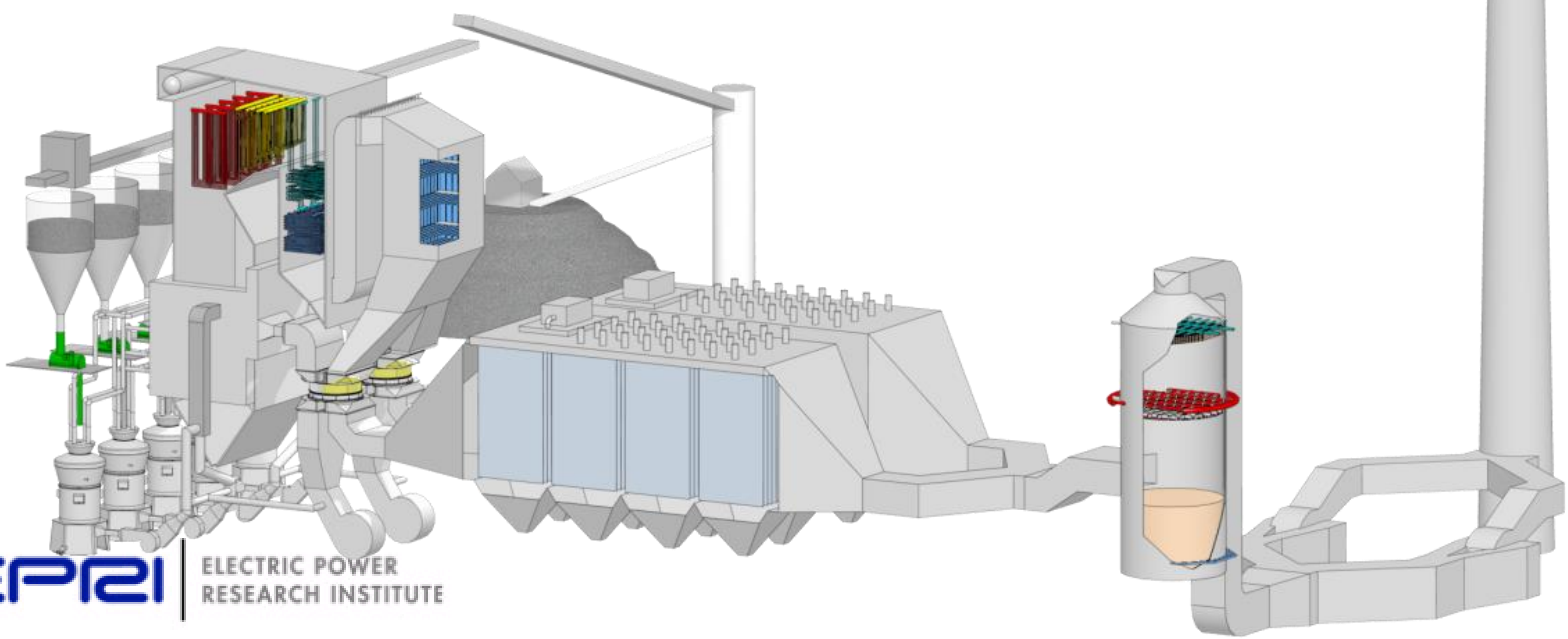
"Typical Opportunities for Heat Rate Improvement Found in Todays PC Plants"

by Shawn Cochran, PE, Richard Storm, PE and Danny Storm



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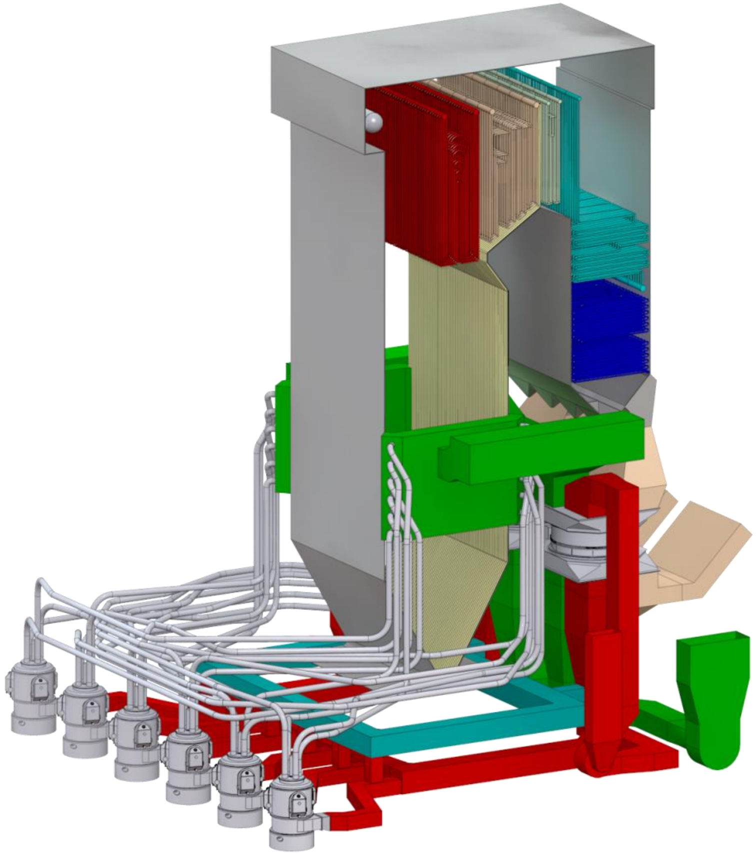
Potential for Heat-Rate Improvement

- The nation's average heat rate is 10,410 Btu/kWhr
- The top five (20)plants average 9,460 Btu/kWhr
  - Although many plants are not designed for a heat rate this low, most plants still have room to improve their heat rate.



Source: Electric Light & Power; Nov/Dec 2014 - Volume 92/06 – Page 21

Some Individual Losses are:

- Dry Gas Loss
- Loss due to moisture in fuel and air
- Loss due to the combustion of hydrogen
- Loss due to unburned carbon (LOI)
- Loss due to air infiltration
- Assumed losses, radiation and convection

Top 20 Coal Plants Ranked by Heat Rate

Table 3: Top 20 Coal Ranked by Heat Rate (2013)*

Rank	Owner/Operator	Plant	State	Capacity MW	Generation GWh	Capacity Factor	Fuel Consumption mmBtu	Heat Rate mmBtu/MWh	2012 Rank
1	AEP	John W. Turk Jr.	AR	609	3,846	72.1%	34,069,108	8.858	
2	First Reserve Corp.	Longview	WV	700	4,457	72.7%	40,623,185	9.115	1
3	Great Plains Energy	Iatan 2	MO	881	6,042	78.3%	55,152,398	9.128	
4	LS Power Group	Sandy Creek	TX	939	3,366	40.9%	30,806,238	9.151	
5	Duke Energy Corp.	Belews Creek	NC	2,270	12,536	63.0%	114,913,240	9.167	2
6	Duke Energy Corp.	Cliffside	NC	1,381	6,220	51.4%	57,064,445	9.174	
7	SCANA Corp.	Cope	SC	415	2,446	67.3%	22,481,012	9.192	4
8	Cleco Power LLC	Brame Energy Center	LA	628	4,042	73.5%	37,893,807	9.376	
9	Duke Energy Corp.	Marshall	NC	2,078	8,360	45.9%	79,052,567	9.456	7
10	NRG Energy Inc.	Keystone	PA	1,700	12,455	83.6%	117,876,401	9.464	8
11	WE Energies	Elm Road	WI	1,268	3,351	30.2%	32,085,709	9.576	
12	LADWP	Intermountain	UT	1,800	12,387	78.6%	119,400,452	9.639	
13	NRG Energy Inc.	Conemaugh	PA	1,700	11,760	79.0%	113,575,163	9.658	11
14	Duke Energy Corp.	W.H. Zimmer	OH	1,300	9,362	82.2%	91,014,788	9.722	
15	Xcel Energy Inc.	Valmont	CO	184	994	61.7%	9,669,147	9.724	18
16	SCANA Corp.	Williams	SC	610	3,344	62.6%	32,517,385	9.725	10
17	CPS Energy	J.K. Spruce	TX	1,340	7,536	64.2%	73,363,174	9.735	15
18	GenOn Energy	Avon Lake	OH	710	2,892	46.5%	28,221,235	9.757	9
19	Associated Electric Cooperative Inc.	New Madrid	MO	1,199	8,194	78.0%	80,128,109	9.779	
20	Southern Co.	Bowen	GA	3,232	12,037	42.5%	118,132,826	9.814	
				Total	**Total**	**Average**	**Total**	**Average**	
		Top 20 Heat Rates		24,944	135,627	63.7%	1,288,040,389	9.46	
		EIA Reporting		306,817	1,548,977	57.6%	16,130,063,115	10.41	

