In-Leakage
The movement of the boiler and the primary materials used to build it are, for lack of a better term, incompatible. The structure needs to be strong, yet as the unit comes up to temperature, that strength is too inflexible to handle the movement. This results in mechanical damage that allows air in-leakage, and jeopardizes unit integrity and heat rate.

- Stress fractures
- Weld cracking
- Refractory failure
- and other failures

Traditional Repair Options
The means to address the material failures are also inadequate as they suffer the same inherent characteristics, inflexibility.

- Weld Repair
- Refractory
- Doing Nothing

The problem with refractory and weld repairs is that they do not typically last. The forces (thermal expansion) responsible for the original casing crack and refractory damage are still present. They are rigid and unable to move with the expansion and contraction associated with the cycling of the boiler.

1. **Weld repairs** are stronger than the surrounding material and when the boiler heats up, the casing cracks once again, typically adjacent to the repair weld.

2. **Refractory** simply begins crumbling again, providing little or no sealing benefit.

Continually utilizing these tactics is an ongoing money & outage time suck, …then they often get deferred. Their lack of reliability ensures repetitive maintenance (which often gets delayed as ash continues to build-up and hurts heat rate), and their lack of predictability can cause sudden spikes in excess air that can jeopardize emissions compliance.

3. **Doing Nothing** – These photos are from an inspection I conducted on December 2, 2013. When I returned to the office, I went through the files and found these photos from an inspection we conducted in February 23, 2007, almost 7 years earlier.

I have yet to work with a plant where not getting something done was a function of people not doing their job. It has always been lack of budget. (consider the earlier example of the plant that lost their baghouse.) Doing nothing is no longer an option if those authorizing the budgets expect a given plant to be available and dispatchable.

These repetitive maintenance issues are universal and have frustrated boiler operators since the implementation of the waterwall tube steam generator. The problem has been that flexible materials that are cost-effective are unable to handle the high heat.
Ultimately, where cracks to manifest themselves, is where the boiler is telling us it needs an expansion joint. Which brings us to a proven flexible sealing system, ISOMEMBRANE®.

ISOMEMBRANE® High Temperature Sealing System
ISOMEMBRANE® is a patented, multi-layered, flexible sealing system designed specifically to solve leakage issues in high-temperature environments that experience cycling and multi-plane movement.

Flexible, Resilient, Adaptable

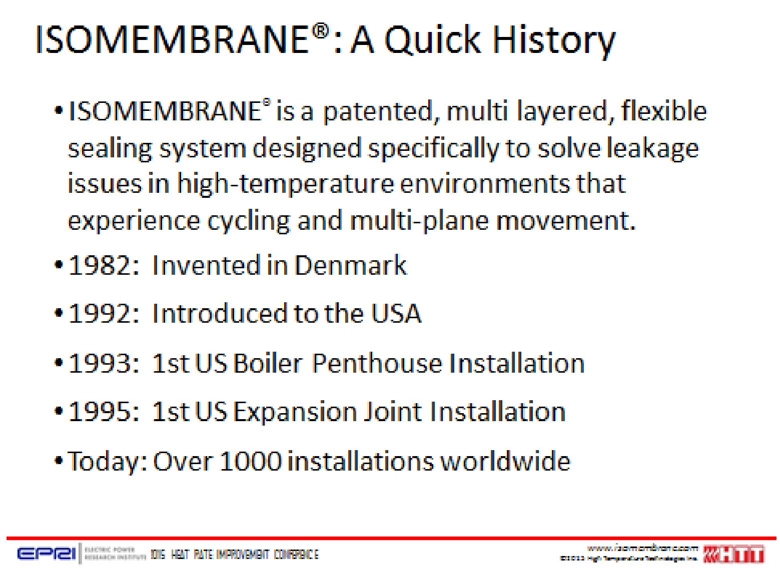
- High temperature threshold (1,800+°F)
- Resilient in multi-plane movement, cycling environments
- Malleable, long-term sealing
- Adaptable in-site fabrication
- No custom engineering details required
- Lowest installed cost
- Budget flexibility
- Fast, cost-effective method to eliminate leakage in dead air spaces and ductwork

With over 1000 installations around the world, ISOMEMBRANE® has proven to solve leakage issues and deliver long-term, maintenance-free service in areas of the boiler & flue gas stream.

- 1982: Invented in Denmark, by a refractory company, Hasle Refractories, established in 1843
- 1992: Introduced to the USA, by a weld repair R-Stamp company, CEM…now High Temperature Technologies, Inc.

Two companies that had essentially an annuity business. Steady repeat business. But ultimately unsatisfying. Their goal was to fix a problem, not temporarily pacify it. Weld repairs and refractory in these applications are commodity options that don't add value.

- 1993: 1st US Boiler Penthouse Installation
- 1995: 1st US Expansion Joint Installation
- Today: Over 1000 installations worldwide delivering reliable, maintenance-free sealing



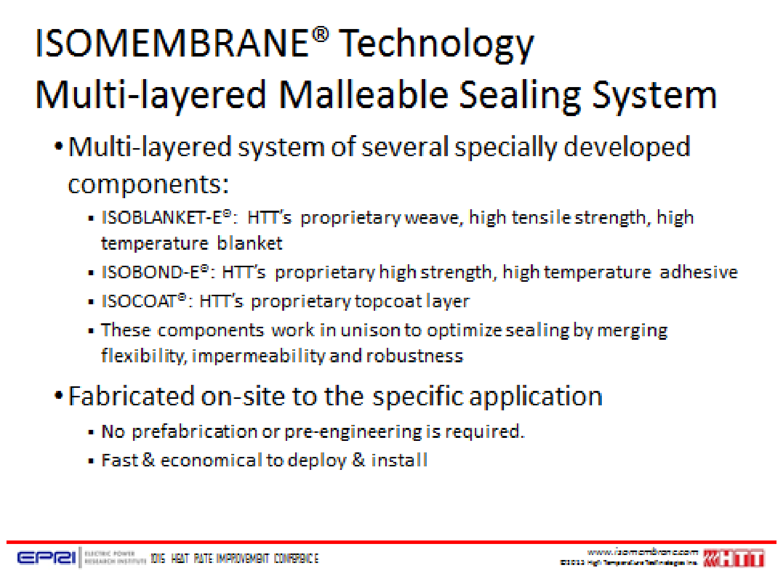
Over 30 years of service experience in Penthouse and other dead air spaces applications has demonstrated that ISOMEMBRANE® delivers crack and penetration sealing service life that typically exceeds 5-10 times the functional life of refractory or weld repairs. We are seeing most ISOMEMBRANE® installations lasting the life of the tubes. Additionally, when ISOMEMBRANE® is utilized to seal a full area, as opposed to patch repairs, most of our customers capitalize the installation. This cannot be done with weld or refractory repairs.

