IMPROVING COAL PLANT EFFICIENCY

Some ideas to consider for existing coal units to "Work Toward" Compliance with the EPA Clean Power Plan, Rule 111d Coal Plant Efficiency Improvements

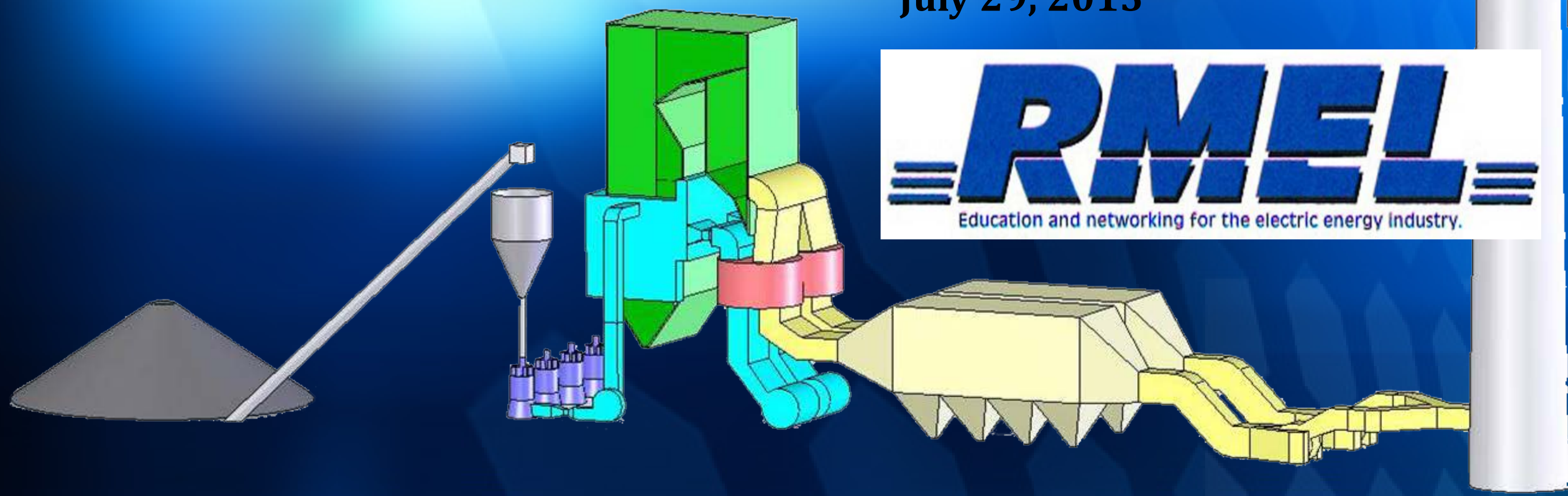
Presentation by:

Dick Storm of Storm Technologies, Inc.

Slides and Data by Storm Technologies Staff

RMEL Plant Management Conference

July 29, 2015



EPA Document; Excerpt 111 (d)

1. BSER Factors Informing State Emission Rate Goals

(BSER = Best System Emission Reduction)

- The GHG Abatement Measures TSD describes the four categories of emission reduction measures (building blocks) used in determining the state emission rate goals. That document describes EPA's historic data review and analysis underlying each technology and informing EPA's assessment of its feasibility and cost-effectiveness as part of a BSER. The technology estimates determined through EPA's analysis and documented in the GHG Abatement Measures TSD are summarized below. These estimates are used in EPA's calculation of state emission rate goals, as described in this TSD.
- Heat Rate Improvement
  Proposed ----- 6% Heat-Rate (includes, **"Upgrades"** ?)
- Alternative -- 4% Heat- Rate (**"Operational"** Improvements)

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Beyond The Plant Fence Coal Plant Heat-Rate "Challenges"

- Low Natural Gas Prices Creating a Gas First Dispatch which then causes....
- Low Capacity Factor Operation as a Result of Lower Cost Gas First and then "Must Run" Renewables and Nuclear Units
- Cycling which Creates Startup Losses
- Air Heater Fouling from Operation at Low Loads and Especially, Low Night Load Demand
- Low Steam Temperatures at Reduced Loads
- Slagging and Fouling from Burning the least cost fuels

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EXAMPLE OF RANGE OF "BEST HEAT-RATES" (EL&P)

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

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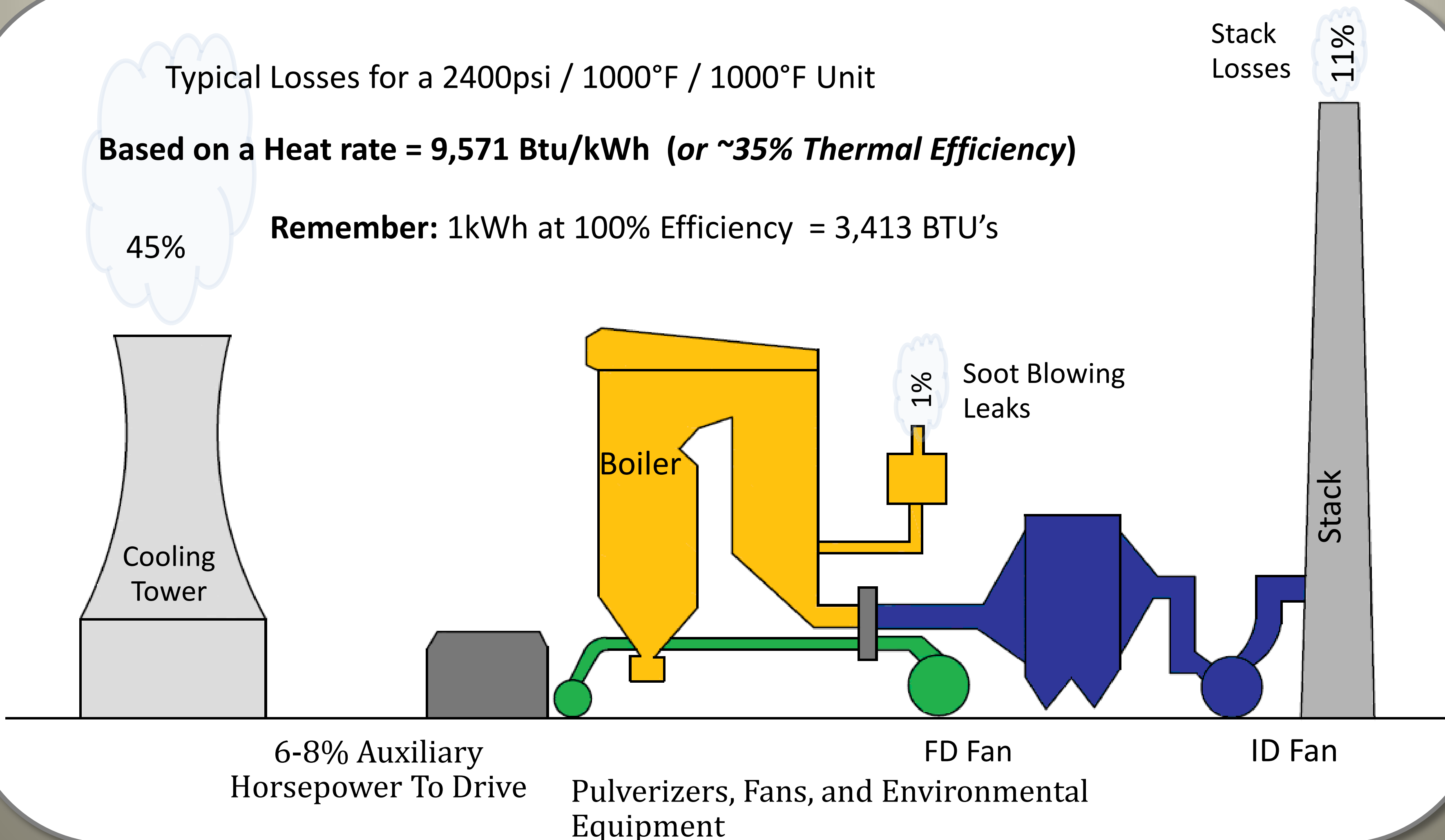
TYPICAL "BEST" SUB-CRITICAL UNIT HEAT-RATE PERFORMANCE

Typical Losses for a 2400psi / 1000°F / 1000°F Unit

Based on a Heat rate = 9,571 Btu/kWh (*or ~35% Thermal Efficiency*)

Remember: 1kWh at 100% Efficiency = 3,413 BTU's



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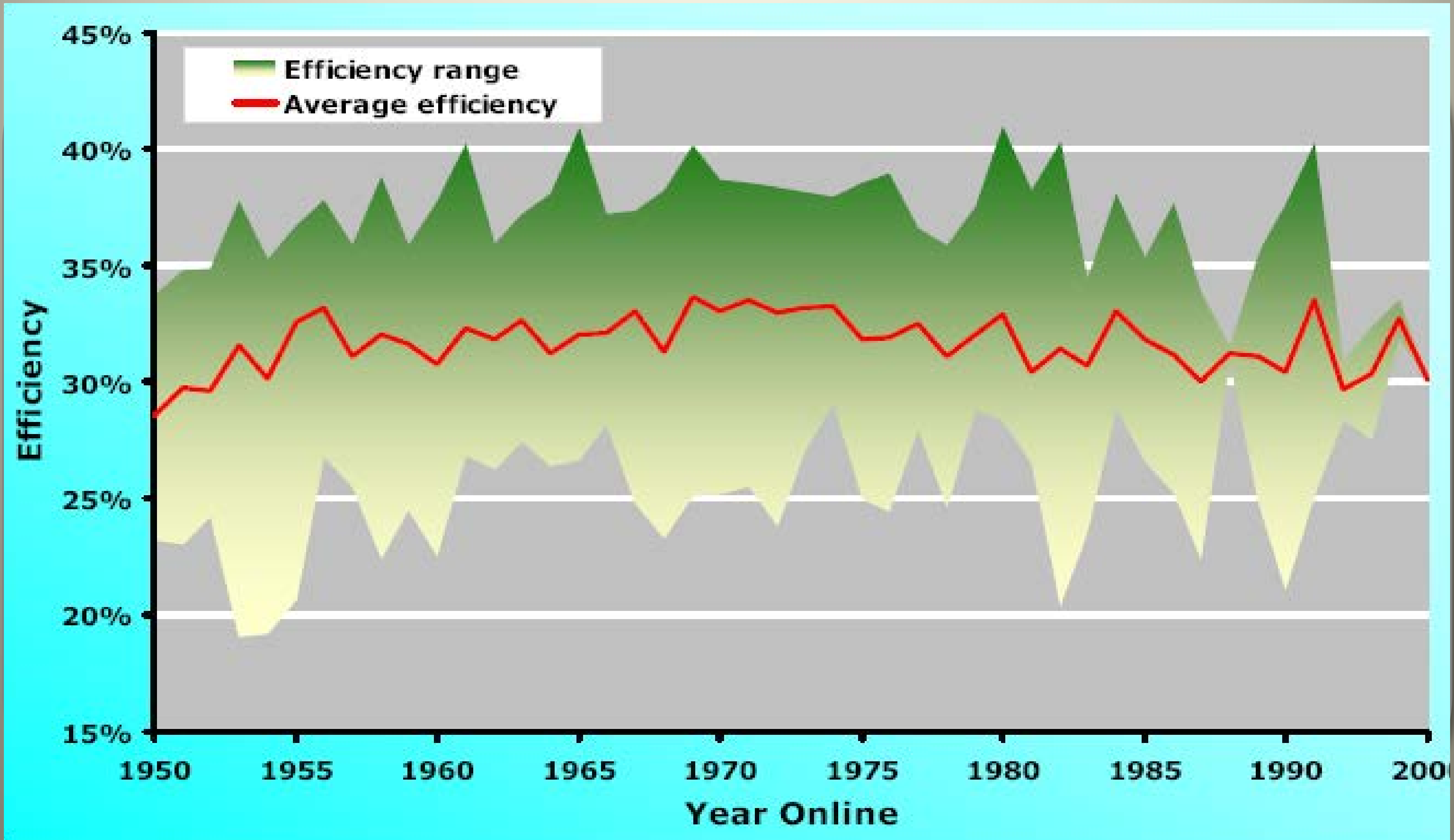
NETL-Plot of the USA Coal Fleet Efficiency



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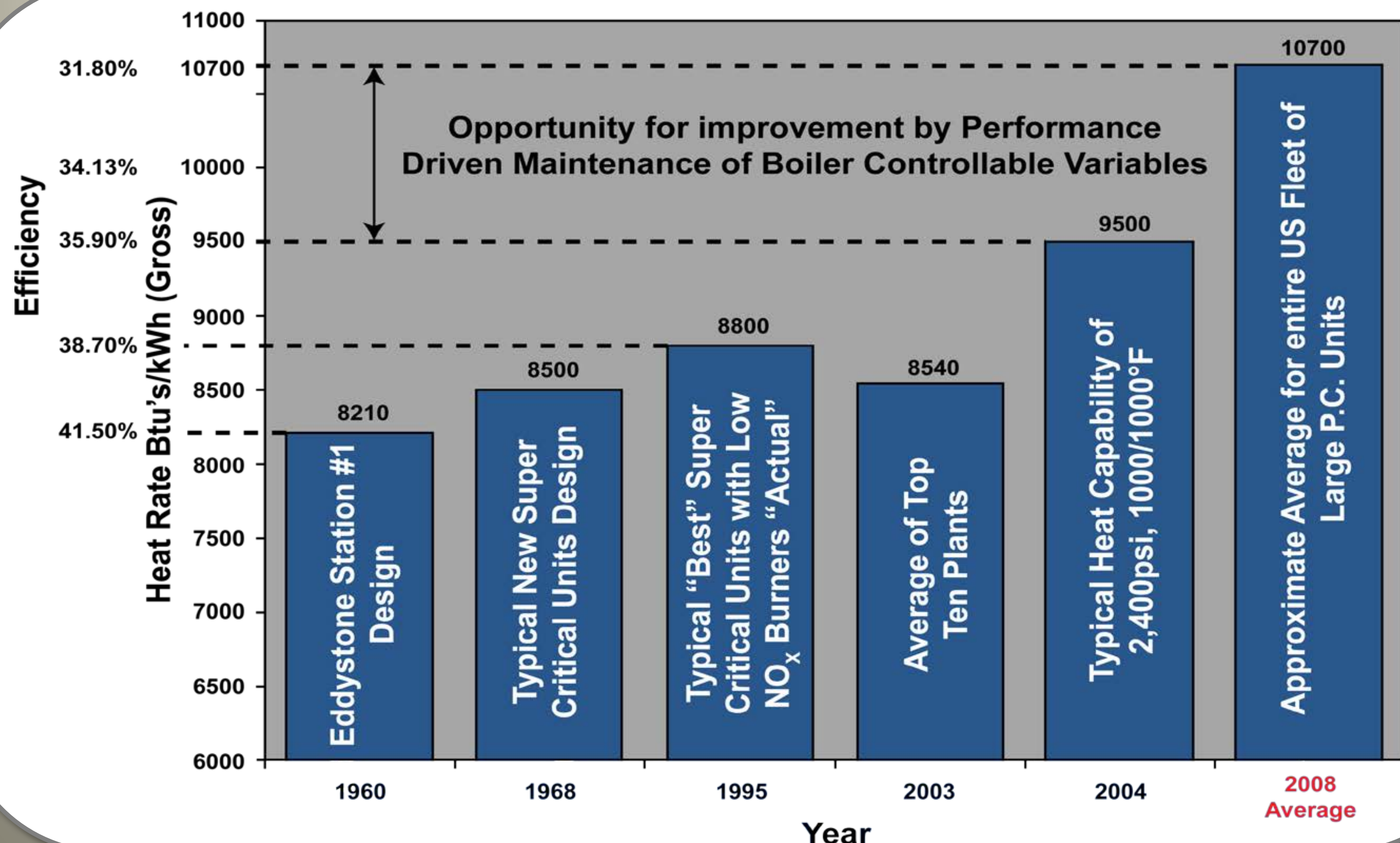
OPPORTUNITIES FOR APPLYING EXCELLENCE IN O&M