*Excludes cogenerating facilities

Notes:

Most all of these plants are Super-Critical

Source: Electric Light & Power; Nov/Dec 2014 - Volume 92/06 – Page 21

Top 20 Coal Ranked Plants by Generation

Table 1: Top 20 Coal Ranked by Generation (2013)

Rank	Owner/Operator	Plant	State	Capacity MW	Generation GWh	Capacity Factor	Fuel Consumption mmBtu	Heat Rate mmBtu/MWh	2012 Rank
1	Southern Co.	Miller	AL	2,675	20,446	87.2%	211,126,418	10.33	5
2	Southern Co.	Scherer	GA	3,423	20,259	67.6%	209,944,877	10.36	1
3	FirstEnergy	Bruce Mansfield	PA	2,510	17,489	79.5%	176,520,201	10.09	4
4	Duke Energy Corp.	Gibson	IN	3,157	17,331	62.7%	179,536,594	10.36	3
5	Ameren Corp.	Labadie	MO	2,447	17,295	80.7%	176,285,010	10.19	9
6	Salt River Project	Navajo	AZ	2,250	17,132	86.9%	173,630,418	10.14	7
7	DTE Energy Co.	Monroe	MI	3,135	16,183	58.9%	162,733,221	10.06	8
8	AEP	Rockport	IN	2,600	15,808	69.4%	155,975,375	9.87	2
9	AEP	Gen. J. M. Gavin	OH	2,598	15,677	68.9%	158,822,147	10.13	6
10	Luminant	Martin Lake	TX	2,455	15,253	70.9%	167,676,053	10.99	10
11	NRG	W.A. Parish	TX	2,499	15,222	69.5%	160,716,157	10.56	17
12	MidAmerican Energy	Jim Bridger	WY	2,111	14,817	80.1%	152,600,705	10.30	16
13	AEP	John E. Amos	WV	2,900	14,312	56.3%	143,510,896	10.03	19
14	TVA	Cumberland	TN	2,522	13,569	61.4%	138,712,401	10.22	12
15	Westar Energy	Jeffrey	KS	2,179	13,372	70.1%	148,069,363	11.07	
16	AES Corp.	J.M. Stuart	OH	2,308	13,314	65.9%	132,168,644	9.93	
17	PPL Corp.	Ghent	KY	1,932	13,154	77.7%	143,322,094	10.90	
18	NRG	Limestone	TX	1,689	12,872	87.0%	132,375,967	10.28	
19	PPL Corp.	Colstrip	MT	2,094	12,738	69.4%	135,760,144	10.66	
20	FirstEnergy	Harrison	WV	1,984	12,707	73.1%	125,798,231	9.90	
				Total	**Total**	**Average**	**Total**	**Average**	
		Top 20 Generating		49,468	308,950	72.2%	3,185,284,916	10.32	
		EIA Reporting		306,817	1,548,977	57.6%	16,130,063,115	10.41	

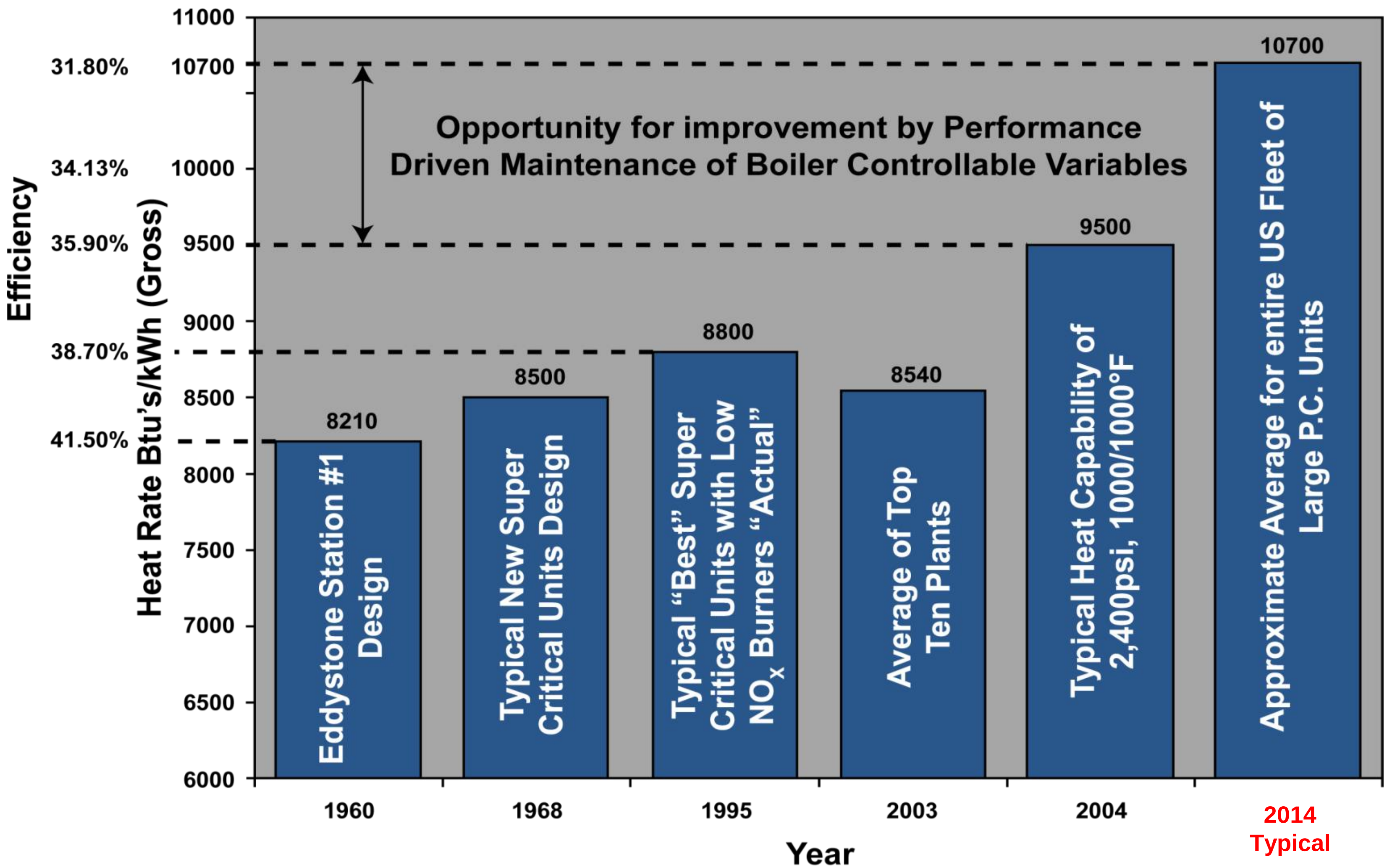
Notes:

Heat Rate Varies from 9,900–11,000 Btu/KwHr

Noted for Room of Improvement

Source: Electric Light & Power; Nov/Dec 2014 - Volume 92/06 – Page 18

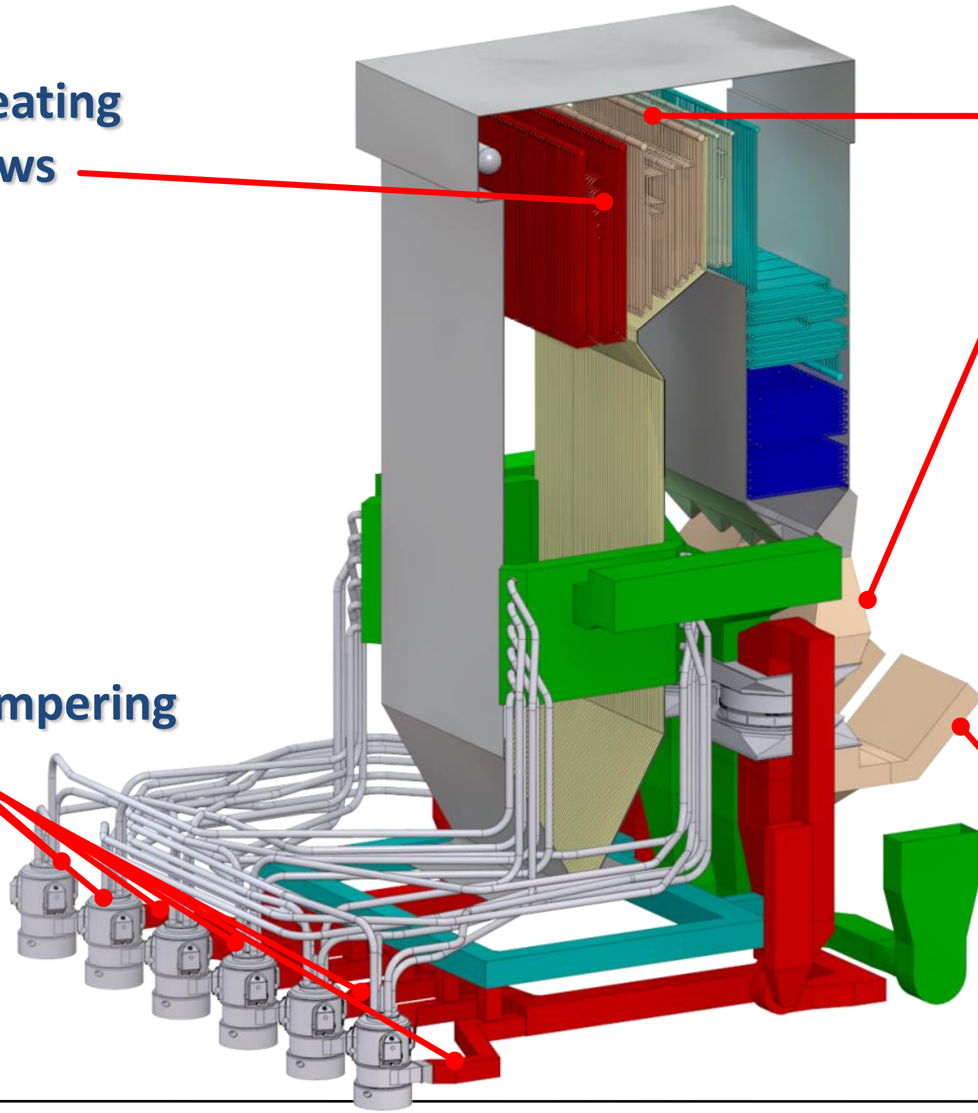
General Heat-Rate by Design and Operation



22 Controllable Heat Rate Factors

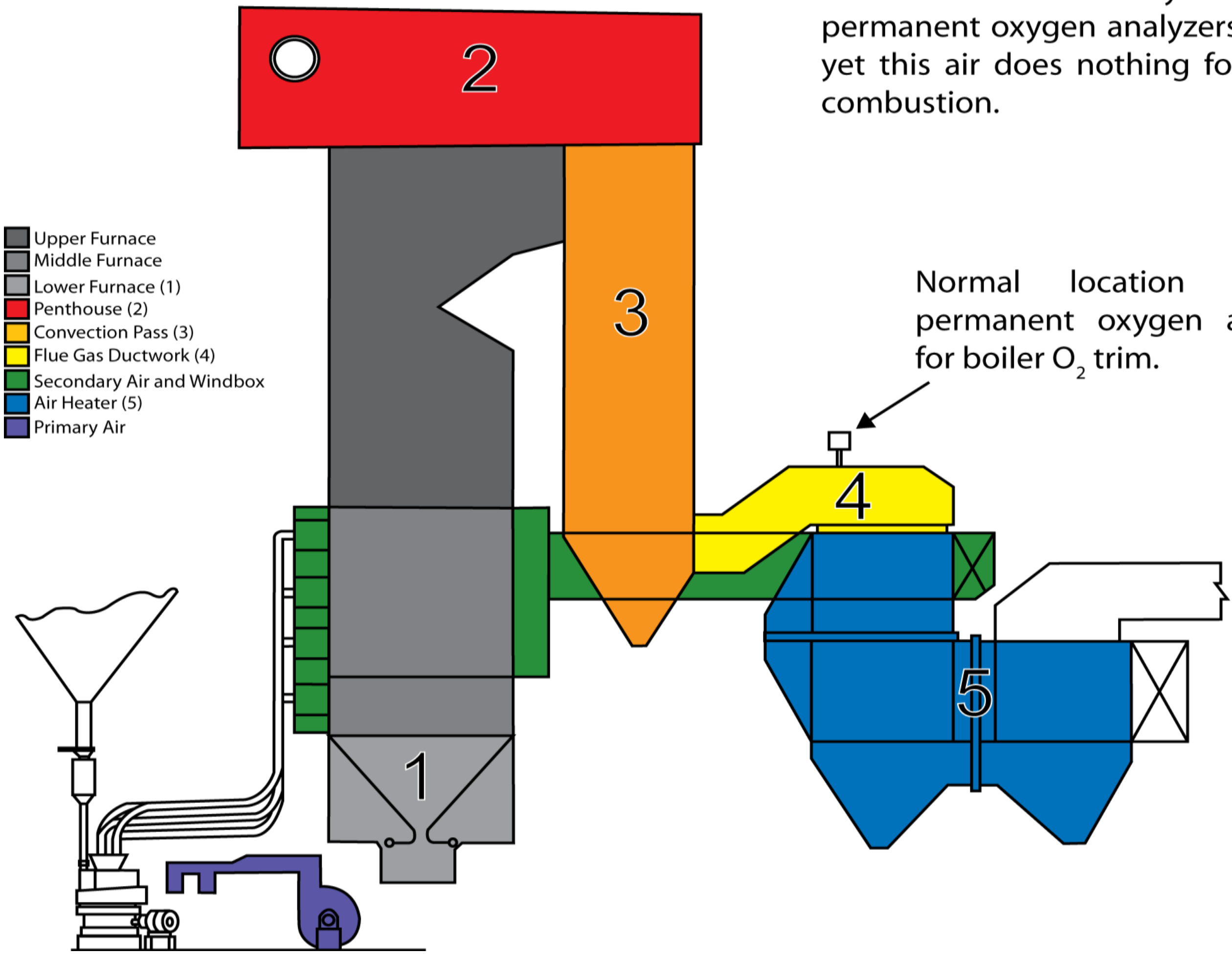
1. Flyash LOI (Carbon Content)
2. Bottom ash carbon content
3. Boiler and ductwork air in-leakage
4. More precise primary airflow measurement and control, by reducing tempering air
5. Reducing pulverizer air in-leakage on suction mills
6. Pulverizer throat size and geometry optimization to reduce coal rejects and compliment operation at lower primary airflows
7. Secondary airflow measurement and control for more precise control of furnace stoichiometry, especially important for low NOx operation
8. Reduction of extremely high upper furnace exit (FEGT) peak temperatures, which contribute to "Popcorn Ash" carryover to the SCR's and ApH's, High spray water flows, Boiler slagging and fouling, and high draft losses due to fouling. The high draft losses cause increased in-leakage, increased fan auxiliary power wastage and increased associated losses with the high spray water flows.
9. High de-superheating spray flow to the superheater
10. High de-superheating spray flow to the reheater
11. High air heater leakage (note: Ljungstrom regenerative airheaters should and can be less than 9% leakage)
12. Airheater Outlet Temperature
13. Superheater outlet temperature
14. Reheater outlet temperature
15. Airheater exit gas temperature, corrected to a "no leakage" basis, and brought to the optimum level.
16. Burner "inputs" turning for lowest possible excess oxygen at the boiler outlet and satisfactory NOx and LOI. Applying the "Thirteen Essentials"
17. Boiler exit (economizer exit) gas temperatures ideally between 650oF to 750° F, with minimal air in-leakage (no dilution!)
18. Cycle losses due to valve leak through – i.e. spray water valves, reheater drains to the condenser, superheater and re-heater drains and vents, and especially any low point drains to the condenser or to the hot well.
19. "Soot blowing" Optimization – or smart soot blowing based on excellence in power plant operation. (Remember, soot blowing medium is a heat rate cost, whether compressed air or steam)
20. Feed water heater level controls and steam cycle attention to detail
21. Steam purity and the costly impact of turbine deposits on heat rate and capacity.
22. Auxiliary power consumption/optimization i.e., fan clearances, duct leakage, fueling primary air system optimization, etc…