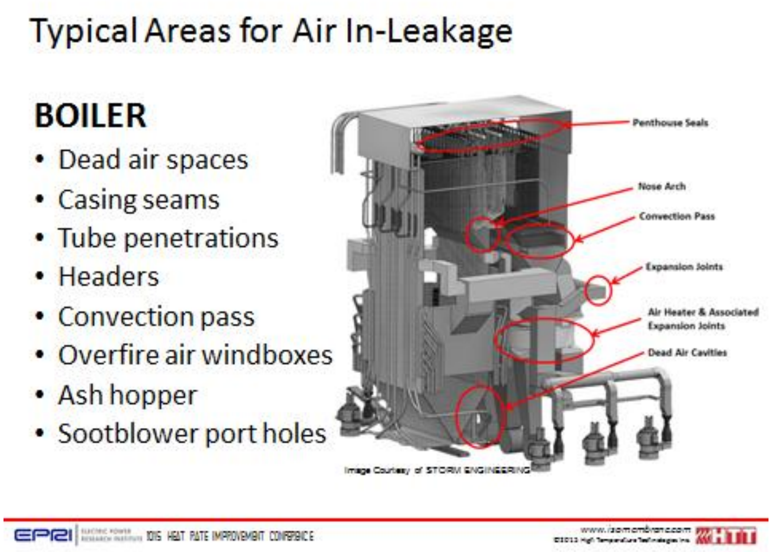
Over 20 years of service experience in expansion joint applications has demonstrated ISOMEMBRANE® consistently provides service life and effectiveness that exceeds OEM type replacement joints.

Why It Works

This system works because several specially designed layered components work in unison to optimize sealing by merging flexibility, impermeability and robustness, making it extremely effective and reliable.

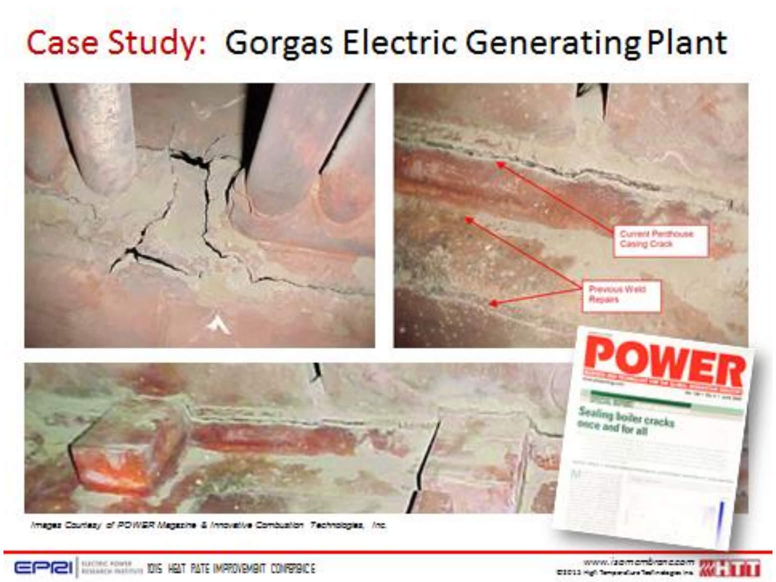
- ISOBLANKET-E®: HTT's proprietary weave, high tensile strength, high temperature blanket
- ISOBOND-E®: HTT's proprietary high strength, high temperature adhesive
- ISOCOAT®: HTT's proprietary topcoat layer
    - These components work in unison to optimize sealing by merging flexibility, impermeability and robustness
- Fabricated on-site to the specific application
    - No prefabrication or pre-engineering is required.
    - Fast & economical to deploy & install

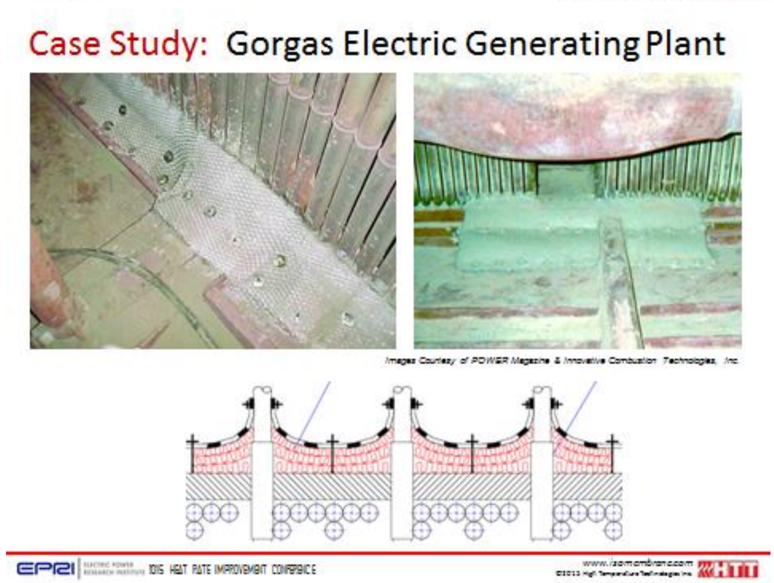




Typical Areas for Air In-Leakage in the boiler:

- Dead air spaces
- Casing seams
- Tube penetrations
- Headers
- Convection pass
- Overfire air windboxes
- Ash hopper
- Sootblower port holes