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Common "Correctable" Boiler Opportunities

- Secondary Combustion at Furnace Exit
- Burner Belt Balancing for Flue Gas consistency (to reduce Ammonia Slip and CO)
- Air Heater Ammonia Bisulfate Deposits
- Air In-Leakage
- High Primary Airflow, Tempering Airflow above optimum is especially harmful to performance
- High Reheater De-Superheating Spray Flow
- Low Steam Temperatures at Reduced Load
- High Draft Losses from Fouling
- Minimum Airflow Calibration for a true 25% Minimum Total Air Flow

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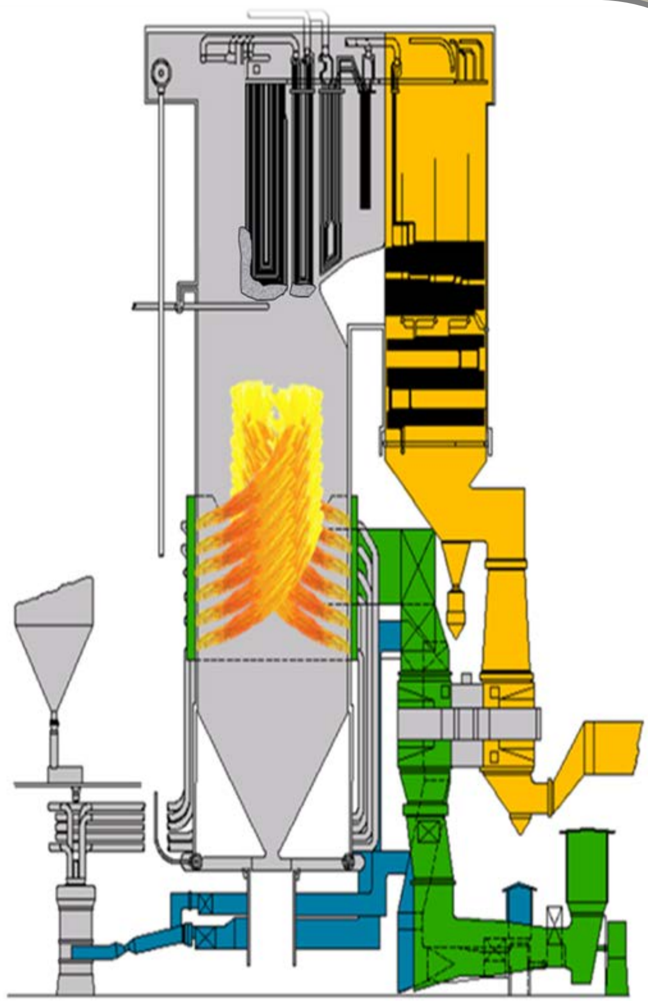
IMPROVING UNIT EFFICIENCY BEGINS AT THE BOILER

BOILER CONTROLLABLE HEAT-RATE FACTORS:

- EXIT GAS TEMPERATURE
- AIR IN-LEAKAGE
- HIGH TEMPERING AIRFLOW
- FLYASH LOI
- STEAM TEMPERATURES
- DE-SUPERHEATING SPRAY WAT FLOWS
- AUXILIARY POWER
- SOOTBLOWING



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"STEALTH" O&M CORRECTIONS POTENTIAL FOR BEST HEAT-RATE, COAL POWER MAGAZINE, AUGUST 2013

Variable	Potential heat rate improvement (Btu/kWh)	Potential annual fuel savings
Boiler and ductwork ambient air in-leakage	300	$819,000
Dry gas loss at the air heater exit	100	$273,000
Primary airflow	75[a]	$204,750
Steam temperature	75	$204,750
De-superheater spray water flow	50	$136,500
Coal spillage	25	$68,250
Unburned carbon in flyash	25[a]	$68,250
Unburned carbon in bottom ash	25	$68,250
Slagging and fouling	25[a]	$68,250
Cycle losses	25	$68,250
All others, including sootblowing and auxiliary power factors	25	$68,250
Total	**750**	**$2,047,500**

Note: a. Interactions between variables will impact meeting this estimate.

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Furnace Exit Secondary Combustion

Common Causes of Secondary Combustion

- **Low Furnace Excess Oxygen**
- **High Primary Airflow**
- **Extreme Fuel Imbalances**
- **Poor Fuel Fineness**
- **Combustion Airflow Proportioning not Optimum** ie; High Over-fire Airflow, High Under-fire Airflow
- **Extreme Secondary Airflow Imbalances**
- **Burner Mechanical Damage** (usually from overheating and warped parts)

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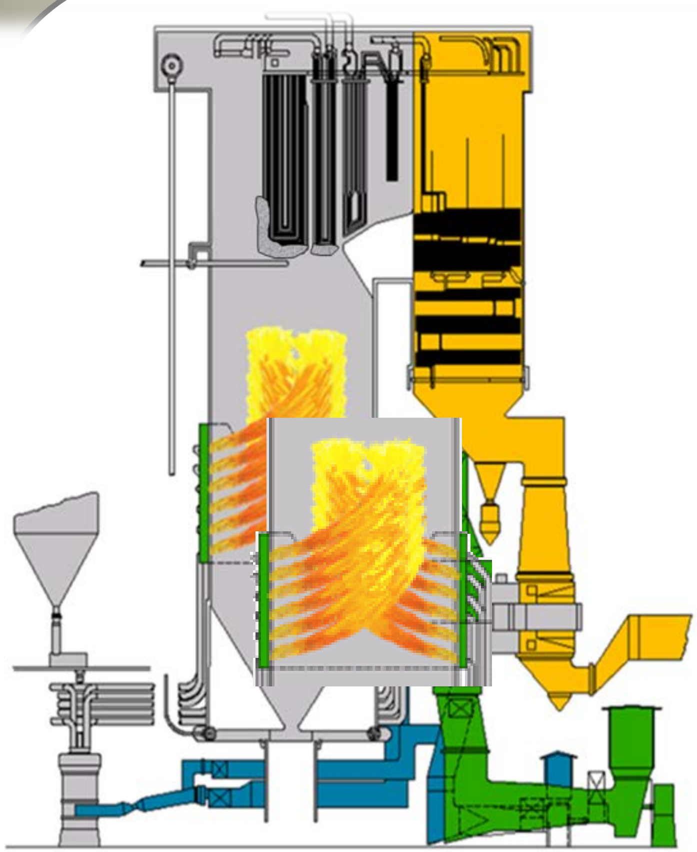
Effective Soot Blowing is Important!



Why?

- **Can mitigate Higher FEGT** due to fuel changes with lower ash fusion temperatures such as: switching fuels or blending. Especially by effective Water-Wall Cleaning:
  - Low Sulfur coal (e.g. PRB)
  - High Sulfur coal (Eastern Bituminous & ILB)

- **Reduction of "Cinder Carryover" to Convection Pass**

Molten ash particles begin to sinter on leading edge of pendant sections Removal can reduce Air Heater and SCR Fouling which causes increased draft losses, increased fan power and increased boiler air in-leakage

- **Reduction of Boiler Exit Gas Temperatures**
- **Reduction of SH and RH Spray Water Flows**

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Combustion Optimization is a Team Effort

- ✓Testing to Identify Opportunities
- ✓Apply Operational Excellence 24/7
- ✓Maintenance Optimization of Pulverizers
- ✓Instrumentation Calibrations and Tuning for best Load Response, best Combustion Performance, best Combustion Airflow Proportioning (Primary Air, OFA and Secondary Airflow's)
- ✓Apply 13 Essentials to the "Burner Belt Input's"
- ✓Be Vigilant of the 22 Boiler Controllable Heat-Rate Factors

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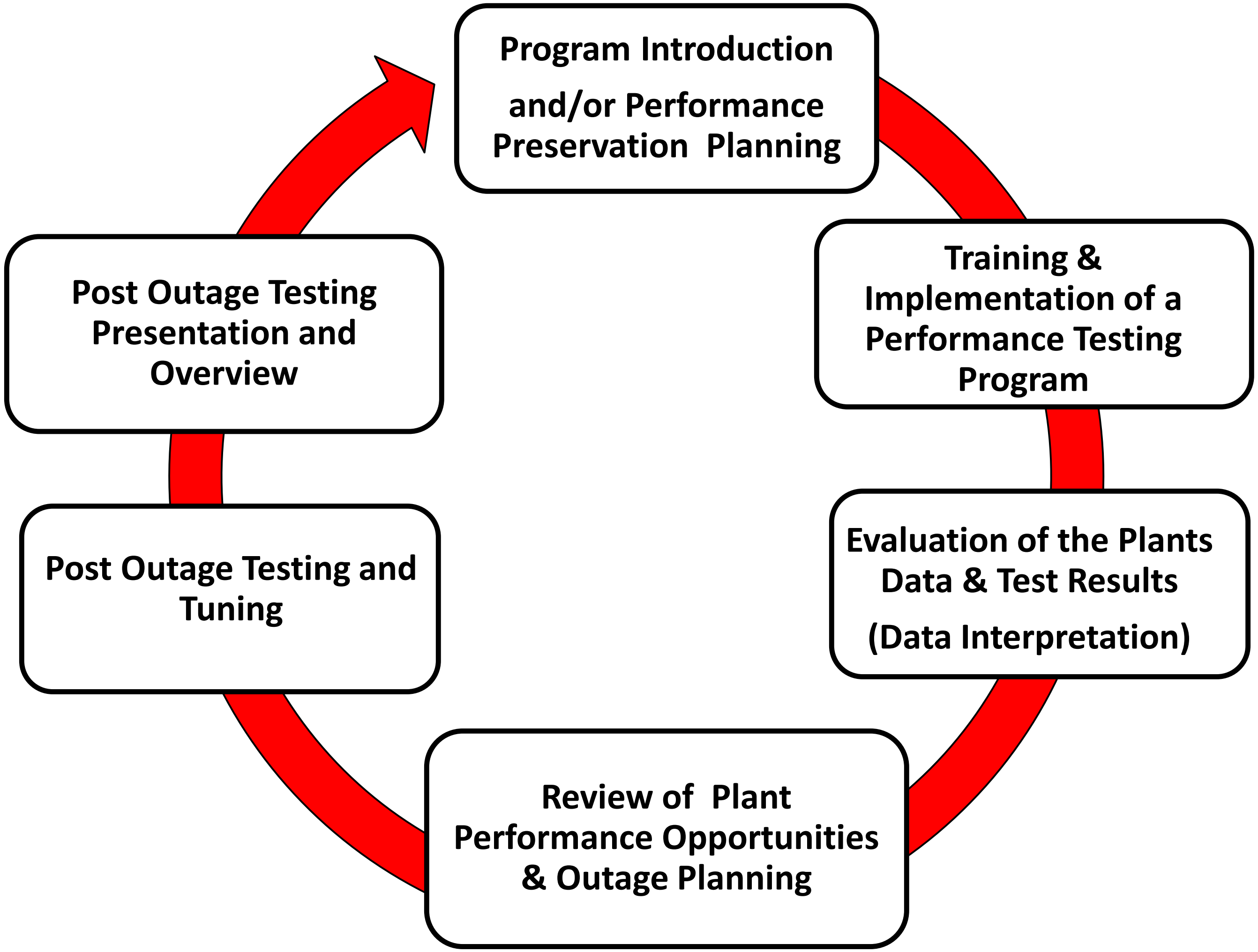
Six Points to Keep "Best" Performance

Teamwork is Needed 12 months of every year



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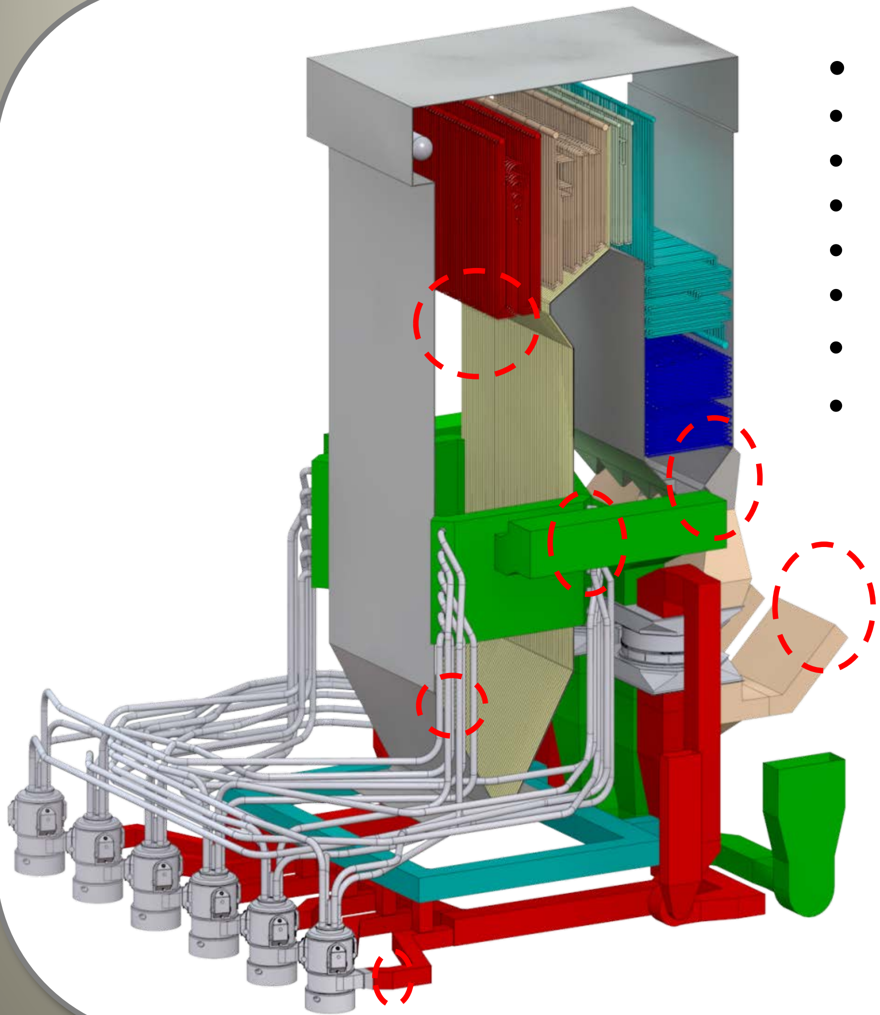
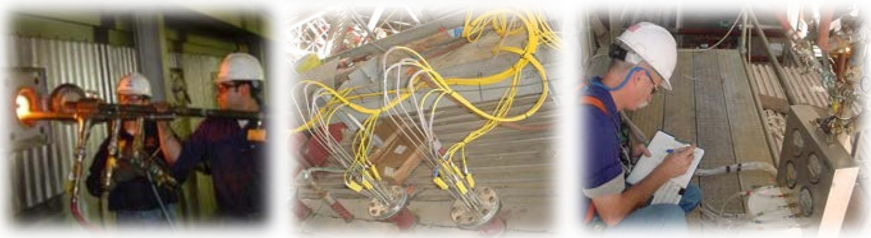
First, Perform a Comprehensive Evaluation
Identify the Opportunities for Improvement