Stealth Opportunities



Stealth Heat Rate Loss No. 1: Air In Leakage

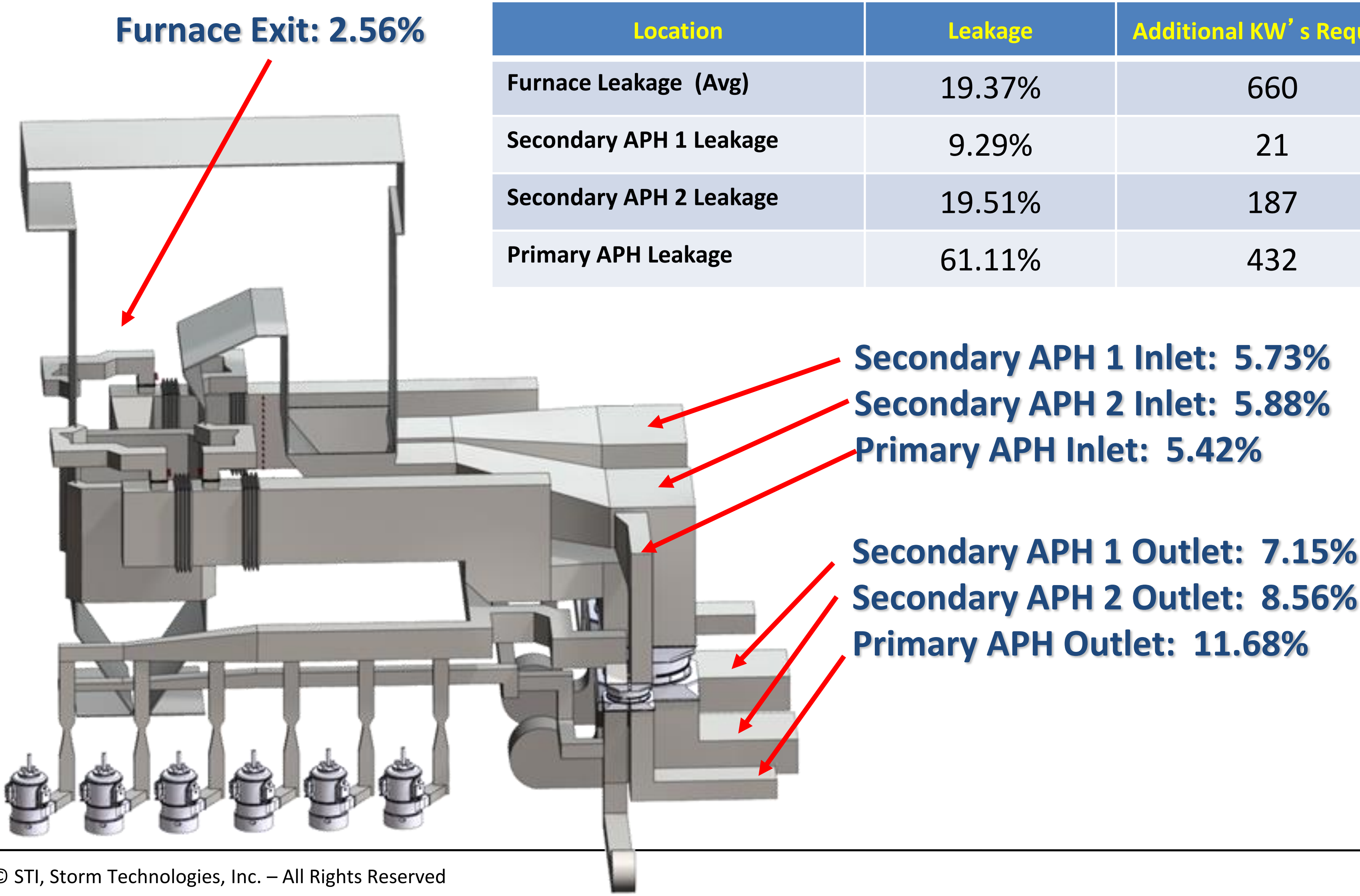
Air in-leakage into zones 2, 3 and 4 are measured by the permanent oxygen analyzers, yet this air does nothing for combustion.



Normal location of the permanent oxygen analyzers for boiler O_2 trim.

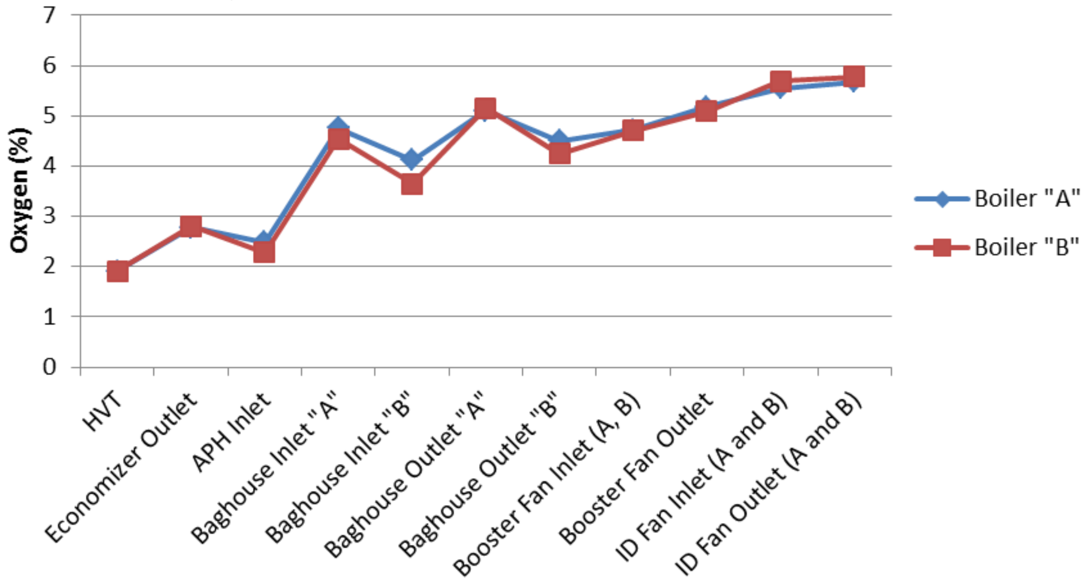
Tracking Oxygen in the Boiler

Location	Leakage	Additional KW's Required
Furnace Leakage (Avg)	19.37%	660
Secondary APH 1 Leakage	9.29%	21
Secondary APH 2 Leakage	19.51%	187
Primary APH Leakage	61.11%	432



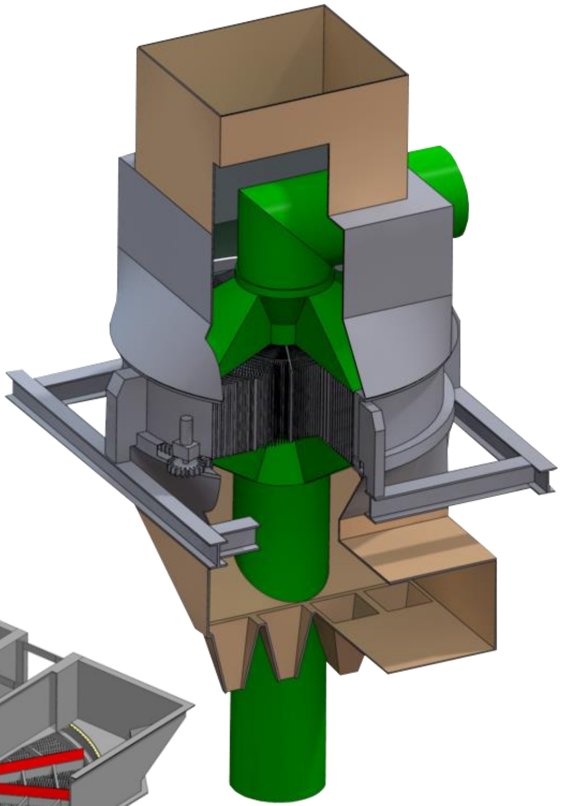
How to Identify Air-In Leakage

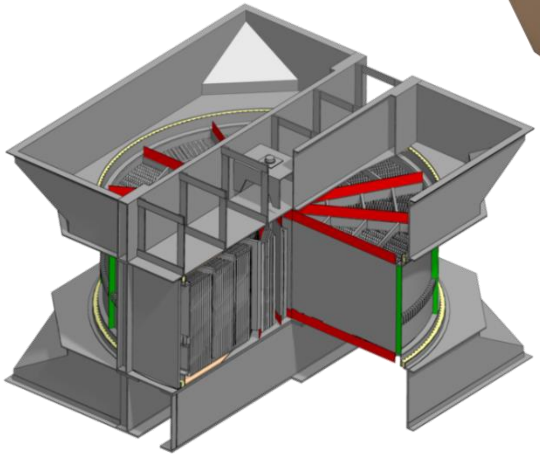
- Obtain good reliable, representative flue gas analyses and then calculate the X-ratio.
- Perform oxygen rise testing from furnace to ID fans.
  - A good test grid is required for accurate data collection and leakage calculations
- Monitor the stack CO_2 or O_2.
- Combine the intelligence and conditions found of boiler inspections with test data, X-ratios and experience.