Case Study: Gorgas Electric Generating Plant – Unit 10 Penthouse

Unit Description : 1972 CE, 788 MW pulverized coal-fired boiler

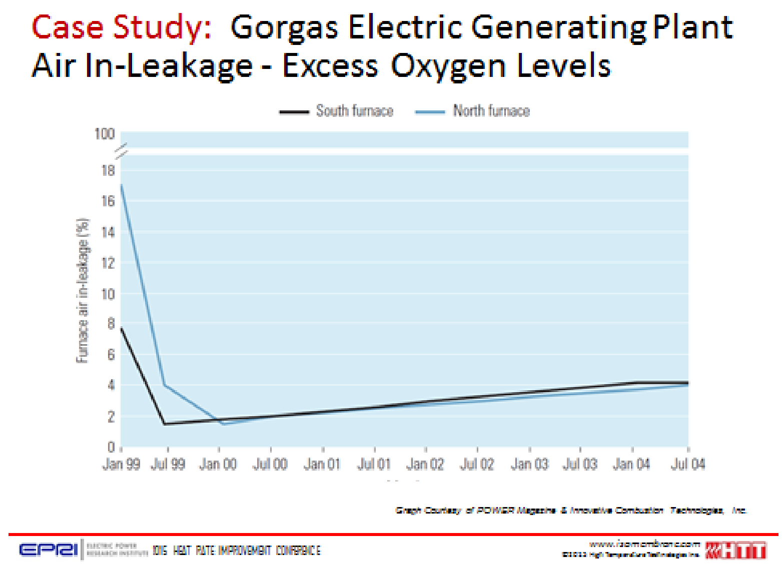
This unit had a history of excessive in-leakage, due in part to the poor condition of the penthouse casing, negatively impacted ID Fan capacity, unit load, and precipitator efficiency (increased precipitator flue gas velocity). Since the mid 80's, outages always included repair of the penthouse casing and refractory.

Most of the cracks were located in the casing around the Pendant Superheat tube penetrations and the area above the convection pass, particularly around the economizer up-leg penetrations. Repairs typically consisted of the addition of non-elastic refractory, either castable or plastic, along with weld repairs to the damaged casing.

In January '99, diagnostic testing revealed that air in-leakage between the furnace exit (nose arch area) and the economizer outlet was excessive, particularly on the boiler "North" furnace. Average unit in-leakage on the "North" furnace was in excess of 17% and the leakage on the South furnace was approximately 12.5%. The difference in the "North" and "South" side leakage was largely due to the presence of a 25' long, 2" to 3" wide crack in the penthouse casing on the "North" side.

Plant Reported Results

Several months later, during the spring 1999 outage, the ISOMEMBRANE sealing system was applied to select penthouse locations to gauge the performance of the sealing technology. The system was installed in areas with the most significant casing damage, specifically, along the 25' long crack above the convection pass and between tube penetrations on the Pendant Superheater.



After the Spring '99 outage, a series of follow up tests (furnace HVT traverses and economizer outlet gas species traverses) were performed to gauge the effectiveness of the sealing system. Results of the traverses revealed that air infiltration had been significantly reduced, especially on the Boiler "North". Average leakage between the furnace exit and economizer outlet was decreased to only 3.20% (4.28% on the "North", 2.11% on the "South").

Plant personnel were sufficiently pleased with the performance of the repair that additional ISOMEMBRANE was installed in other areas of the penthouse during a (1) week outage in the following Fall. Additional testing in February '00 (approximately 4 months after the Fall outage) revealed average furnace exit to economizer leakage of only 2.05%.

Five years later, as part of a routine unit combustion identification performance assessment, gas species traverses were again performed at the furnace exit and economizer outlet to identify leakage quantities and validate plant excess oxygen indication. Results of the tests in May revealed furnace exit to economizer in-leakage of 4.96%. The graphs illustrate initial improvement in leakage with the addition of the ISOMEMBRANE seal as well as the long-term effectiveness of the system.

Per the chart, leakage increased slightly in the 5 years after the initial ISOMEMBRANE installation, but still within desirable levels. According to the plant, the increase in leakage appeared to be the result of damage to the penthouse casing in areas not currently protected with the ISOMEMBRANE system.

16 Years Later

A recent inspection of the ISOMEMBRANE® found it to be in very good condition, has not required any maintenance, and is continuing to effectively seal the areas where it was installed.

Cost Savings

The operational improvements realized an estimated heat rate reduction of 85 Btu/kWh, a 0.9% improvement. (Note the chart for details.) This improvement, reduction in parasitic power use, and avoiding repetitive maintenance requirements has yielded savings for the plant of around $1.6 million per year.

**(Reduction in ID fan auxiliary horsepower needs resulting in the reduction in mass gas flow, x four 1,000 HP ID fans (10% reduction in mass gas flow requires 25% less horsepower) @ $0.02kWh = ~$367,000)*

Case Study: Gorgas Electric Generating Plant
Cost Savings

Parameter	Quantity	Assumed cost or penalty	Annual saving
Flyash loss on ignition	2% reduction in loss on ignition	24.2 Btu/kWh	$233,400
Lost generation (300-MW de-rate to shed furnace slag)	8 hours/outage; one outage every two months	$35/MWh	$504,000
Reduced auxiliary horsepower for 1,000-hp induced draft fans	Four fans (with 70% capacity factor) x 745 kW saving x 8,760 hours = 18,385 MWh	$0.02/kWh bus bar price	$367,700
Desuperheating reheat spray flows	0.2% heat rate for 1.0% of main steam flow	37.2 Btu/kWh	$359,000
Reduced boiler exit gas temperature	10F reduction	23.25 Btu/kWh	$217,600
Total annual savings			**$1,681,700**

Assumptions: Heat rate = 9,300 Btu/kWh; fuel cost = $50/ton; fuel heating value = 12,000 Btu.

- Avoided annual labor & material cost to repair recurring refractory & penthouse casing cracks.
  - Conventional Procedures $20,000 to $40,000 in materials
  - Man hours (~160 for each repair, $8,000-$10,000).
  - Additional delays and cost associated with vacuuming the penthouse.
- Total cost of the two ISOMEMBRANE® Seals was less than $100,000.