- "Stealth Losses" Evaluation
- Quantify Boiler "Air In-Leakage"
- Fuel Line Performance Measurements
- Mill Inlet Primary Airflow Calibrations
- Total Secondary Airflow Measurement & Calibration
- Furnace Exit Gas Temperature & Flue Gas Constituents
- Economizer Outlet Flue Gas Measurements
- ID Fan Discharge / Stack Inlet Flue Gas Measurements



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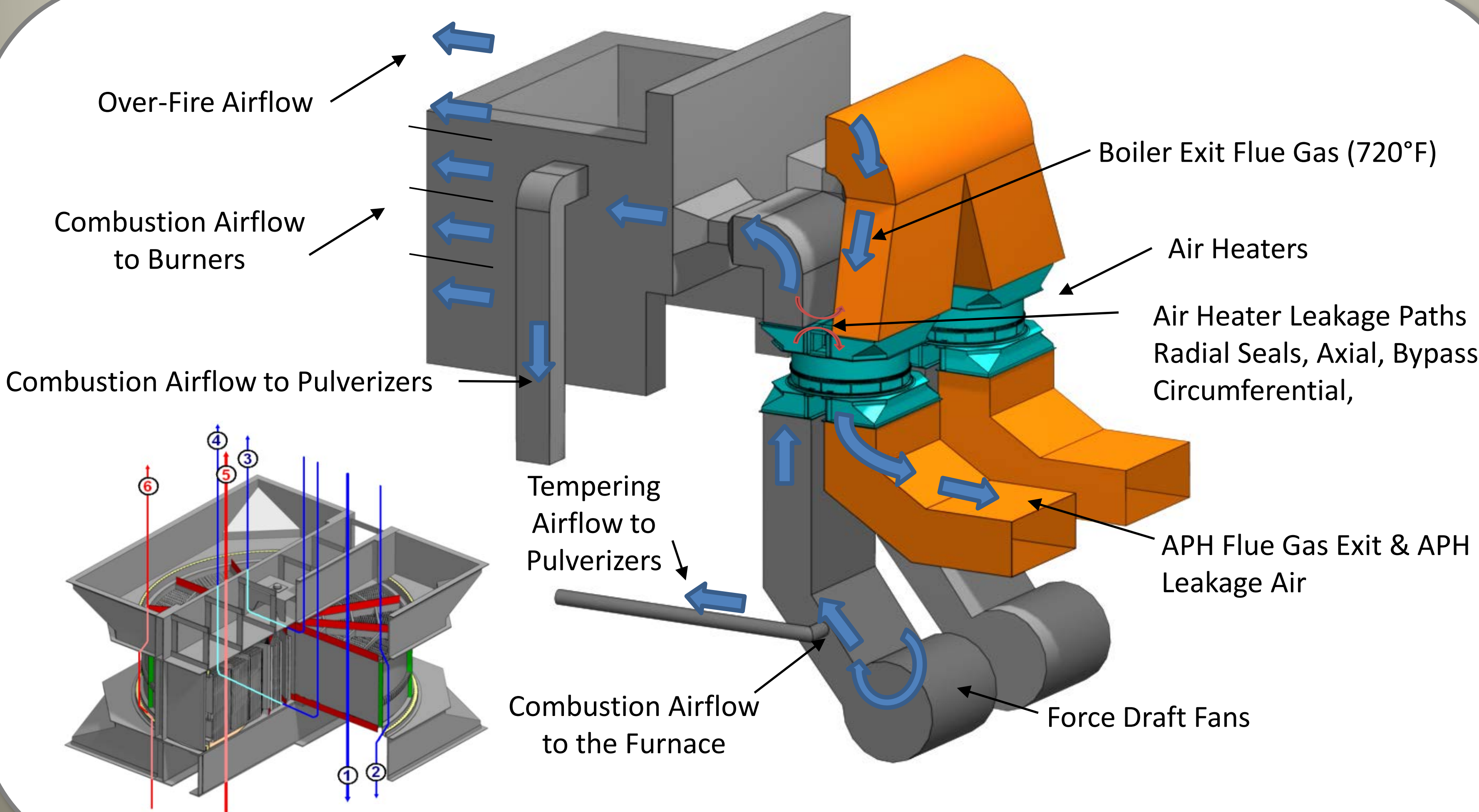
AIR IN-LEAKAGE AND X-RATIO DEVIATIONS
IDENTIFIED BY TESTING, CORRECTED BY MAINTENANCE



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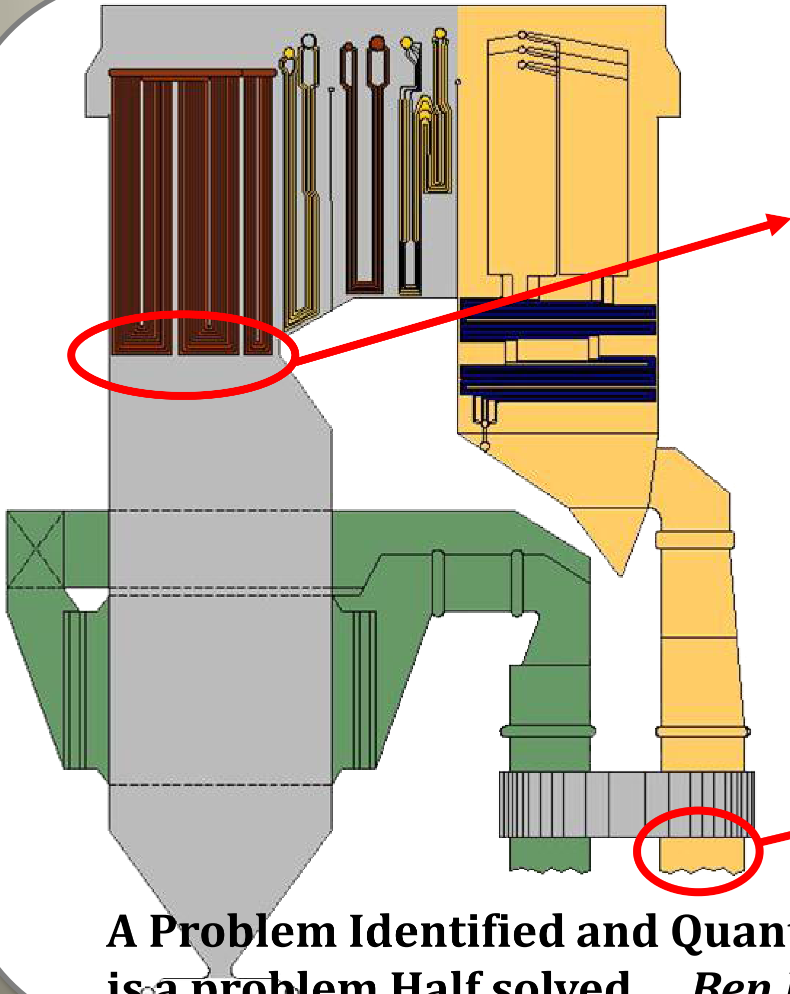
Test to Identify and Quantify Opportunities



A Problem Identified and Quantified is a problem Half solved…. *Ben Franklin*

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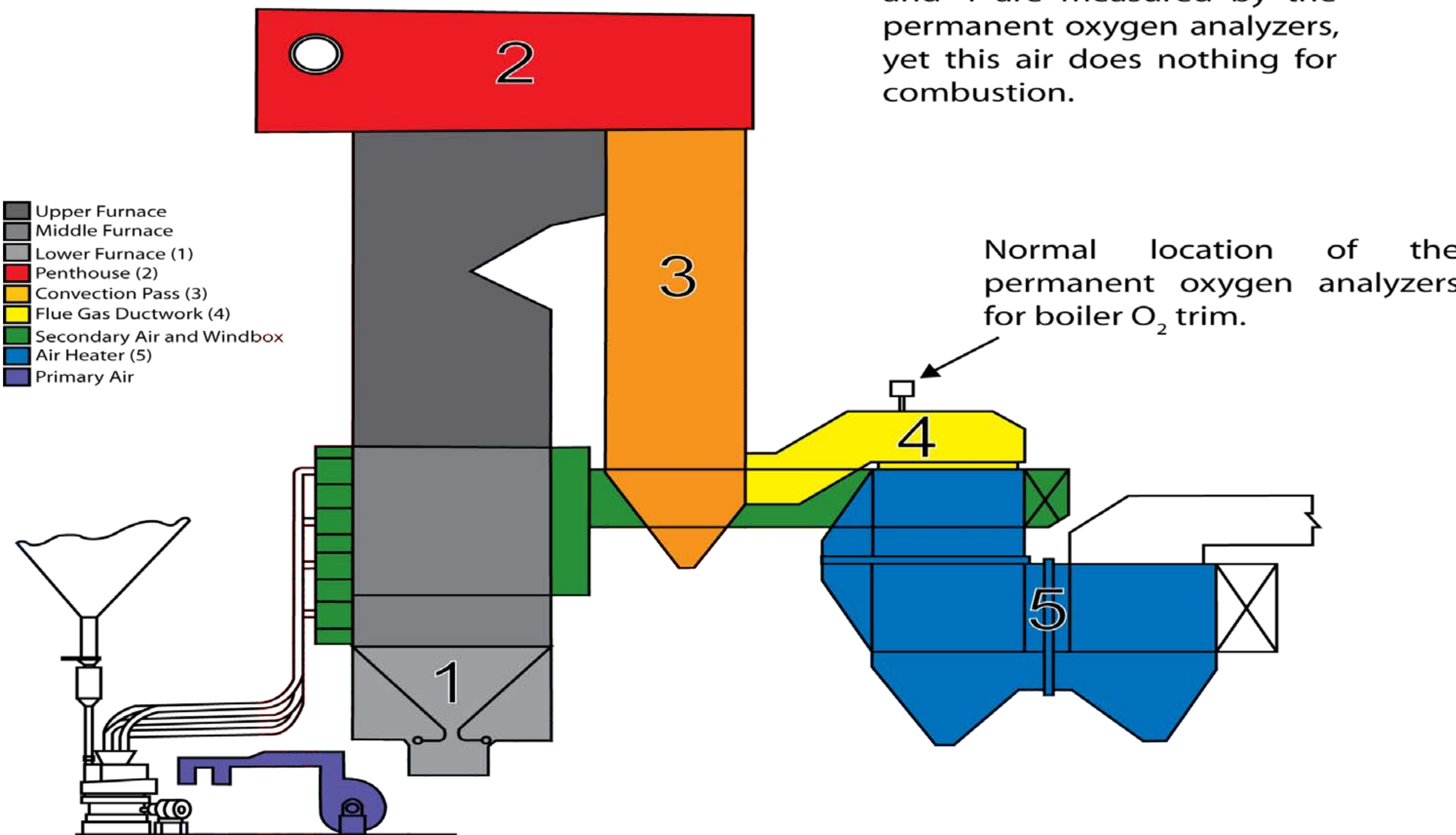
Stealth Heat Rate Loss No. 1: Air In Leakage

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



Examples of Common Boiler Expansion Joint Air-In Leakage

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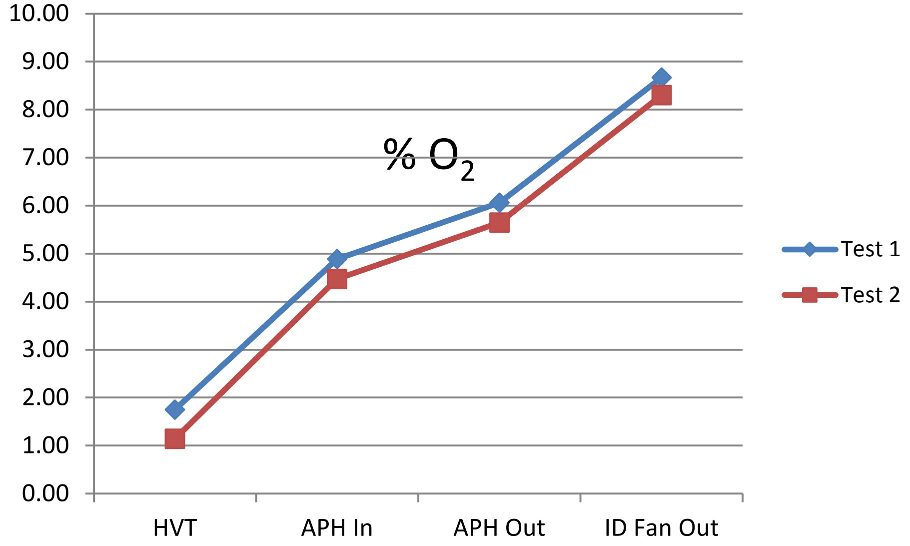
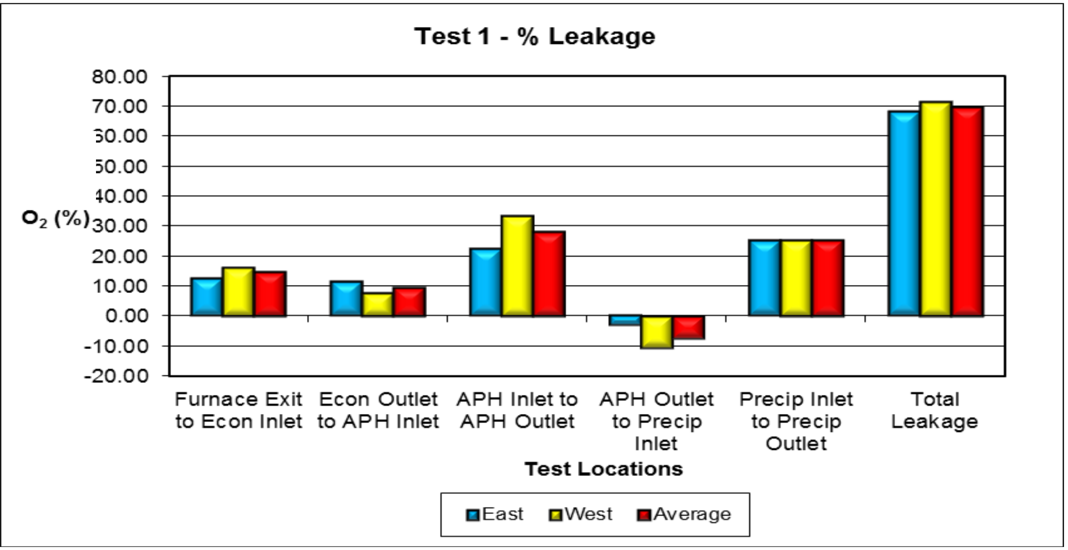
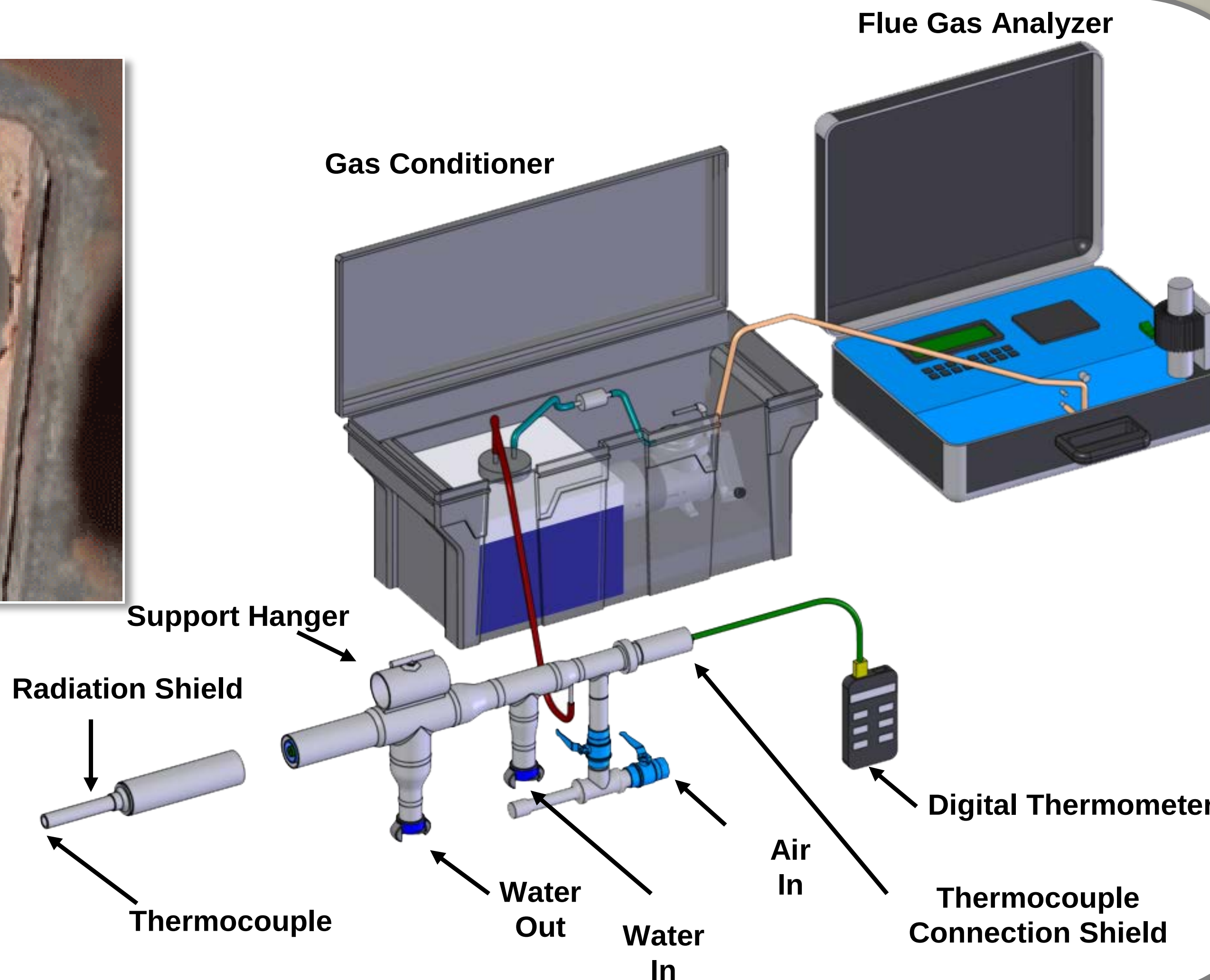
Case Study: Air In-Leakage