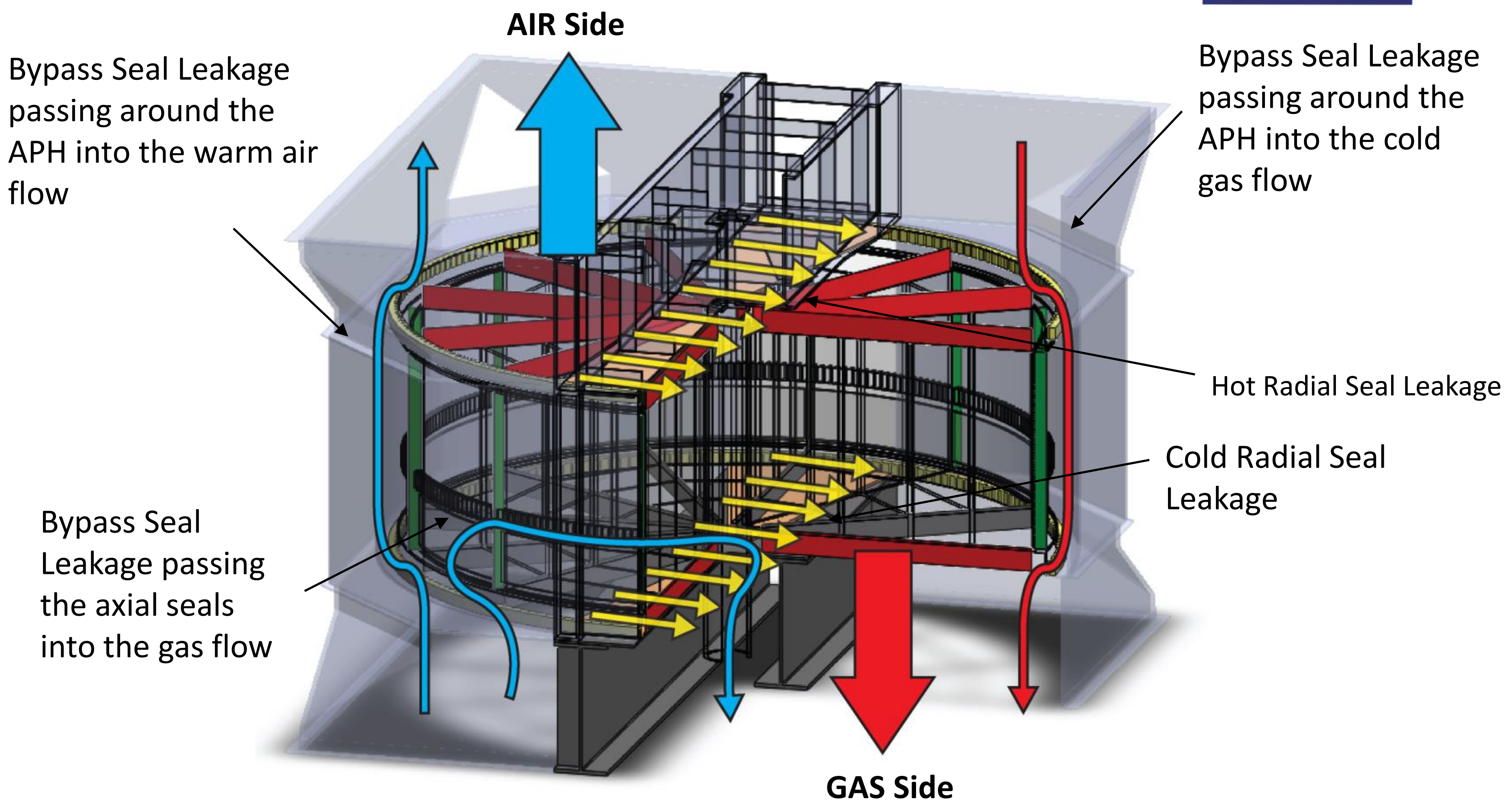
Heat Rate Improvement

- Reduce Secondary Air Heater Leakage
  - Reduce 25-30% down to 12-15%
  - Rothemuhle leakage rates can be reduced by 50%
- Reduce the Secondary Air Heater's Differential
  - Clean APH basket is a must
  - High differential exacerbates both APH leakage & duct in-leakage
  - Compounds auxiliary power consumption loss
- Repair Primary Air Heater Leakage





Regenerative Air Heater (Typical Leakage Areas)



Circumferential leakage through an air heater

Measuring Air Pre-Heater Performance

- Air In-Leakage calculation:

$$\text{Leakage } (\%) = \frac{O_{2\,\text{Out}} - O_{2\,\text{In}}}{20.9 - O_{2\,\text{Out}}} \times 90$$

- Corrected gas outlet temperature:

$$T_{\text{Gas Out Corrected}} = \frac{\%\text{Leakage} \times C_{\text{p Gas}} \times \left(T_{\text{Gas Out}} - \left(60\% \times T_{\text{Air In}} + 40\% \times T_{\text{Gas Out}}\right)\right)}{C_{\text{p Gas}}} + T_{\text{Gas Out}}$$

- Heat transfer efficiency:

$$\text{Heat Transfer Efficiency} = \frac{C_{\text{p Air}} \times \left(T_{\text{Air Out}} - T_{\text{Air, In}}\right) \times \text{Air Mass Flow}}{C_{\text{p Gas}} \times \left(T_{\text{Gas In}} - T_{\text{Gas Out Corrected}}\right) \times \text{Gas Mass Flow Less Leakage}}$$

- X-Ratio:

$$X - Ratio = \frac{T_{gas\ in} - T_{gas\ out(corrected)}}{T_{air\ out} - T_{air\ in}}$$

Opportunities to Minimize Losses

- There are several ways to minimize heat losses:
  - Balance the air and fuel to the burners
  - Properly control, proportion, and stage the air
  - Minimize air in-leakage
- These items are addressed in Storm's "13 Essentials of Optimum Combustion" and "22 Controllable Heat Rate Variables," and can effectively improve heat rate.
- Following are real examples of potential and real performance improvements in several plants that Storm Technologies has visited

Additional Stealth Losses

Steam Cycle Losses:

- High Energy Drains (Valve Leak-by)
- Feed Water Heater emergency drains
- Superheat and Reheat valves and isolation of block valves
- Condenser should be checked regularly. Often 100+ Btu’s can be attributed to drain leakages

STORM®

Specialists in Combustion and Power

Thirteen Essentials of Optimum Combustion for Low NO_x Burners

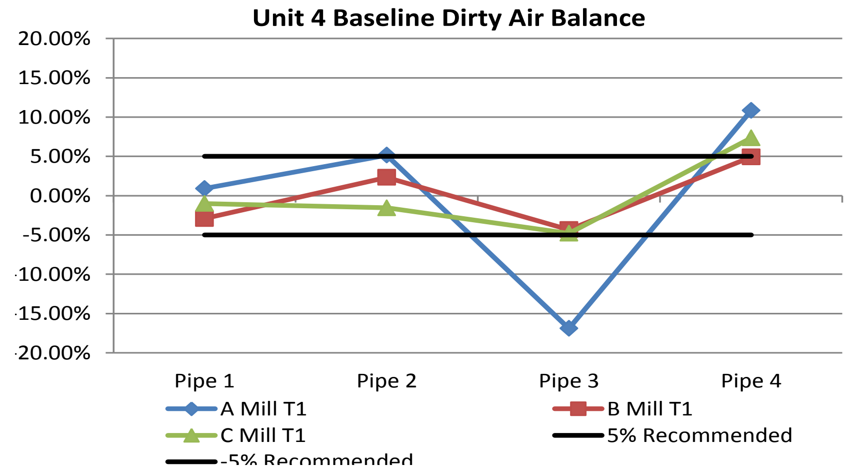
1. Furnace exit must be oxidizing preferably, 3%.
2. Fuel lines balanced to each burner by "Clean Air" test ±2% or better.
3. Fuel lines balanced by "Dirty Air" test, using a Dirty Air Velocity Probe, to ±5% or better.
4. Fuel lines balanced in fuel flow to ±10% or better.
5. Fuel line fineness shall be 75% or more passing a 200 mesh screen. 50 mesh particles shall be less than 0.1%.
6. Primary airflow shall be accurately measured & controlled to ±3% accuracy.
7. Overfire air shall be accurately measured & controlled to ±3% accuracy.
8. Primary air/fuel ratio shall be accurately controlled when above minimum.
9. Fuel line minimum velocities shall be 3,300 fpm.
10. Mechanical tolerances of burners and dampers shall be ±1/4" or better.
11. Secondary air distribution to burners should be within ±5% to ±10%.
12. Fuel feed to the pulverizers should be smooth during load changes and measured and controlled as accurately as possible. Load cell equipped gravimetric feeders are preferred.
13. Fuel feed quality and size should be consistent. Consistent raw coal sizing of feed to pulverizers is a good start.