Chart Courtesy of POWER Magazine & Innovative Combustion Technologies, Inc.

ELECTRIC POWER RESEARCH INSTITUTE 2015 HEAT RATE IMPROVEMENT CONFERENCE

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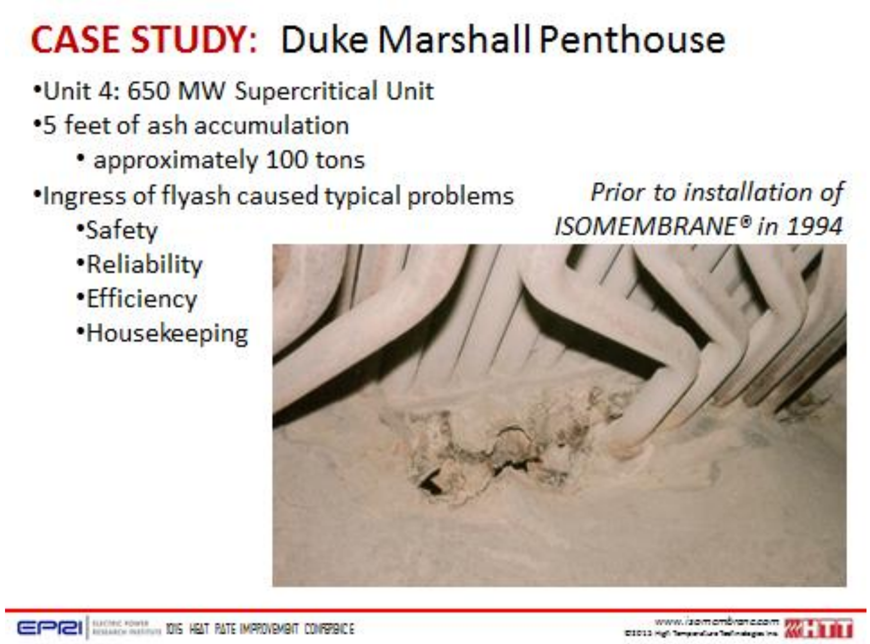


CASE STUDY: Duke Marshall Steam Plant – Unit 4 Penthouse

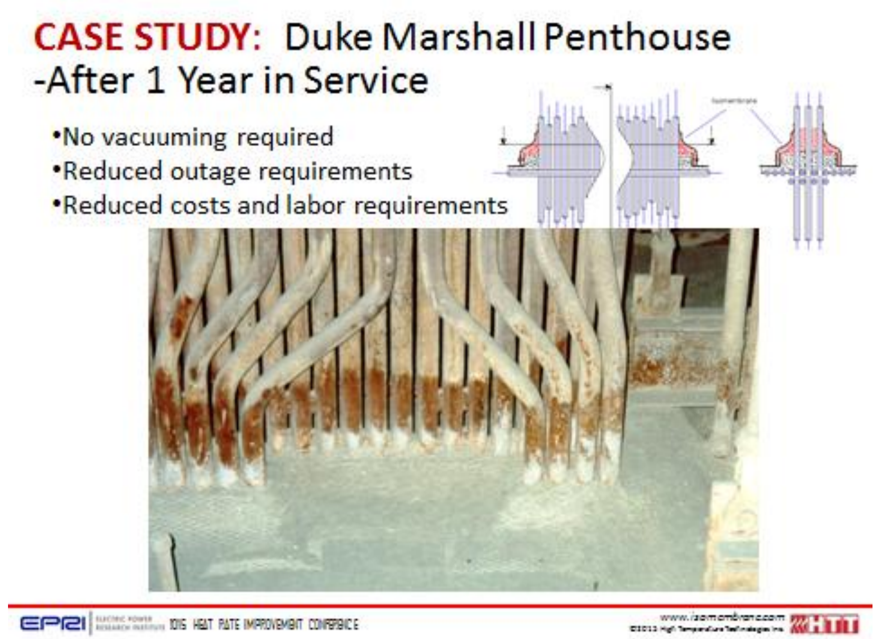
Unit Description : 1970 CE, 650 MW pulverized coal-fired boiler

Deterioration of the original penthouse roof seals resulted in air in-leakage in the penthouse, as evidenced in large accumulations of flyash in the penthouse. Ash dunes of up to five feet in depth were measured. The bulk volume of the flyash in the penthouse approached 100 tons. If a tube leak had occurred, the added weight could have created a dangerous situation.

This ash remained hot, well after shutdown of the boiler, slowing access to conduct repairs. (This can be a huge issue for plants in a forced outage that need access to the penthouse quickly.

Compounding the issue, the specific design of this boiler with two stages of reheat steam, there are more tube penetrations and headers in this penthouse than most boilers. Therefore, ash removal was difficult, time-consuming and expensive.

The air in-leakage through the penthouse casing was practically impossible to arrest at the penthouse boundary. This is because of the many penetrations of steam lines, vents, drains, and the expansion and contraction of the casing for each startup and shut down. These cycles, have left numerous air leak paths through the penthouse casing.



Air in-leakage was causing unit heat rate penalties.

1.) Dry gas loss of heated excess air that provided no benefit to combustion

2.) I.D. fan horsepower was required to remove the additional tramp air

3.) Excess oxygen measured at the oxygen analyzers, resulting in an oxygen starved furnace and increased flyash carbon loss.

The air in-leakage (and associated impacts to heat rate), the ash accumulations, and the inability to gain rapid access to in the event of a tube failure in the penthouse, were the principal justifications for correcting the roof seal leakage. Additionally, there were safety concerns for the maintenance personnel not having to contend with large accumulations of flyash that would hold the heat for days.