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.





Prove Excess Oxygen at the Furnace Exit



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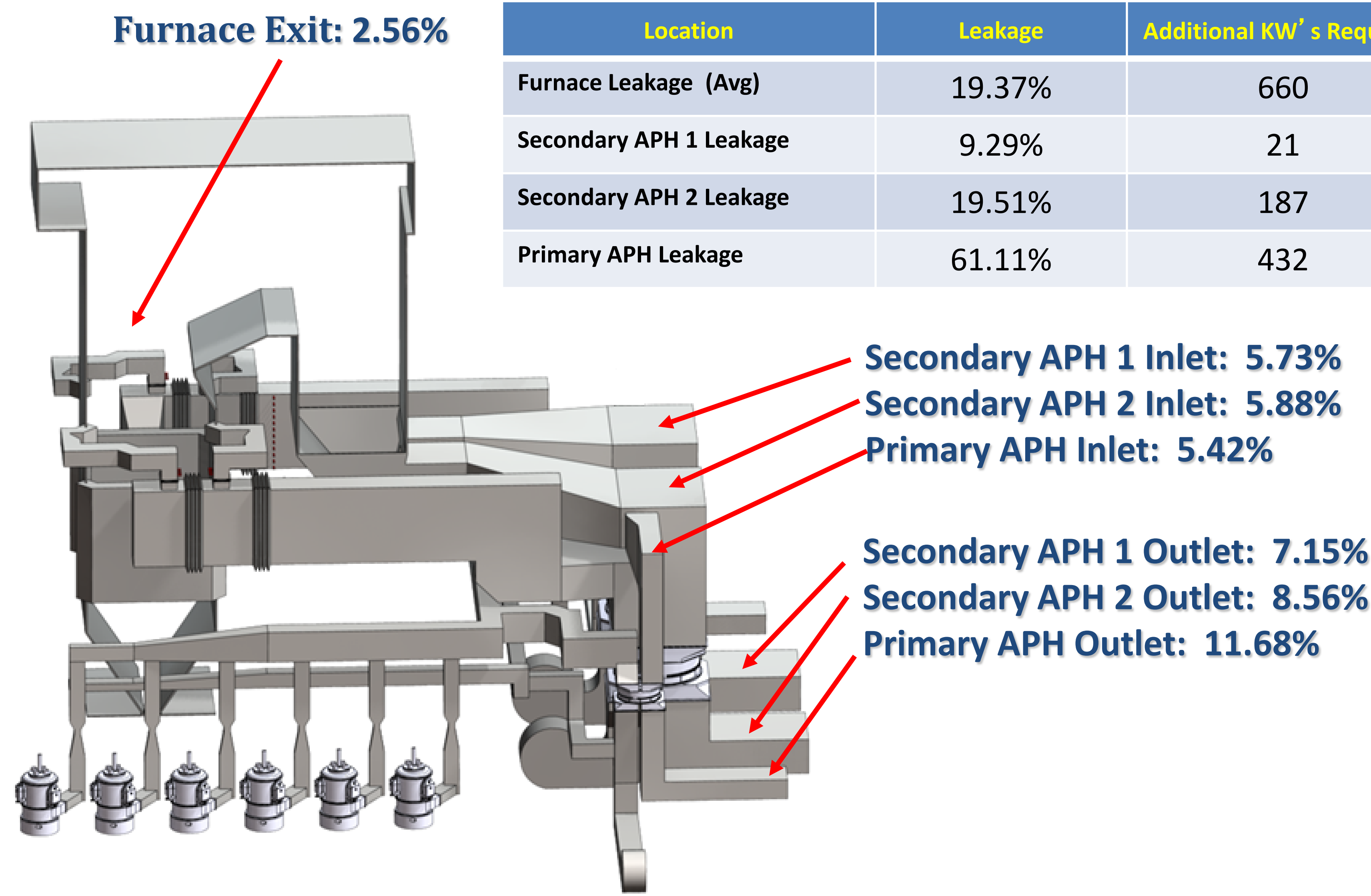
Air In-Leakage
Can be a Very Large "Stealth Loss"

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



Apply the 13 Essentials-Get Inputs Right!

Suggest Review of RMEL Presentation in 2012

"One More Time: First Apply the Fundamentals"

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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.

Flyash Example of Engaging Entire Team

Three part Flyash Analyses, ***Sample MUST be Representative***

200 MESH SIEVE (COARSE ASH)

BOTTOM PAN (FINE ASH)

Place 50 grams of ash on the 200 MESH for sieve analysis

DETERMINE L.O.I. OF RESIDUE ON 200 MESH SCREEN AND IN PAN

L.O.I. OF FINE ASH MUST BE LESS THAN 2% (low volatile eastern fuels); or less than 0.2% (high volatile western fuels)

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Five Steps to Improved Heat-Rate

- Engage the Entire O & M Team
- Test and Identify "Stealth Opportunities" for Improvement
- Optimize the 22 Boiler Controllable Variables
- Identify Equipment Opportunities
- Apply "Upgrade" Improvements to Boiler, Turbine & Balance of Plant

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Example: Results of Corrected Boiler "Inputs"

- Reduced Secondary Combustion
- Reduced De-Superheating Spray Water Flows
- Less Draft Losses
- Lower Flyash LOI
- Less High Temperature SH Sootblowing
- Reduced sootblowing steam losses

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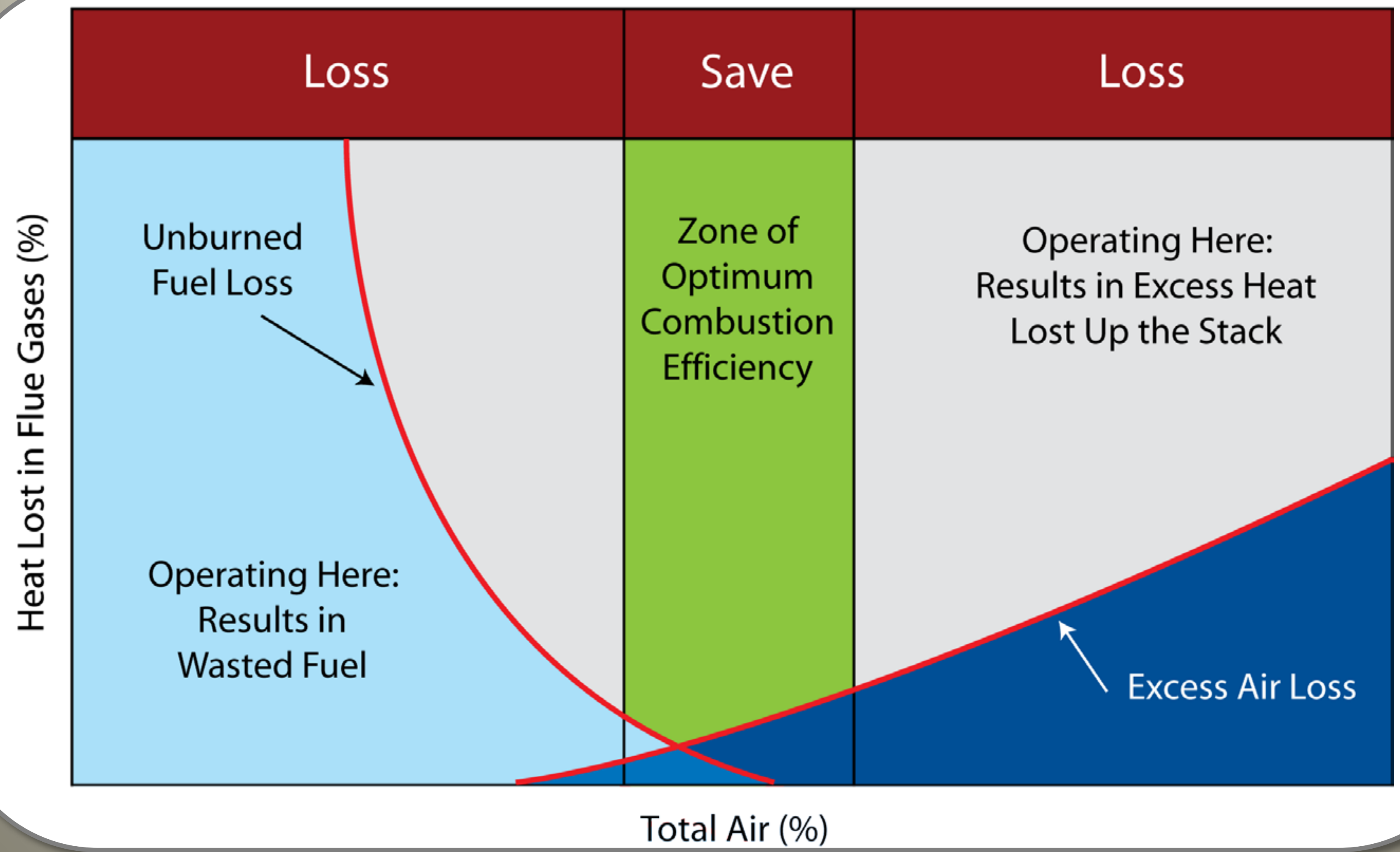
Optimizing Combustion Airflow Proportioning & Total Combustion Air



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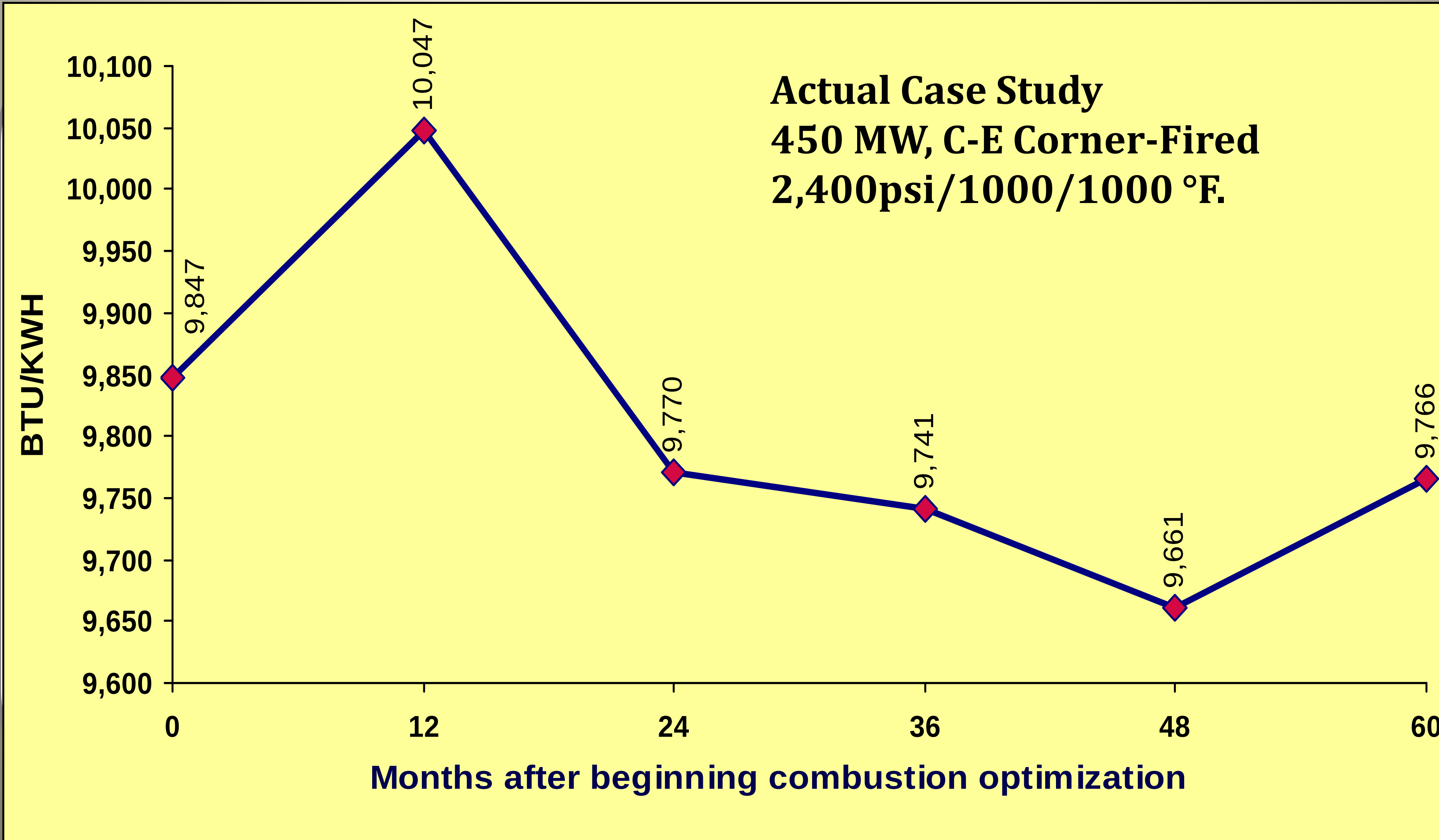
Results of Applying Corrections to Controllable Heat Rate Variables at the Boiler