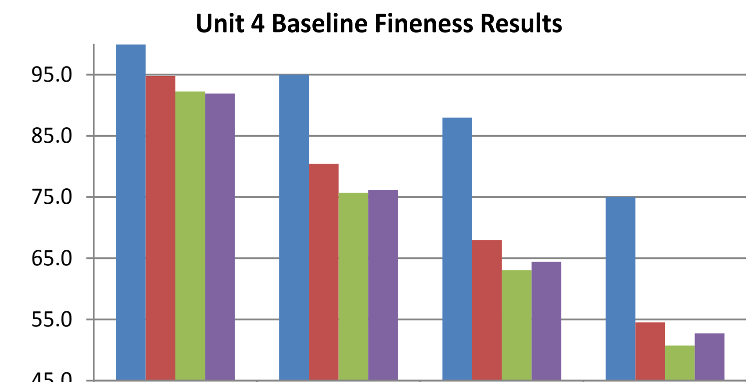
Typical Opportunities Identified for Improvement as a Result of Diagnostic Testing

- Air in-leakage prior to the air heater
- Air heater leakage
- A.H. Exit Gas Temperature (corrected for leakage) higher than design
- High Primary Airflow
- High FEGT and Major Stratifications
- Auxiliary Power is excessive due to high APH differential and air in-leakage
- Unbalanced furnace requires higher total airflow
- Burner tuning issues
- NO_X and/or LOI Improvements

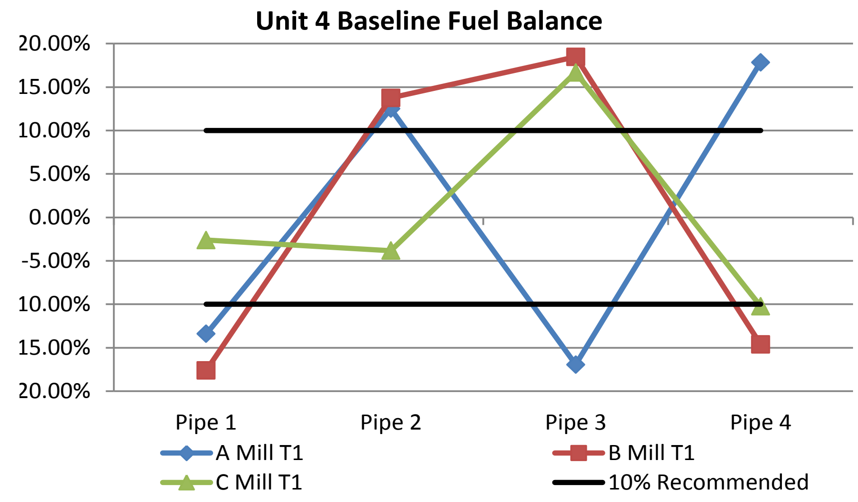
Case Study: Imbalanced Pulverizers

The pulverizers in this unit are not properly balanced. This will result in an uneven burn in the boiler. Also, the coal fineness is to coarse based on our recommendations, causing incomplete combustion. Both of these circumstances result in poor efficiency and a less than optimal heat rate.



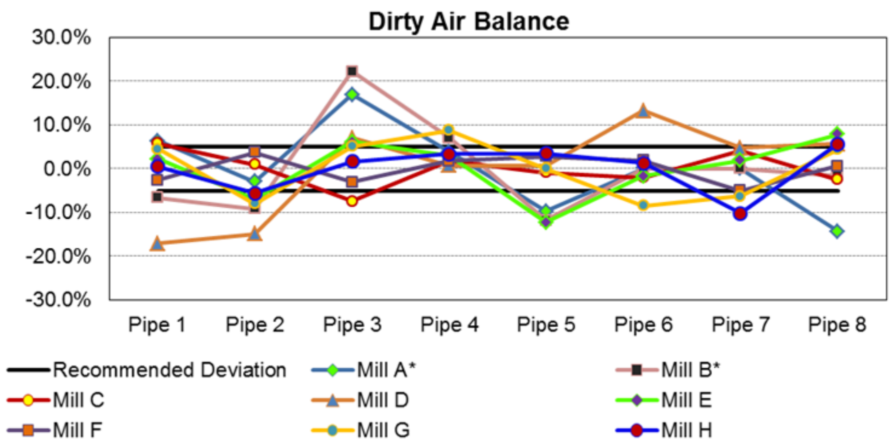


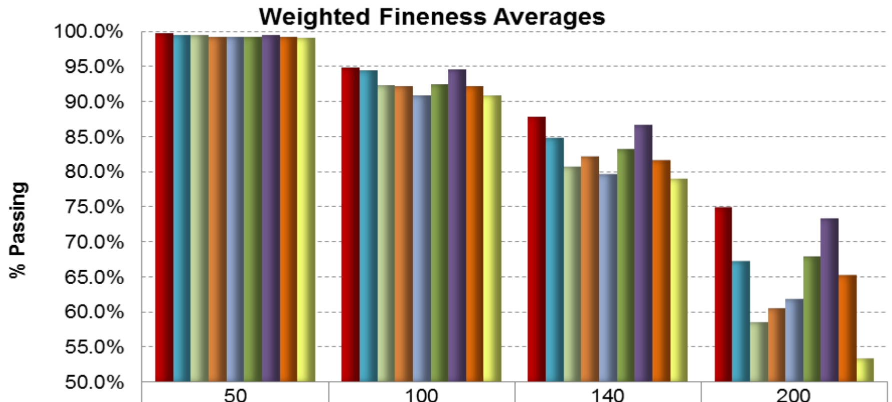
	50 Mesh	100 Mesh	140 Mesh	200 Mesh
Goal	99.9	95	88	75
A Mill T1	94.8	80.5	68.0	54.5
B Mill T1	92.3	75.7	63.1	50.7
C Mill T1	91.9	76.2	64.4	52.7



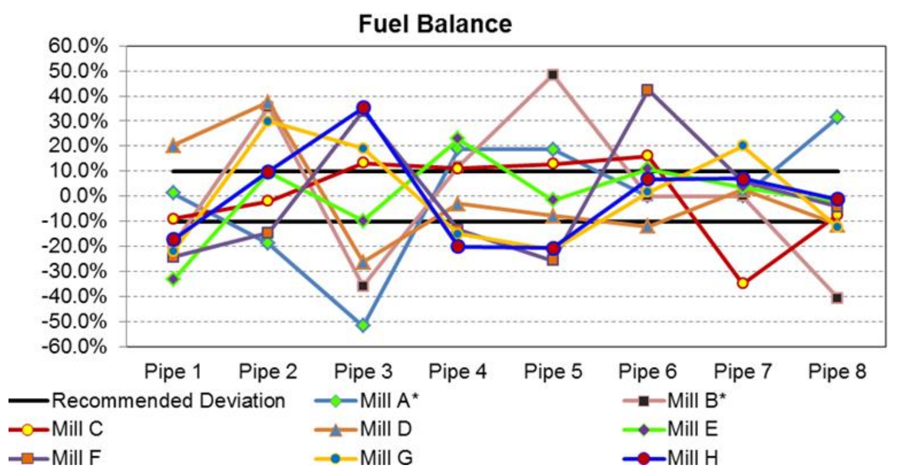
Case Study: Imbalanced Pulverizers

This is another case of imbalanced pulverizers. Balancing the flow through the pipes and increasing the fineness of the coal will effectively impact the overall efficiency of the system and decrease heat rate.