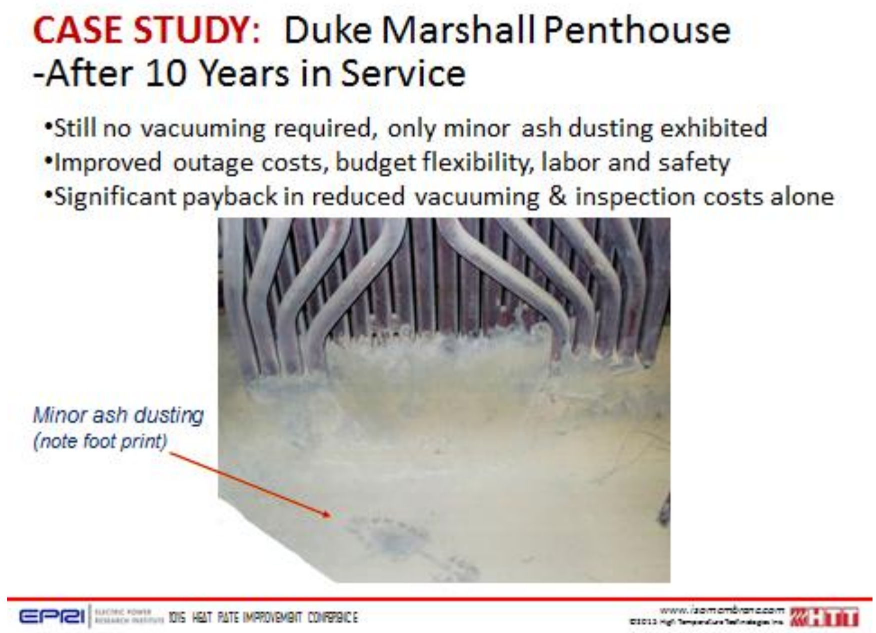
Sealing System Installation

In 1994, ISOMEMBRANE® was installed. In 1995, after 1 year, no vacuuming was required, and the plant was able to divert money and time to other areas previously required for penthouse casing and penetration repairs. The projected savings in maintenance repairs were about $65,000 for vacuuming that was not required, and $80,000 in weld repairs.

<u>10 Years Later</u>

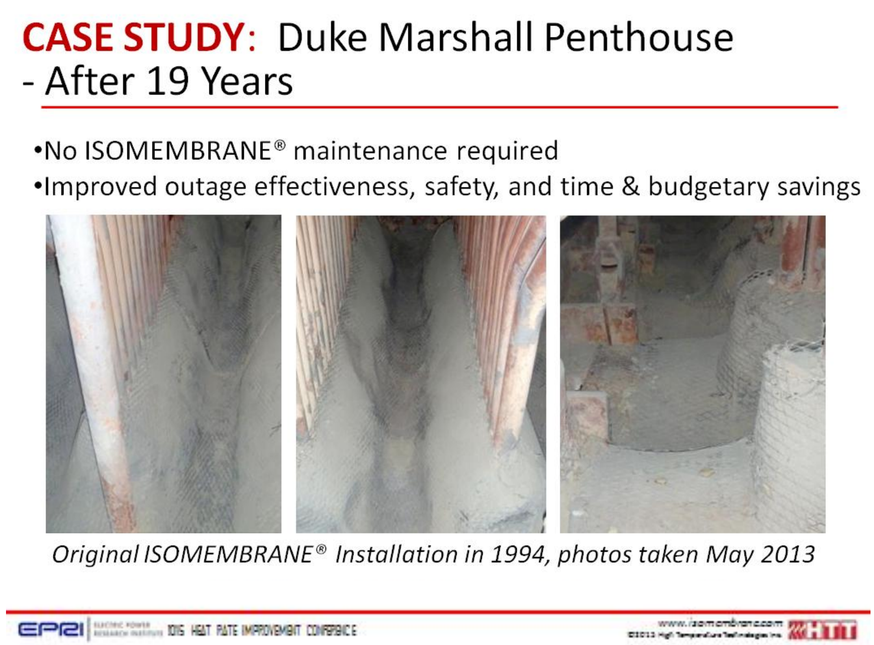
2004 – After 10 years in service the penthouse still remained clean with only a dusting of ash present. (Note the footprint in the photograph.) Aside from the heat rate improvements, the ongoing annual savings have been reduced maintenance costs (approximately $120,000/yr), more expedient repairs (reduced cool down time for repairs in the penthouse), and safety.

In 2008, after 14 years in-service, the plant replaced a large number of platens. At that time we returned to seal the newly installed tube penetrations as the plant wanted another 14 years of maintenance-free service.



<u>19 Years Later</u>

In 2013, we had the opportunity to inspect some of the areas where tubes had not been replaced and found the ISOMEMBRANE® fully intact and sealing.

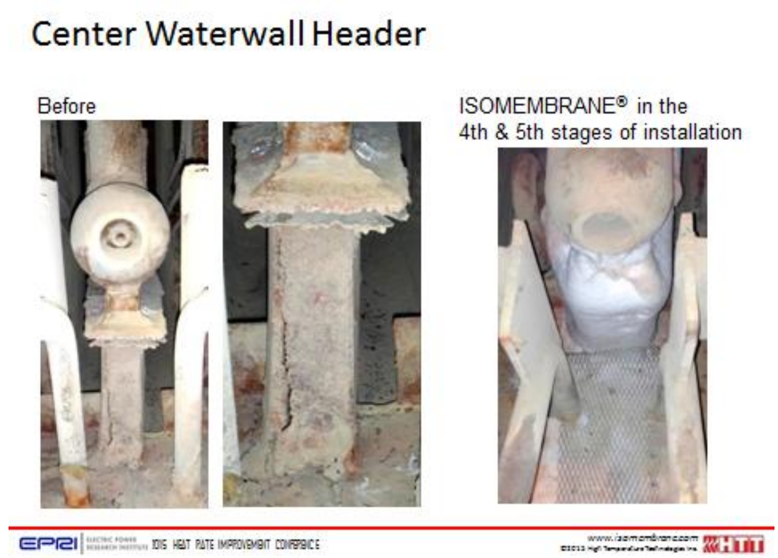


Other Dead Air Space Opportunities to Stop Air In-Leakage

Additionally, there are a several other dead air space applications where flexible sealing provides enhanced reliability.

Center Wall Header.

This is a very common stress point that is prone to failure. It's also an area that is time-consuming to repair. This area had cracking under the header extending about 6 feet along both sides of the bellows, down the casing, and extending about another 8' along the floor from the casing base. The photo shows the ISOMEMBRANE® in the 4th and 5th stages of installation in a 10-stage process. This area was sealed in an 8-hour shift.