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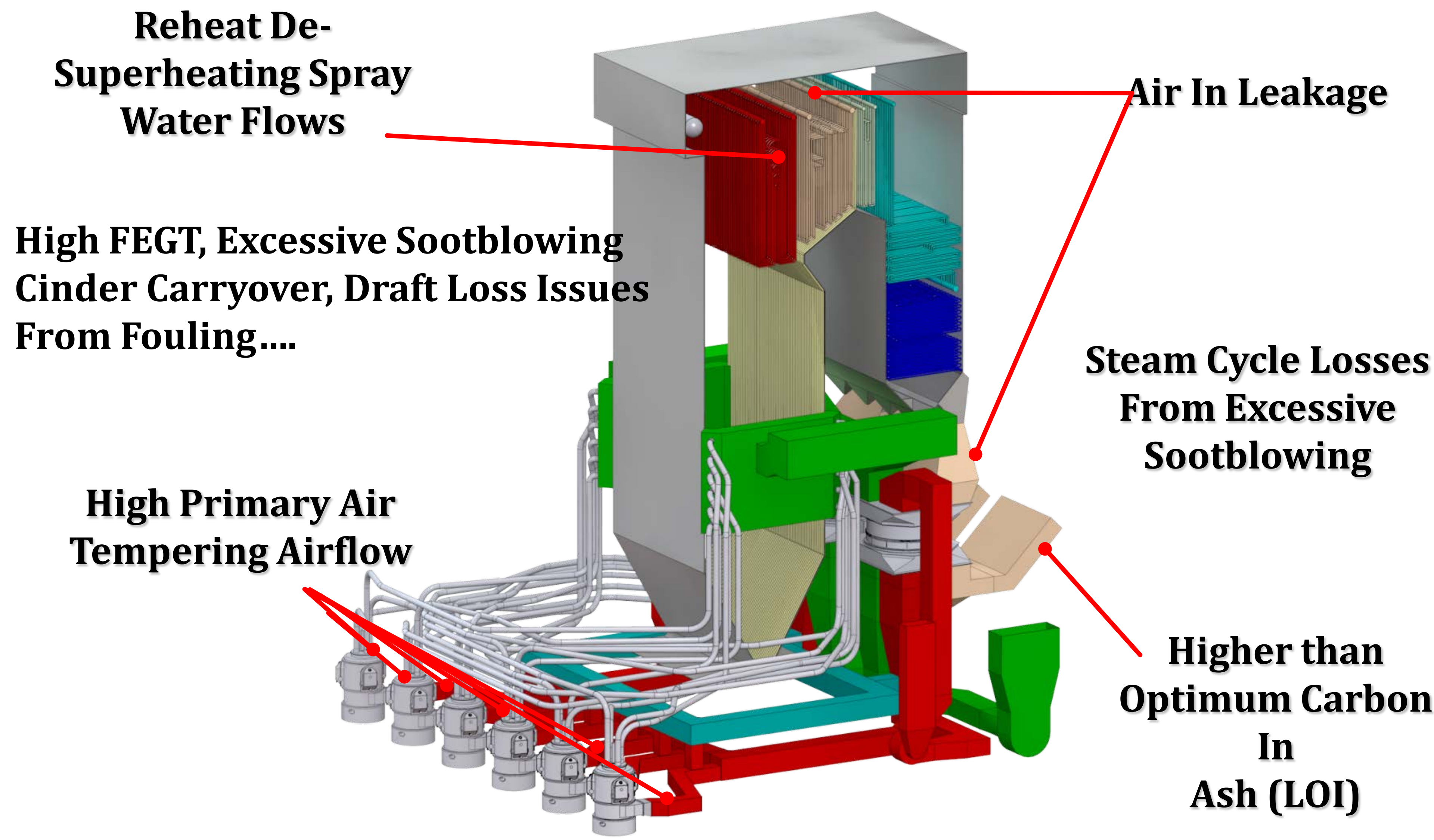
Excellence in O&M
"Stealth" Heat-Rate Improvement Opportunities



APPLYING "INPUTS" EXCELLENCE TO A WALL-FIRED 650 MW, 2400 PSI /1,000/1,000 ° F.

Improved all of these:

- Air in-leakage prior to the air heater
- Air heater leakage
- A.H. Exit Gas Temperature (corrected for leakage)
- Reduced High Primary Airflow (new PAF Ramps)
- Corrected High FEGT and Major Stratifications
- Auxiliary Power is reduced by lowering Plenum PressureAPH
- Air in-leakage after the Air Heaters
- Balanced furnace and reduced total airflow
- Burner tuning for best "Burner Belt" Combustion
- NO_X and/or LOI Improvements
- Pulverizer fineness and distribution
- Optimizing burner belt performance with better S/A Distribution
- Cooling Tower Corrections
- Condenser air leakage
- **Most Important: ALL of the O&M Team was engaged**

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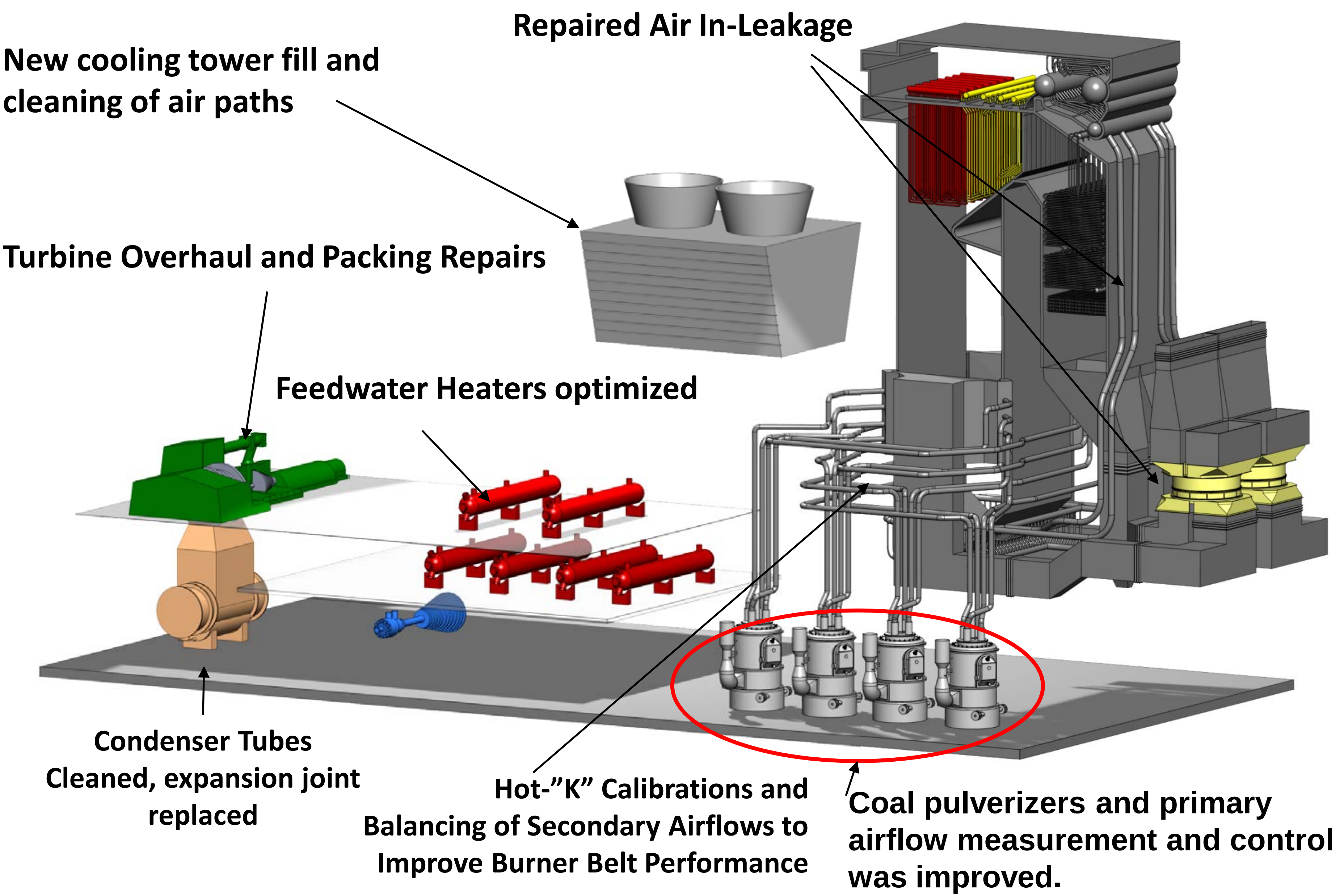
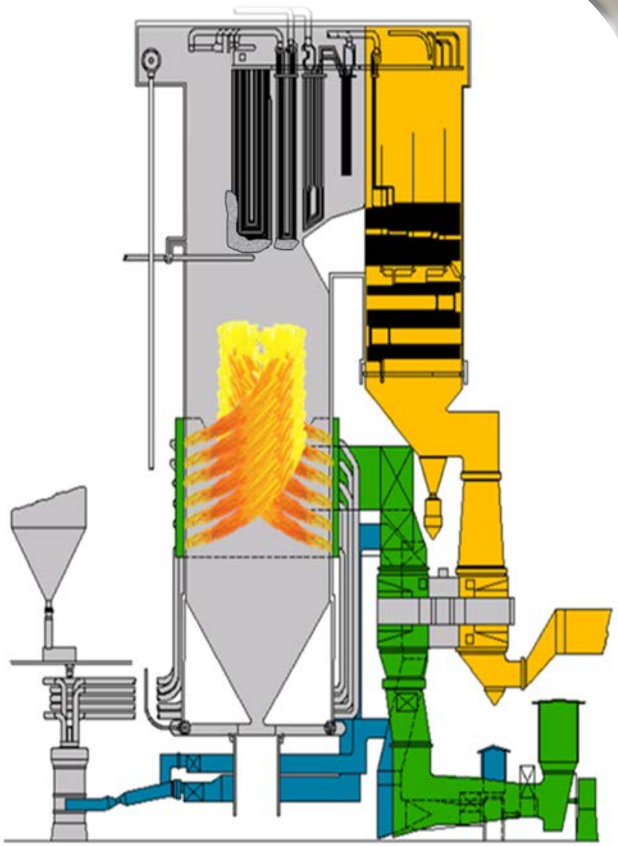
A Comprehensive Approach, Boiler, Turbine, ALL Major Equipment and ALL Personnel, Following One Plan



IMPROVING UNIT EFFICIENCY BEGINS AT THE BOILER

BOILER CONTROLLABLE HEAT-RATE FACTORS:

- EXIT GAS TEMPERATURE
- AIR IN-LEAKAGE
- HIGH TEMPERING AIRFLOW
- Pulverizer Tuning Optimizations
- 25% Minimum Combustion Airflow
- FLYASH LOI
- STEAM TEMPERATURES
- DE-SUPERHEATING SPRAY WATER FLOWS
- AUXILIARY POWER
- SOOTBLOWING



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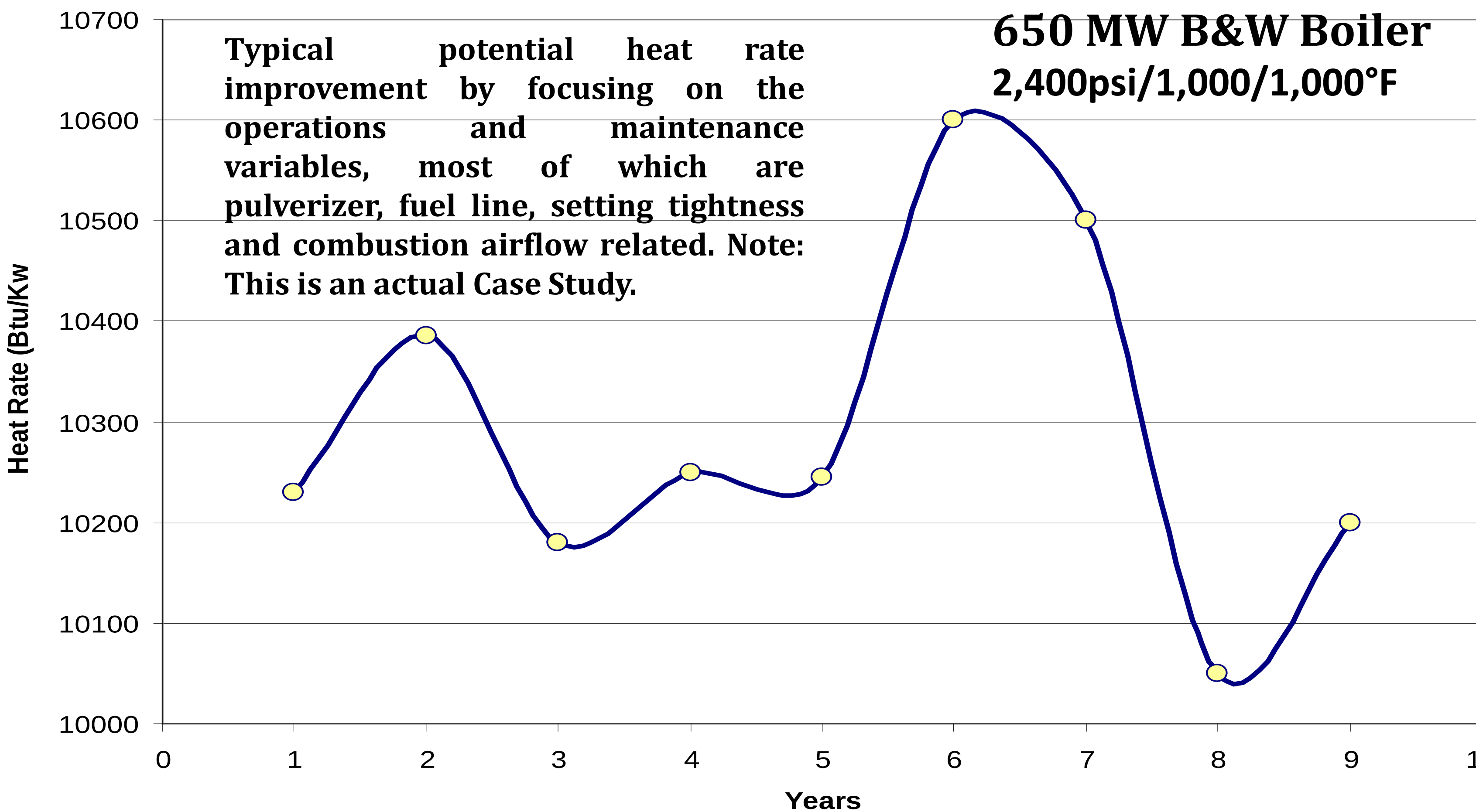
Heat- Rate Improvement Results with Applied Excellence in O & M