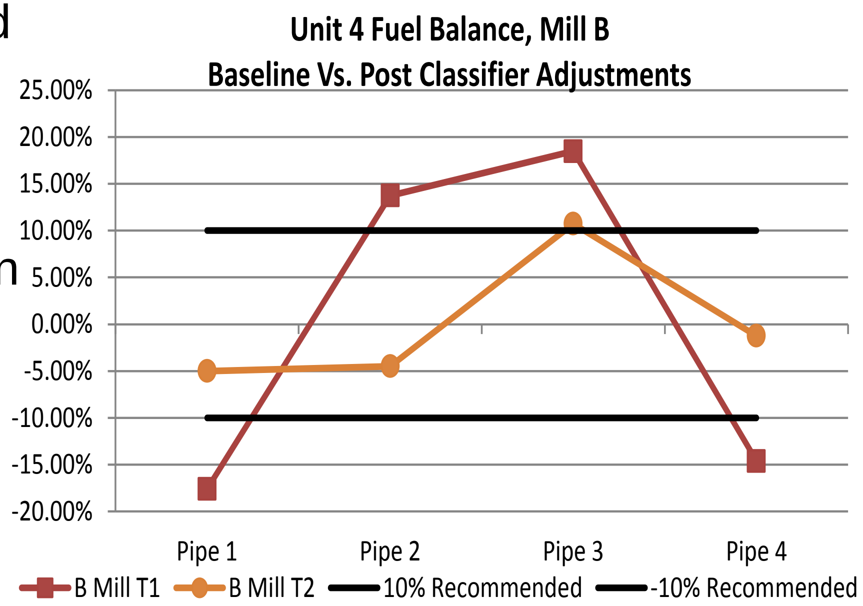


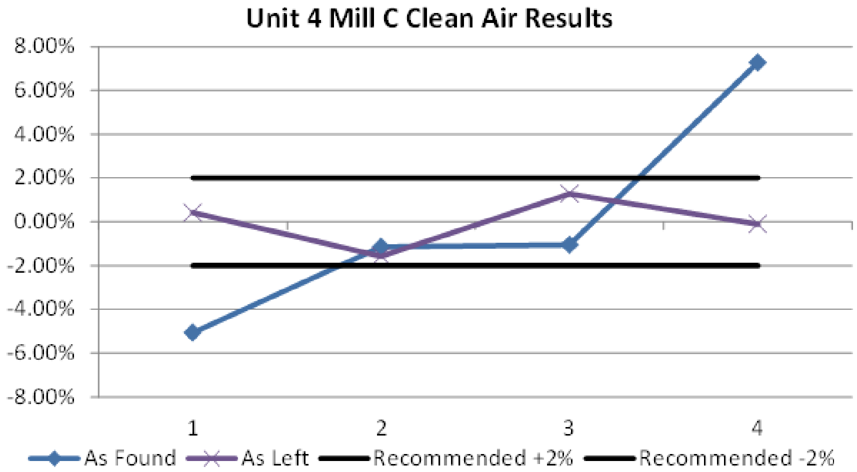
	50	100	140	200
Recommended Fineness	99.9%	95.0%	88.0%	75.0%
Mill A*	99.6%	94.6%	84.9%	67.3%
Mill B*	99.5%	92.5%	80.8%	58.5%
Mill C	99.3%	92.3%	82.3%	60.5%
Mill D	99.3%	91.0%	79.7%	61.9%
Mill E	99.3%	92.5%	83.3%	67.9%
Mill F	99.6%	94.7%	86.7%	73.4%
Mill G	99.4%	92.3%	81.7%	65.3%
Mill H	99.2%	91.1%	79.0%	53.3%

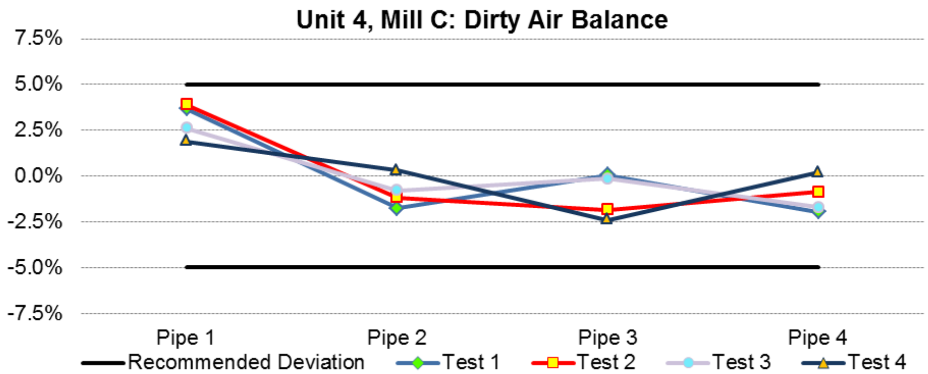


Case Study: Imbalanced Pulverizers

- In both cases, the problem was addressed the same way.
  - Changing the setting of the classifier blades to improve fineness
  - Balancing the primary air, using clean air and dirty air tests for reference.
- The results improved combustion and increased efficiency.

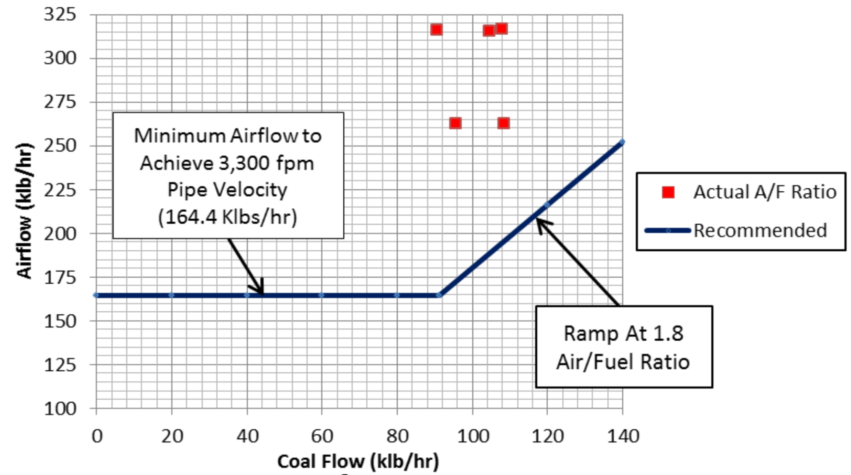




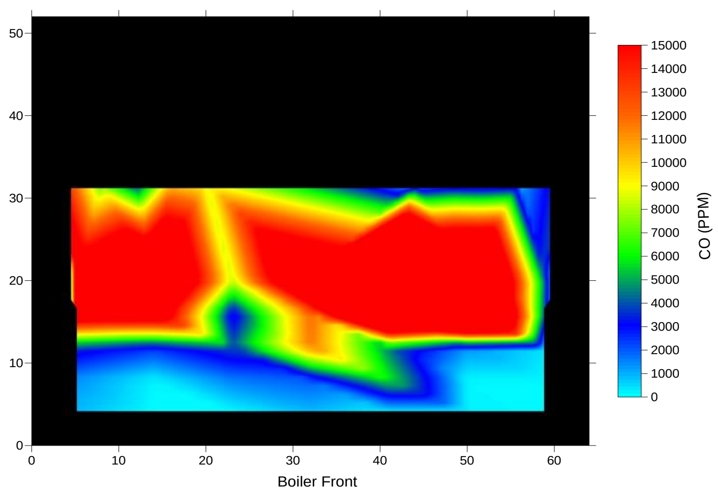


Case Study: Poor Airflow Control

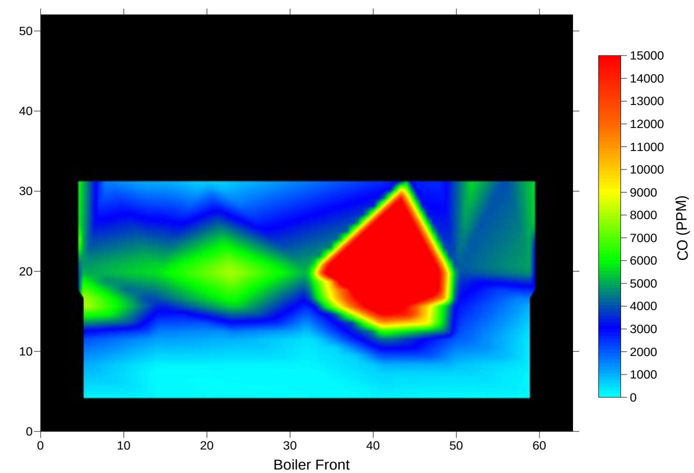
In this case, the primary air to fuel ratio was excessive. This condition caused the fuel to "outrun" the secondary air, resulting in incomplete combustion. The unit not only had a poor heat rate, but also had CO spikes. Setting and maintaining the proper airflow ratio helped to resolve this problem.