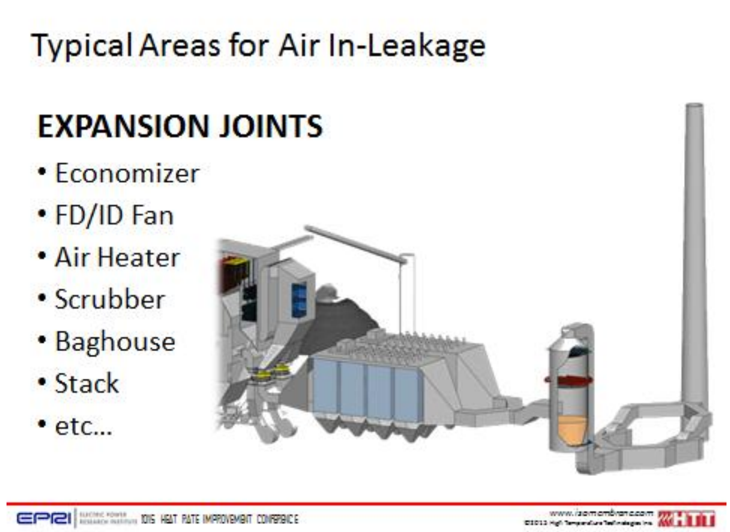
Nose Arch

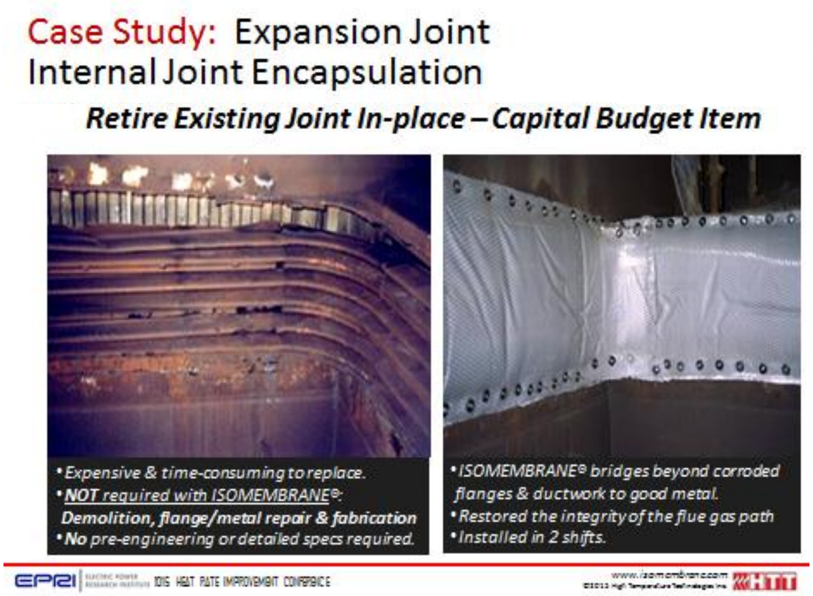
The dissimilar movement of the waterwall panel to the nose arch creates another area prone to leakage.

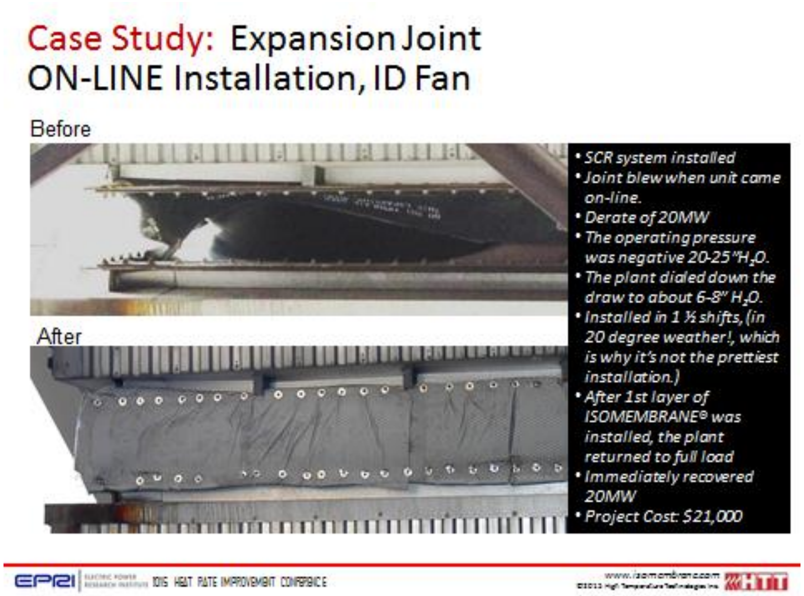
Ash Pit Water Trough Seal/ Coutant Bottom

Trough seals are a common problem area, and their lack of reliability renders them eventually ineffective. In this case, the failed trough seal was allowing excess air, resulting in excess NOx emissions, lower furnace slagging and heat loss out of the bottom of the boiler (impacting safe access to the area).

The maintenance manager stated that all these issues are now resolved and they "have seen a significant reduction in the excess air leakage into the boiler and NOx emissions are controlled." Controlling excess air has also improved boiler efficiency. He added that the ISOMEMBRANE® "has been very reliable and looks the same as when it was first installed."







Expansion Joints

Failed expansion joints pose a real risk to compliance, availability and net generation.

Since the first expansion joint encapsulation 20 years ago, ISOMEMBRANE® has demonstrated that it can consistently provide service life and effectiveness that exceeds OEM type replacement joints. Here are a few ISOMEMBRANE® expansion joint applications that demonstrate opportunities for the plant to restore the integrity of the flue gas path, at lower cost, less plant engineering time and shorter installation time.