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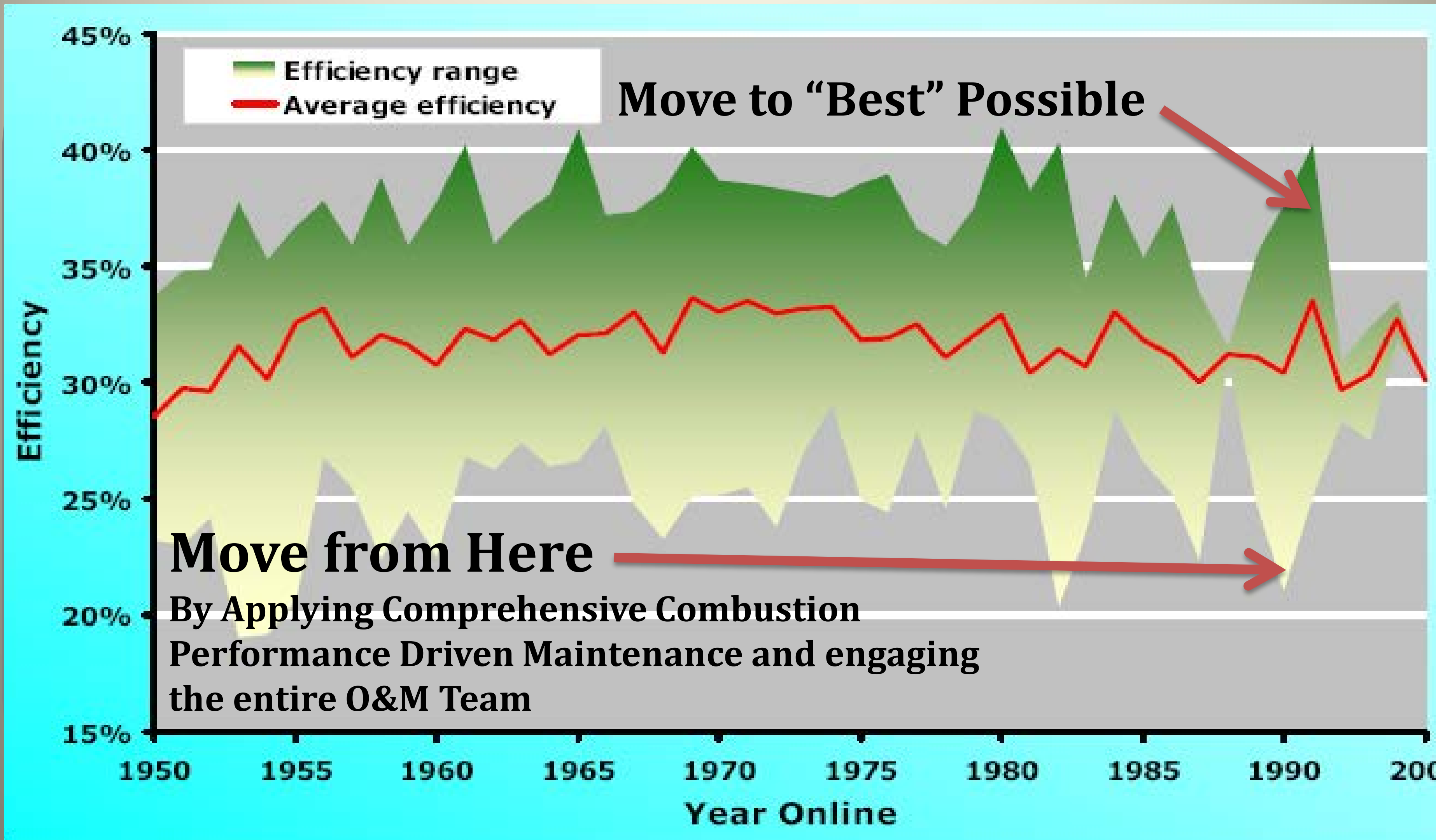
Results of Applying Best Practices of Combustion Optimization Can Place Your Plant in Better Position



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THE EIGHT MOST COMMON CORRECTABLE LOSSES ARE:

(IN OUR EXPERIENCE)

- **Boiler and Setting Air in-leakage**
- **High furnace exit gas temperatures which cause high Reheater and Superheater desuperheating spray water flows**
- **High Boiler Exit Gas and Airheater Exit Gas Temperatures**
- **High primary airflows** (especially harmful is high tempering airflow that bypasses the air heaters)
- **Higher than optimum carbon in ash** (Bottom ash and Flyash)
- **Steam cycle losses (especially those caused by high FEGT and excessive soot-blowing to mitigate slagging)**
- **Correct Burner Belt Fuel and Combustion Air Balance and Reduce CO and Ammonia Slip which contributes to Air Heater Fouling**
- **Air Heater Leakage and Non-Optimized Air Heater Exit Gas Temperature**

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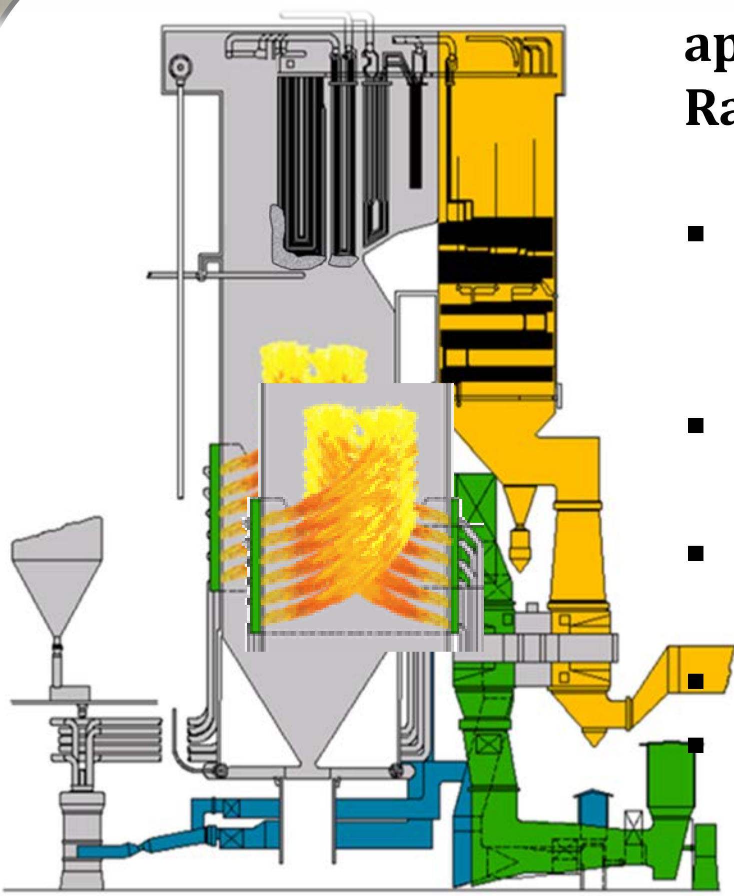
22 Heat Rate Variables

1. Flyash Loss On Ignition (LOI)
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 fired 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 NO_x 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 water flow to the superheater
10. High de-superheating spray water flow to the reheater
11. High air heater leakage (note: Ljungstrom regenerative airheaters should and can be less than 9% leakage)
12. Auxiliary power consumption/optimization i.e., fan clearances, duct leakage, primary air system optimization, etc
13. Superheater outlet temperature
14. Reheater outlet temperature
15. Airheater outlet temperature
16. Airheater exit gas temperature, corrected to a "no leakage" basis, and brought to the optimum level
17. Burner "inputs" tuning for lowest possible excess oxygen at the boiler outlet and satisfactory NO_x and LOI. Applying the "Thirteen Essentials"
18. Boiler exit (economizer exit) gas temperatures ideally between 650°F to 750°F, with zero air in-leakage (no dilution!)
19. 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
20. "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)
21. Feed water heater level controls and steam cycle attention to detail
22. Steam purity and the costly impact of turbine deposits on heat rate and capacity

ONE OTHER PROBLEM: THE EPA-NSR RULES MAY NOT HAVE GONE AWAY (THIS IS MY UNDERSTANDING OF NSR CHALLENGES FOR SOME UTILITIES)



There are Boiler Improvements that can be applied to significantly Improve Overall Heat Rate. But some are at Risk of NSR:

- Adjust Surface of Superheater and Reheater for better steam temperatures, less De-superheating sprays
- Replace Air Heaters with New: Better Seal Leakage 5-7% instead of 15%+
- Upgrade Pulverizers for reduced auxiliary power, better fineness
- Add VFD's to large Fan Motors
- Install Turbine "Upgraded" Rotors

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Equipment "UPGRADES?"
Is NSR an Obstruction To "Best Performance"
(NSR=New Source Review)

"Upgrades" Is this still a "Dirty Word"

Imagine what the utility industry could do without NSR....
EPA References "Upgrades" in the Rule. Do they mean it? Can you Trust them?
Articles and Presentations on this topic were Published by Dick Storm in:

POWER Magazine, August 2009

EPRI

2011, 2013 Heat-Rate Conference Presentations

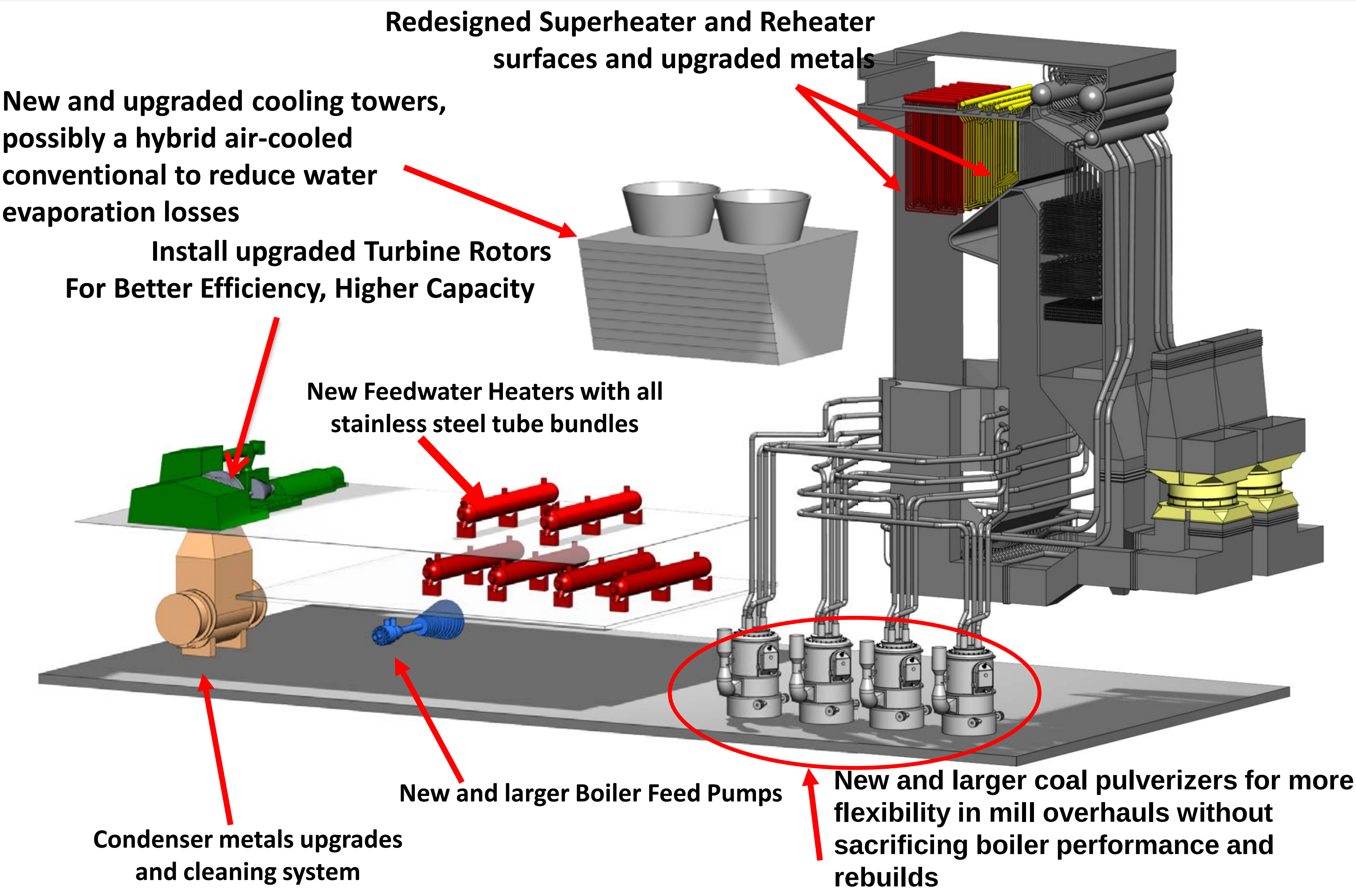
ACC- American Coal Council

New Source Review is, in my understanding, still a threat.

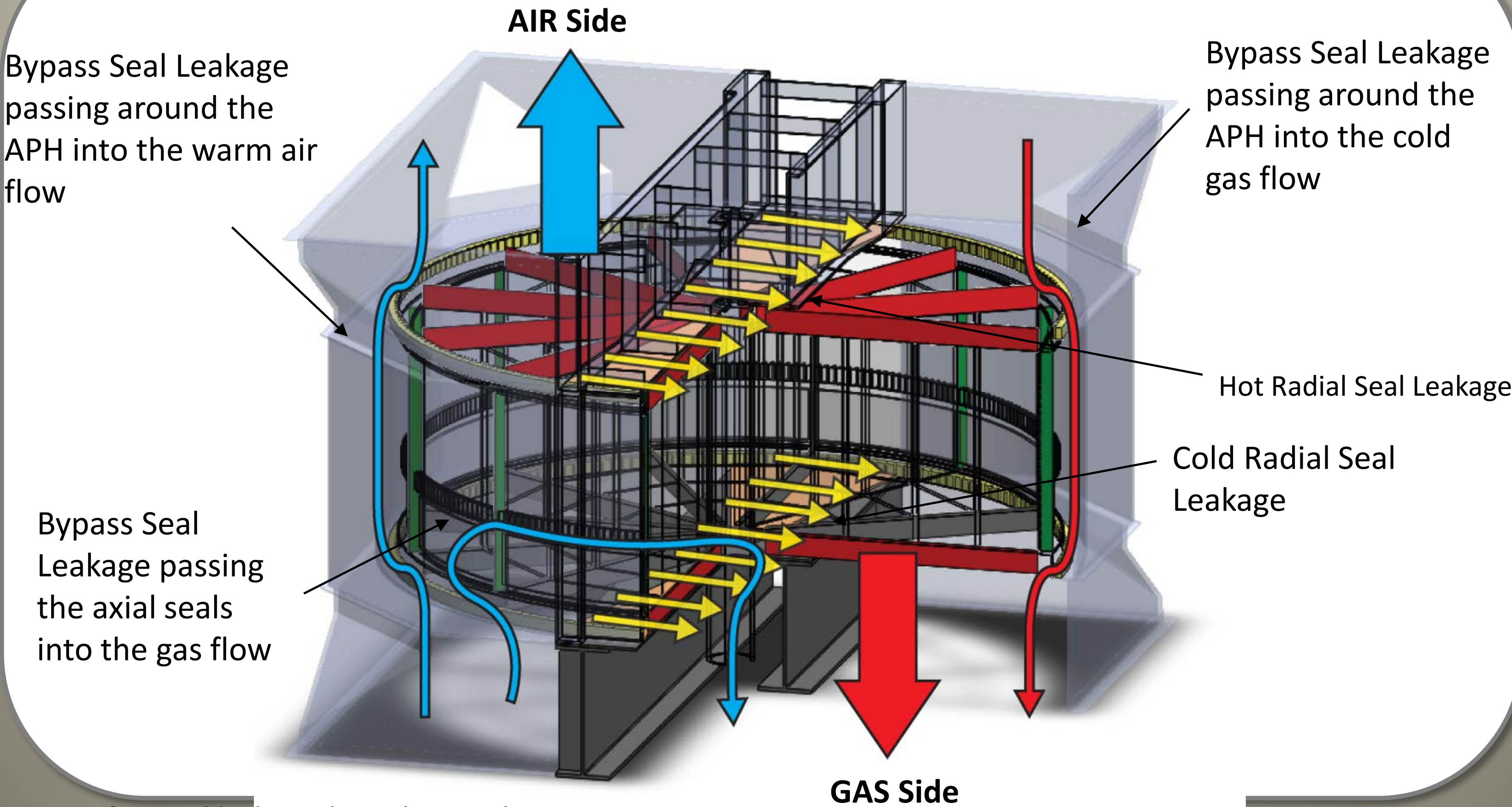
Small changes to Boilers were considered "Upgrades" by some managers: Such as:

- Installing New and Larger Primary Air Fans for a Fuel Change to PRB Fuel
- Changing Superheater Surface to Optimize Heat Absorption of the SH and RH
- "Upgrading" SH and Reheater Alloys to Stainless Steel
- Changing troublesome Rothemuhle Air Heaters to "Upgraded" Current best Design Ljungstrom's to improve Leakage and Efficiency

"IF" no threat of NSR, Significant Heat-Rate Performance Improvements are Possible



How about “Upgraded” New Regenerative Air Heaters? Especially to replace High Leakage Rothemuhle AH’s



Circumferential leakage through an air heater

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Boiler Upgrades to Consider for Maximum Efficiency, Reliability and Increased Capacity

Change/Upgrade Surface Proportions of Superheater and Reheater:

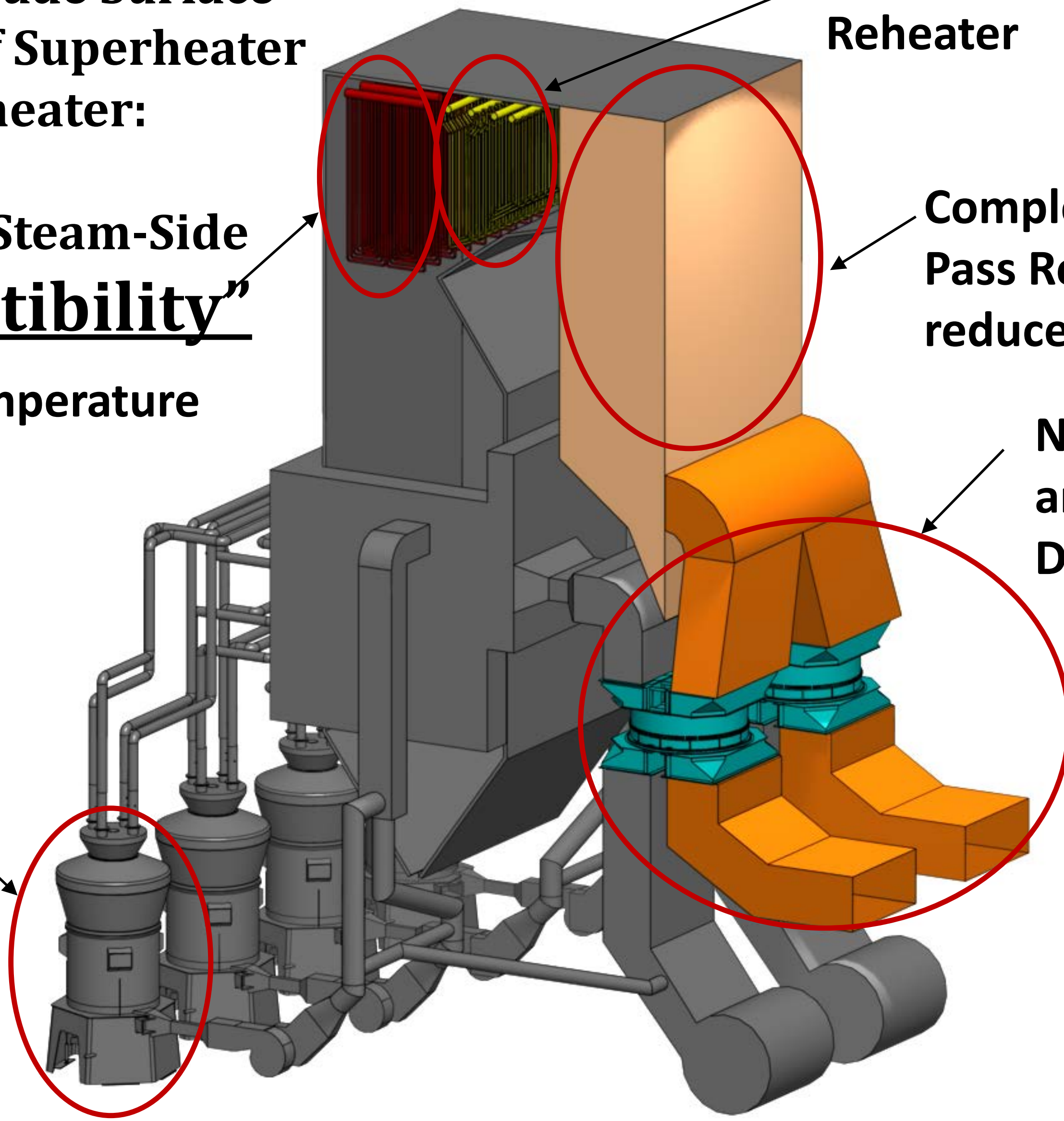
Correct:

"Fire-Side/Steam-Side

<u>**Incompatibility"**</u>

Upgrade High Temperature Superheater Metals

New and Larger Pulverizers



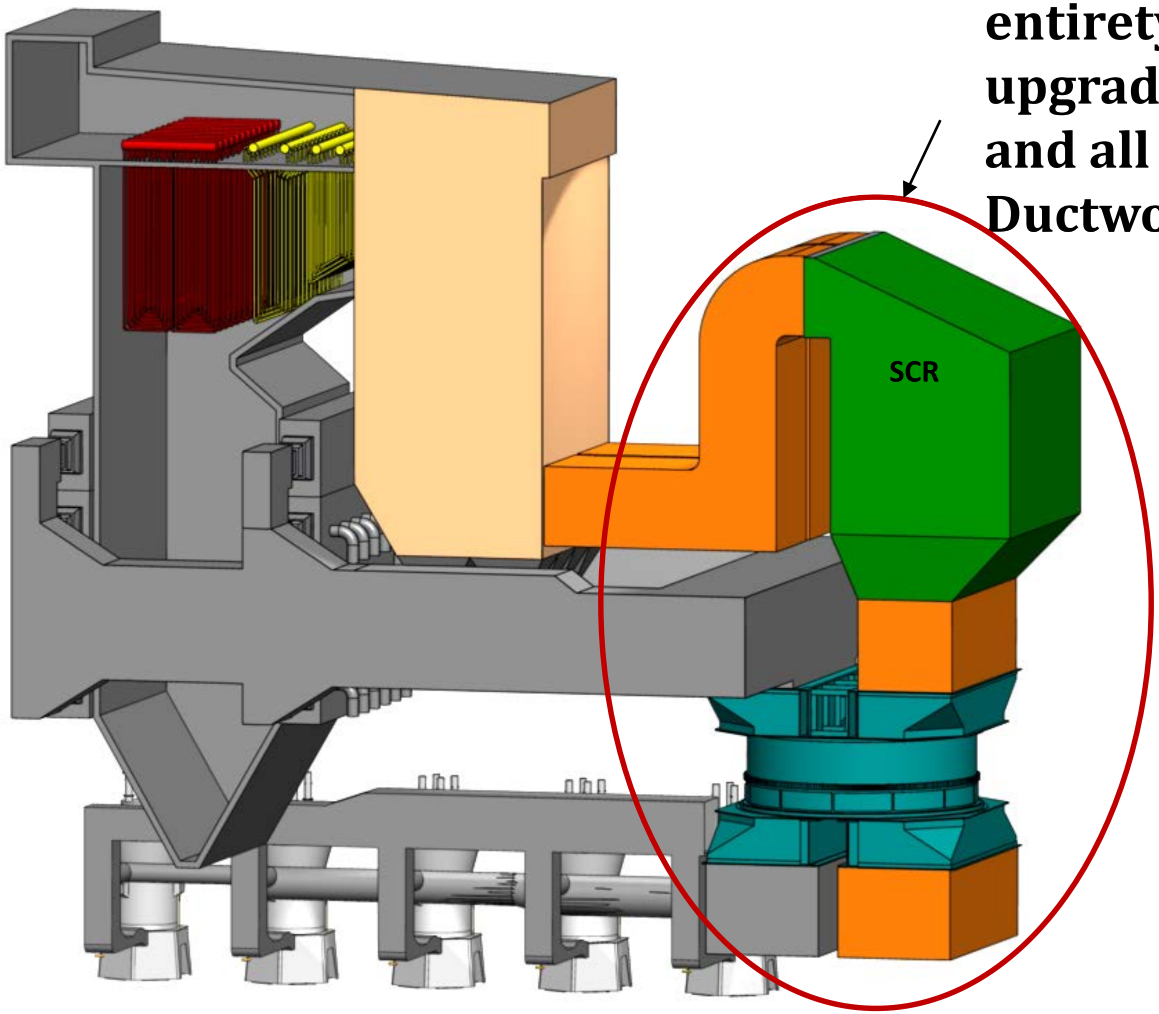
Upgrade High Temperature Reheater

Complete Convection Pass Refurbishment to reduce Air In-Leakage

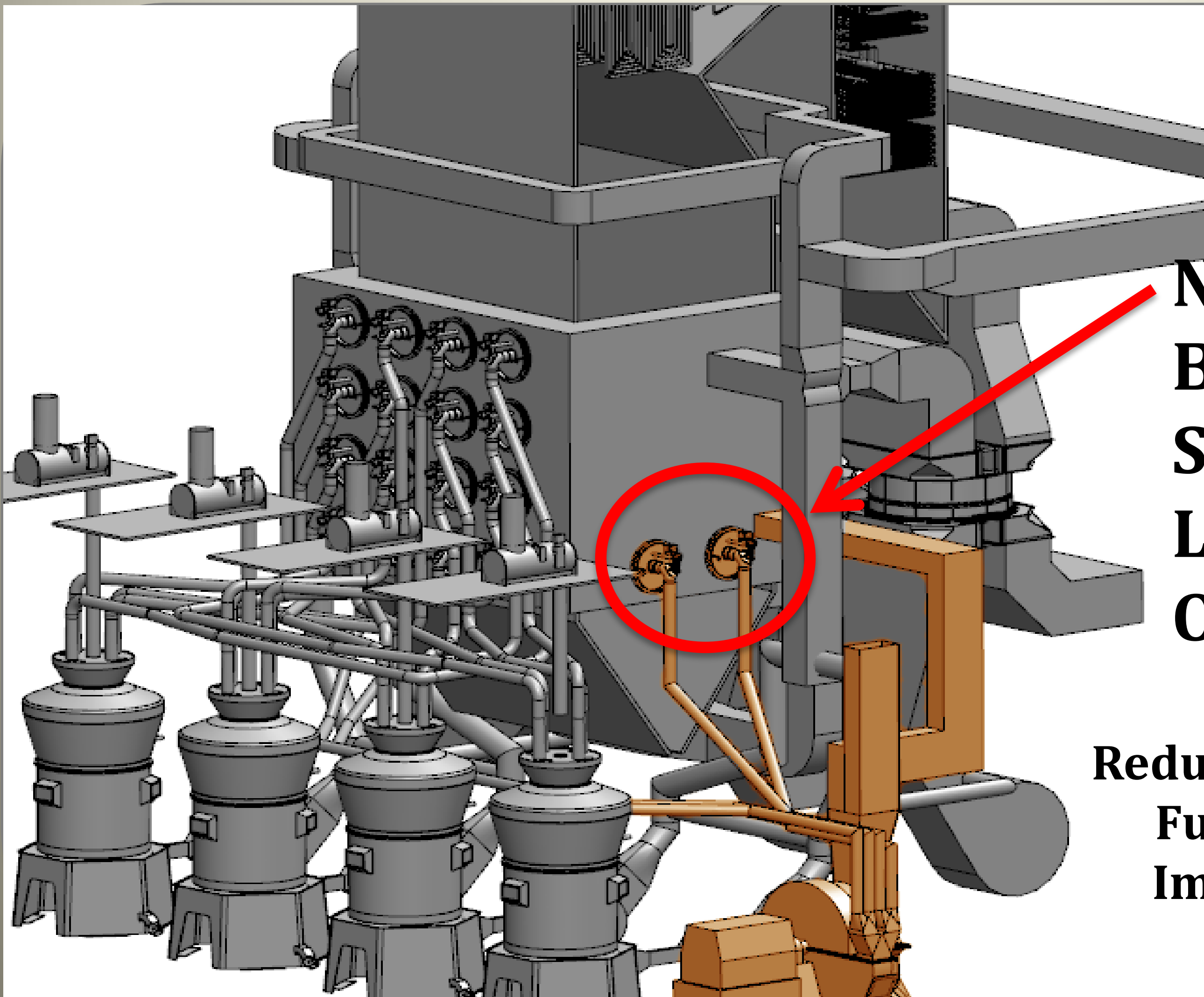
New Air Heaters and connecting Ductwork

Boiler Improvement Potential for Heat Rate, Capacity and Reliability Improvement

Replace the existing Air Heaters in their entirety with upgraded Air Heaters and all New Ductwork



Install New Low Load, Retro-Fitted Sidewall Mounted Burners



New Low Load Burners for Startup and Low Load Operations

Reduce Startup Ignition Fuel Consumption
Improve Low Load "Turn Down"

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POWER Magazine, Feb. 2015 HR Improvements

"Upgrades" to Work Toward 6% Heat-Rate Improvement

Improvement	Range of heat rate benefit	Payback period
Improving combustion controls and monitoring	0.25%—1.00%	<1 year
Increased condenser cleaning and repair of air leaks	0.30%—2.00%	<1 year
Turbine seal improvements	0.50%—2.30%	1—3 years
Increased feedwater heater monitoring, maintenance, and repair	0.20%—1.00%	1—3 years
Air heater seal repair or upgrade	0.10%—0.50%	2—3 years
Preheating combustion air with waste heat	0.10%—0.30%	2—3 years
Increased cleaning of turbine deposits	0.25%—3.50%	2—4 years
Low-pressure turbine blade upgrade	1.00%—2.00%	2—4 years
Replacement of main fan motors with variable frequency drives	0.20%—0.50%	3—5 years