Before

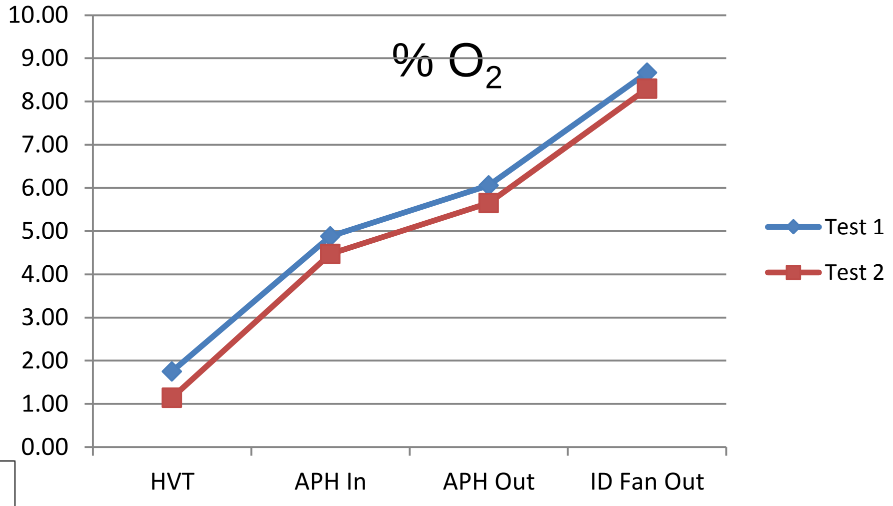


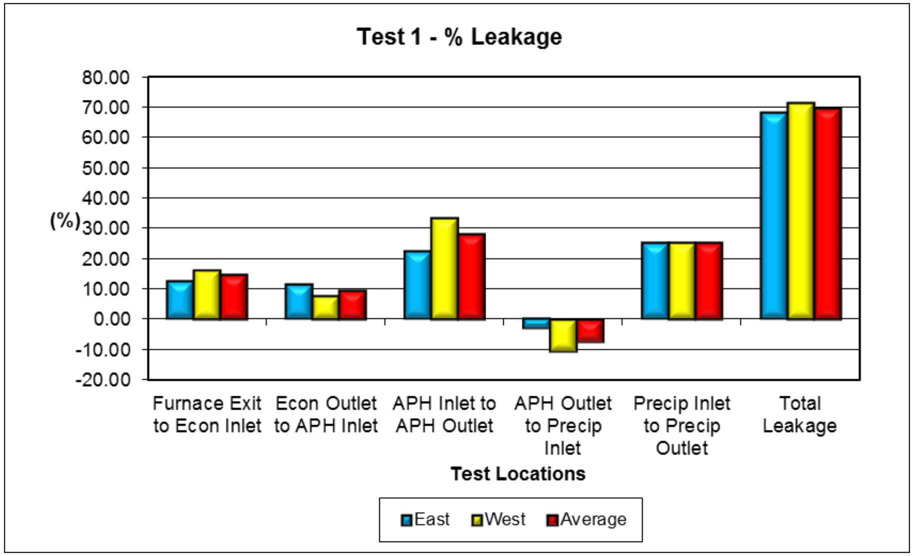
After



Case Study: Air In-Leakage

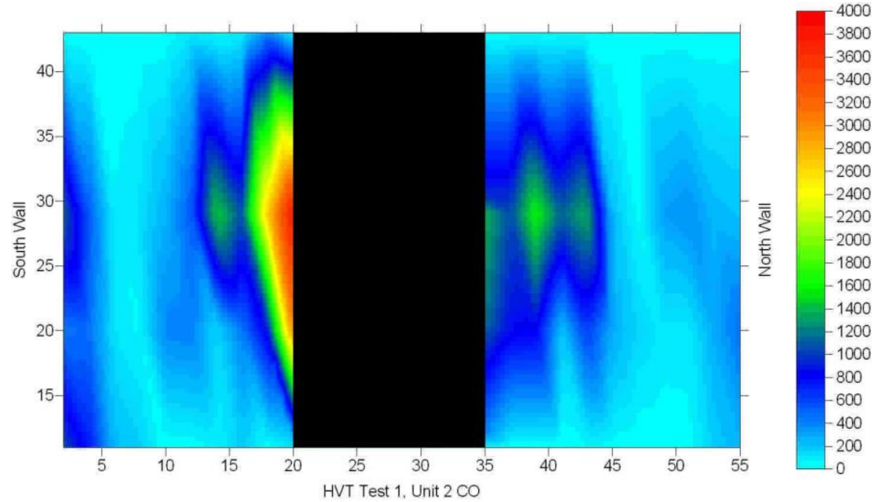
These examples show air in-leakage after the furnace exit. The ideal condition of no leakage would leave the O_2 percentage constant. Leaks in the system cause heat losses and thus decrease the system efficiency.

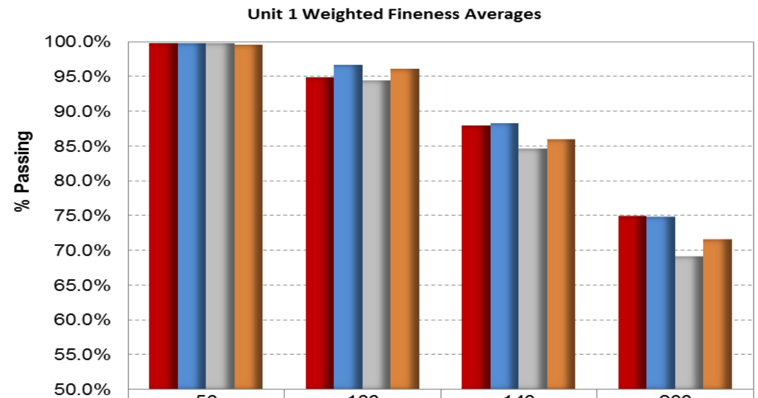




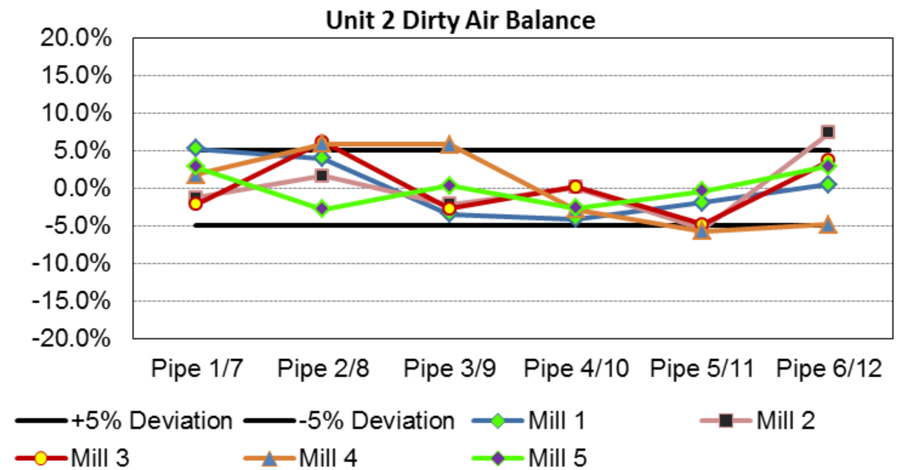
Maintaining the System (Performance Preservation)

- The best way to keep a low heat rate is to monitor and control the known variables that can cause losses.
- This way, problems can be resolved before they become big issues.
- These charts show the "as found" characteristics of one plant Storm has been regularly servicing for 10 years.
- Consistent maintenance works!





	50	100	140	200
Recommended	99.9%	95.0%	88.0%	75.0%
Mill 1	99.9%	96.7%	88.4%	74.9%
Mill 3	99.9%	94.5%	84.7%	69.2%
Mill 5	99.7%	96.2%	86.0%	71.6%



Stealth Heat - Rate Factors

Isolating the impact of a change

As the list below reveals, the typical coal-fired utility boiler has many O&M variables that can be controlled to lower the plant's heat rate (note how many directly involve air in-leakage):

- Pulverizer primary airflow.
- Air heater leakage.
- Boiler and ductwork air in-leakage.
- Pulverizer coal spillage.
- Flyash unburned carbon content.
- Bottom ash unburned carbon content.
- Superheater de-superheating spray water flow.
- Reheater de-superheating spray water flow.
- Superheater outlet steam temperature.
- Reheater outlet steam temperature.
- Air heater exit gas temperature.
- Excess air at the boiler exit.
- Leakage from the boiler vent and drain valves.
- Auxiliary power consumption due to non-optimized combustion, poor tuning, or inattention to maintenance of fans or ductwork.
- Sootblowing frequency and duration.

500 Btu's /kWhr Potential Saving Cost

• Reduction of Air In-Leakage and Dry Gas Loss	240 Btu/kWhr
• Reduction of Air Heater Leakage	60 Btu/kWhr
• Reducing Pulverizer Coal Rejects	40 Btu/kWhr
• Reduced Carbon in Ash	100 Btu/kWhr
• Reduced De-superheating Spray Flows	60 Btu/kWhr

Thank You

Presented by: Danny Storm

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