ISOMEMBRANE® reduces time and money requirements for several reasons:

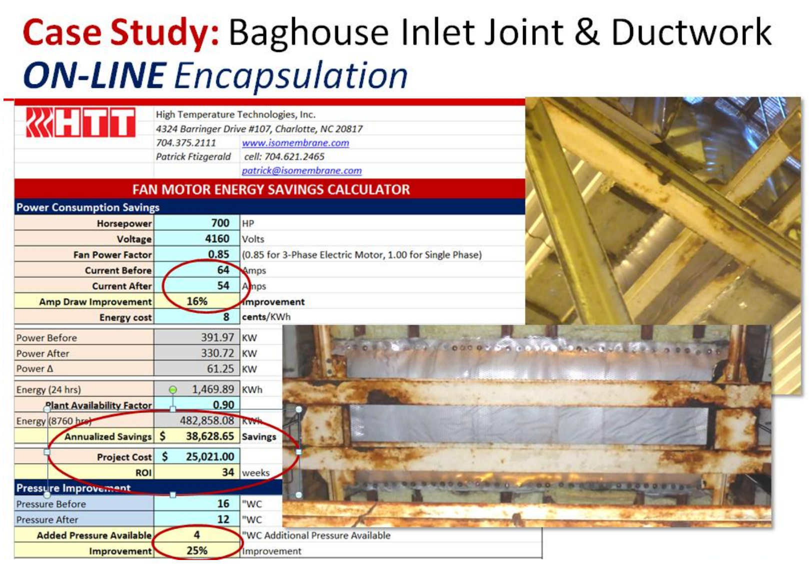
- ISOMEMBRANE® is fabricated on-site, so no pre-engineering is required from the plant - just basic joint dimensions and operating specifications.
- Extensive ductwork and flange repair is unnecessary because the joint can be encapsulated beyond corroded flanges & ductwork to good metal.
- Because the existing joint is encapsulated, demolition and removal is unnecessary.
- An ISOMEMBRANE® joint encapsulation is recognized as a "like-kind" replacement, can be ***capitalized***. The existing joint is simply "retired in place"
- Because ISOMEMBRANE® can be installed internally, scaffolding costs can be reduced significantly.
- Many negative draft joints can be encapsulated while the unit is ***online***, given a safe work environment.

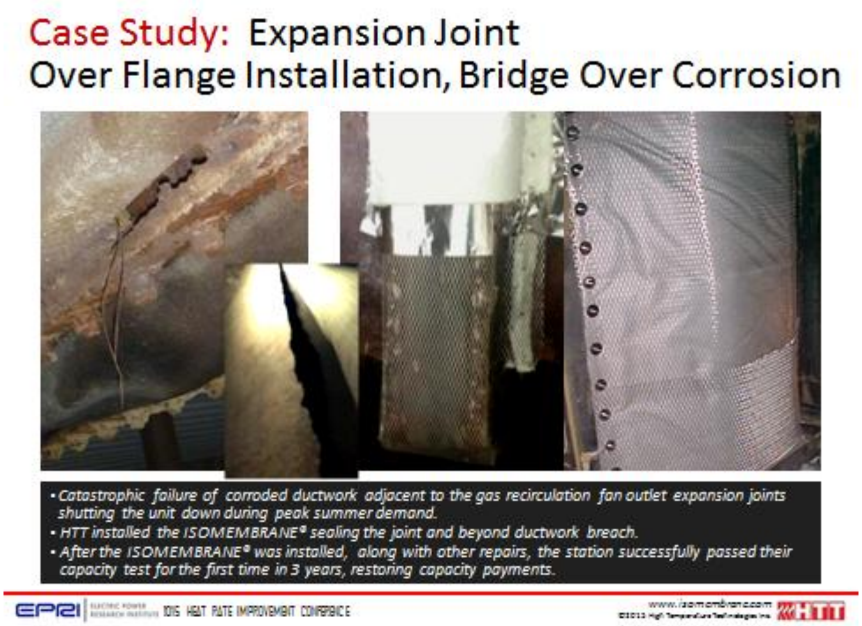
Case Study: 690MW CE Tangential Fired-Coal Boiler

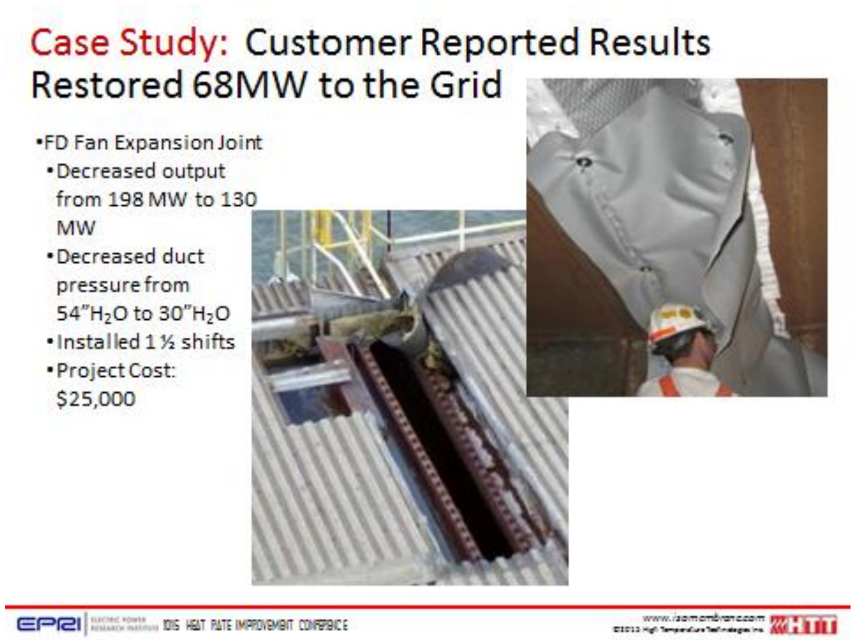
In 2003, the plant had just installed an SCR system. When the unit came online, the variance in pressures caused the ID Fan joint to fail. The failure forced a derate of 20MW and prevented the plant from conducting their acceptance test.

The plant was is a position to take the unit offline. It was determined the encapsulation could be completed safely while the unit was online after the plant dialed down the draw to about 6-8" WC (down from 25"WC). With the draw and an outside temperature of 20^{o}F, it was a challenging work environment. After HTT completed the first layer, the plant was able to return to full load, recovering their lost MW's.