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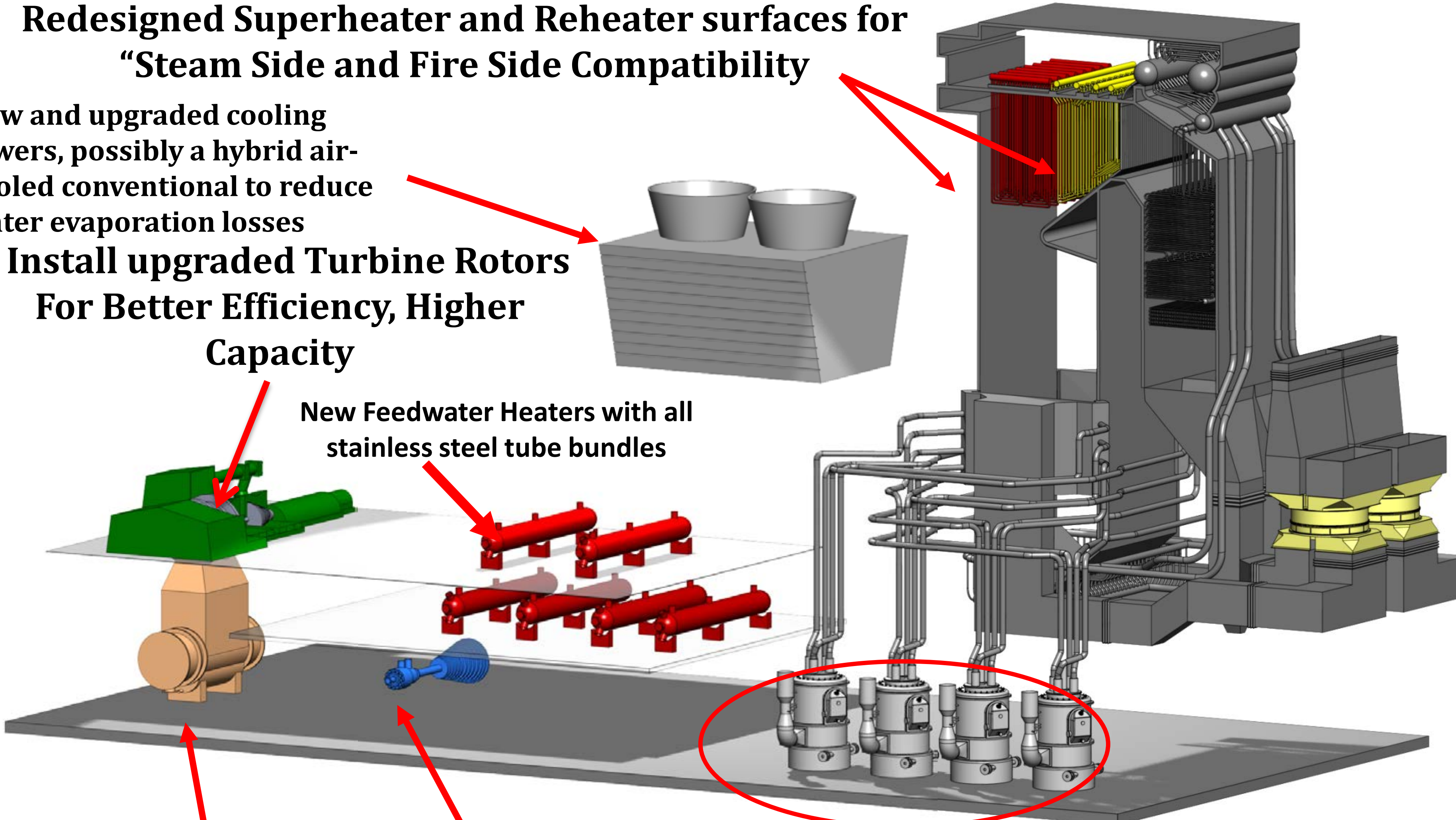
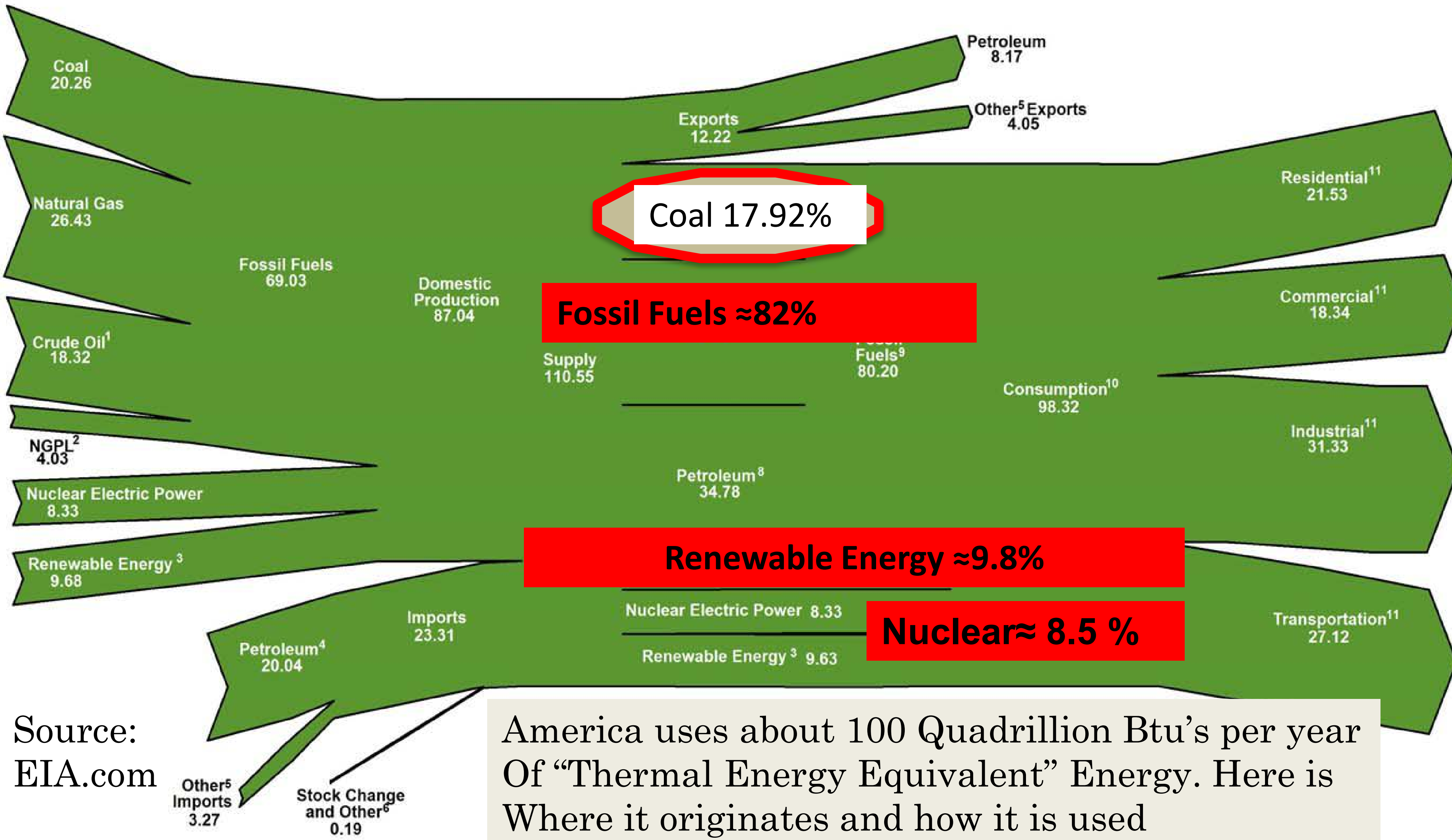
Is “UPGRADE” a Dirty Word?
Or is it a Viable Option to Improve Performance?



Just a Reminder, 90% of our Energy Comes from Traditional Sources, Including Coal

America's True Total Energy Supply & Demand



Source:
EIA.com

America uses about 100 Quadrillion Btu's per year Of "Thermal Energy Equivalent" Energy. Here is Where it originates and how it is used

Popular Myth: Renewable Power CAN Power America

Coal remains the most reliable energy source for Bulk Power supply. We should use it well! NSR prevents doing plant improvements for best efficiency!

Total Renewables by 2014 EIA:
9.8% of America's Energy

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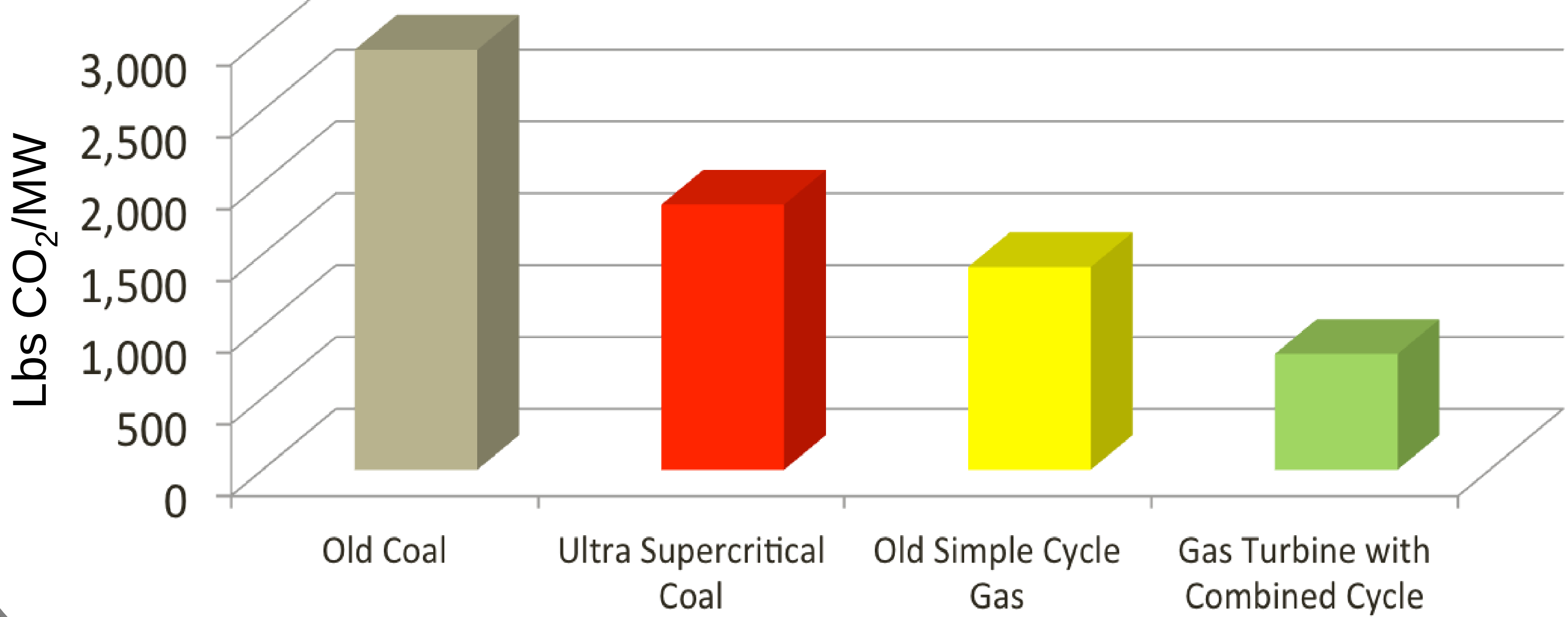
CO_2 Production per Megawatt



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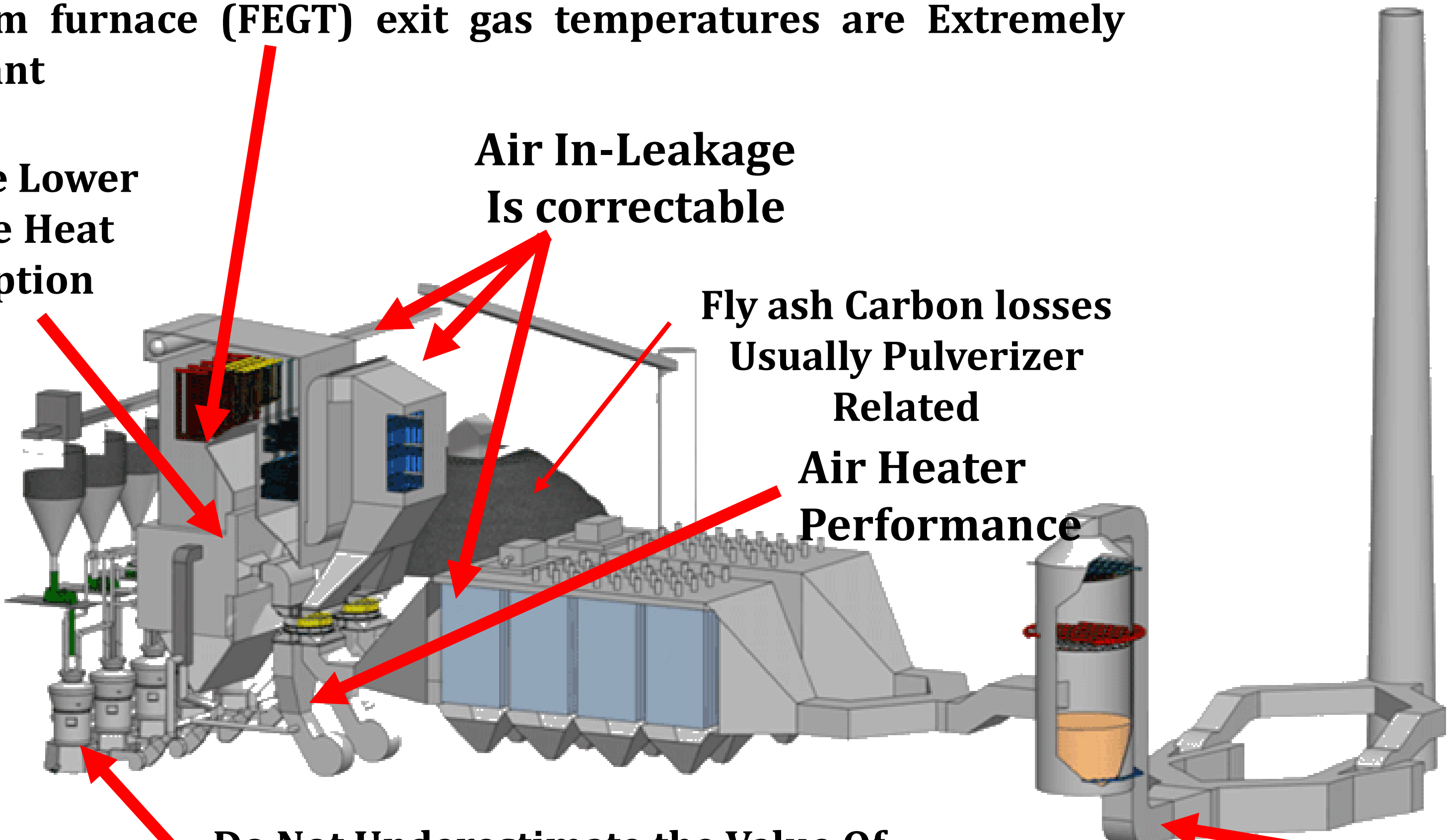
THE BEST HEAT RATE REQUIRES A COMPREHENSIVE APPROACH OF THE ENTIRE O&M TEAM AND LESS MEDDLING BY FEDERAL REGULATIONS



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More New Plants Like Turk and Iatan #2 Should Please All Groups! Good for Reliable Power, Good for American Manufacturing and Good for the Environment

Modern USA Built Ultra Supercritical Boilers

High Thermal Efficiency and Low Emissions

- Turk plant shown at right has 39% efficiency. One of the most efficient and cleanest coal plants in the world.
- Operates at supercritical pressure and steam temp. of 1,100° F.
- High Temp and pressures enable more efficient operation of Rankine cycle.
- Increase in efficiency reduces fuel consumption, and thereby reduces emissions.

AEP's John W Turk Jr Plant, the first ultra-supercritical generating unit.

Source: www.aep.com - Supercritical Fact Sheet

REFERENCES AND ADDITIONAL INFORMATION, FYI

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411 North Depot Street
Albemarle, NC 28001
Office: 704.983.2040

Thank You!

Any Questions?

Dick Storm

Ph 704-983-2040

Storm Technologies, inc.

PO Box 429

411 Depot Street

Albemarle, NC 28001

richard.storm@stormeng.com

www.stormeng.com