The total job was completed in 1.5 shifts, at a total cost of $21,000. Soon after completion, the plant successfully completed their acceptance test. After 12 years in service, the ISOMEMBRANE® joint encapsulation is providing effective joint function and seal performance.







Case: 53 MW B&W Mass Burn Waste-to-Energy Boiler

This Northeast waste-to-energy was experiencing fan limitations due to a leaking expansion joint and corroded adjacent ductwork upstream of the baghouse inlet. ISOMEMBRANE® was installed over the 12' joint breach and 2 feet beyond either side of the joint, encapsulating the joint and corroded ductwork. The plant immediately noted a decrease in fan pressure from 16"WC to 12"WC, and the amp draw went from 64 amps to 54 amps. Not only did the plant eliminate their fan limitations, it is projected the annual savings in reducing the excess parasitic fan power consumption equals about $38,000/year (@8cents/KWh). The capacity they recovered was worth just under $250,000 the following year. The ISOMEMBRANE® system was installed in 2 shifts. The unit was online during this installation.

Case: 882MW CE Oil-Fired Tangential-Fired Dry Bottom Boiler

This Mid-Atlantic peaking power station experienced a catastrophic failure of the ductwork adjacent to the gas recirculation fan outlet expansion joints, creating a safety issue and forcing an unscheduled outage during peak summer demand. This gas recirculation arrangement has two sets of fans and two identical expansion joints that needed to be addressed. The operating temperature of the joints is 700°F and operating pressure is +6"H_2O.

After the lagging was removed, it was determined the ductwork decay around the flanges extended 12-18" into the ductwork beyond the joint flanges. HTT installed ISOMEMBRANE®, sealing the joint and beyond ductwork breach.

Plant reported results:

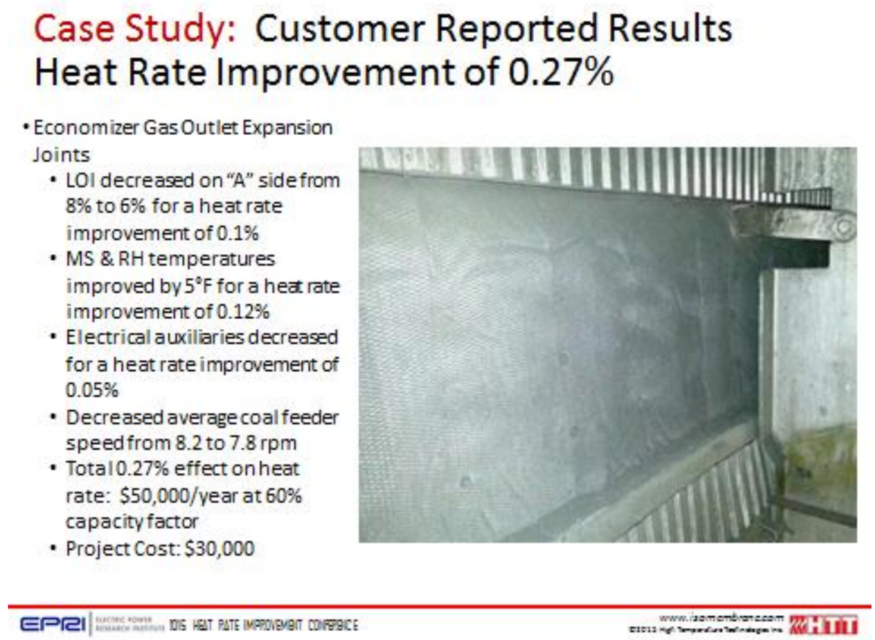
Plant Manager – *"After the ISOMEMBRANE® was installed, combined with other repairs conducted; we successfully passed our capacity test, for the first time in 3 years."*

Case Study: 190MW B&W Wet Bottom Coal-Fired Boiler

This unit was operating at 198 MW when the FD fan expansion joint failed reducing their output 68 MW to 130 MW, forcing the unit offline. The ISOMEMBRANE® installation job was completed in 1.5 shifts. After which the plant returned to full load.

Case Study: 125MW CE Coal Tangential-Fired, operating at 138MW

Here are the customer reported results after they conducted a number of performance tests after an ISOMEMBRANE® encapsulation of the economizer gas outlet expansion joint. They evaluated LOI samples, main steam temperatures, reheat temperatures, draw on electrical auxiliaries, and a variety of other performance parameters.



- LOI decreased on "A" side from 8% to 6% for a heat rate improvement of 0.1%.
- Both main steam and reheat temperatures improved by 5°F for a total heat rate improvement of 0.12%.
- Electrical auxiliaries decreased for an improvement in HR of 0.05%.
- Decreased average coal feeder speed from 8.2 to 7.8 rpm for a fixed load of 138 MW.
- All of these improvements on Boiler 9 total to 0.27% effect on heat rate of $50,000/yr at 60% capacity factor.

<u>Appendix: Reference Materials</u>

- "**Coal-Fired Power Plant Heat Rate Improvement Options, Part 1,"** Sam Korellis. *(POWER Magazine Article)* http://www.powermag.com/coal-fired-power-plant-heat-rate-improvement-options-part-1/
- "**Coal-Fired Power Plant Heat Rate Improvement Options, Part 2,"** Sam Korellis. *(POWER Magazine Article)* http://www.powermag.com/coal-fired-power-plant-heat-rate-improvement-options-part-2/
- **"Range & Applicability of Heat Rate Improvements,"** Sam Korellis. *(EPRI Document: 3002003457)* http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=00000000 3002003457
- **"MATS & The Impact of Air In-Leakage on Emissions"** Patrick T. Fitzgerald. *(Pollution Control Users Group Presentation Summary)* (Available through HTT. patrick@isomembrane.com)
- *"***MACT Compliance: You Might be Closer Than You Think,"** Steve Ostenak, Jeremy Timmons, Dick Storm, John Cavote. http://www.neundorfer.com/compliance.aspx,
- "**Sealing boiler cracks once and for all,"** Henry F. McNeill Jr., David Peppers, Alabama Power. (*POWER Magazine Article)* (Available through HTT. patrick@isomembrane.com)