REINHOLD ENVIRONMENTAL Ltd.

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ASME ENERGY FORUM

Power Plant Efficiency: Saving Fuel

An abridged version of a webinar presented on September 25, 2014

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ASME
SETTING THE STANDARD

Outline

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- EPA Guidelines
- RCEEW Power Plant Efficiency Improvement Committee
- Basis of presentation
- Main Contributors
- Some Definitions
- Sargent & Lundy Report
- Coal-Fired Unit Components
- New Source Review (NSR)
- Summary – 6% Efficiency Improvement?

EPA Guidelines

- The U.S. Environmental Protection Agency (EPA) has proposed a new rule that will reduce carbon dioxide (CO_2) emissions from existing coal-fired power plants. Part of the rule is based on an EPA claim of improved plant heat rate of up to 6%. Some claim that no more than a 1% gain can be obtained while others claim that EPA was too conservative.

RCEEW Power Plant Efficiency Improvement (PPEI) Committee

- The RCEEW formed a new committee formed largely from the Fuel Delivery Systems Upgrade Committee and new members
- As the PPEI began its work, it was decided that the best way to publicize its efforts was through an ASME webinar – held on September 25, 2014

Basis of presentation

- Heat rate improvements are a good economical and proven method of reducing fuel usage and overall plant emissions.
- CO_2 reductions can be better achieved by keeping coal plant operating in a base loaded condition as opposed to low load, and cycling.
- This presentation looked at Power Plant Efficiency Improvement opportunities in the major component areas of a coal fired power plant.

Main Contributors

Experts in the field of design and operation of coal fired power plants.

- Block Andrews, Burns and McDonnell – *New Source Review*
- Grant Grothen, Burns and McDonnell – *Combustion* and *Fans*
- Peter Spinney, NeuCo – *Neural Networks*
- Jeffrey Kite, Diamond Power International, Inc. *Intelligent Sootblowers*
- Angelos Kokkinos, Babcock Power – *Boiler Island*
- Tony Licata, Licata Energy and Environmental – *Emissions Controls*
- Steve Moorman, Babcock & Wilcox – *Air Heaters*
- Cannon Pearson, Paragon Technologies – *Air Heaters*
- Peter Spinney, NeuCo Inc. – *Neural Networks & Intelligent Sootblowers*
- Michael Smiarowski, Siemens Power – *Turbine Island*
- Robert Sommerlad, Consultant – *Combustion*
- James Staudt, Andover Technology Partners – *Cycling Operations*

Basis of presentation (Cont.)

- The base of the evaluations is the 2009 Sargent & Lundy (S&L) report "Coal Fired Power Plant Heat Rate Reductions" used by EPA in their current rule on Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units.
- Heat rate is a common measure of a power plant's efficiency.
- We looked at what is the potential feasible *heat rate improvement*.
- The presentation also looked at how the different *heat rate improvement* opportunities interact with each other.
- It was also apparent that Electric utilities were already doing *heat rate improvements*

Some Definitions

- **Heat Rate** - the amount of energy that is input into the system divided by the electricity gen
  - ✓ Heat Rate, (Btu/kWh) = (Energy Input in Btu/hr)/(Power Output in kWh).
- **Heat rate** is reported as either gross or net:
  - ✓ Gross: the power output includes all output generated.
  - ✓ Net: the power output includes <u>only</u> the output that is sent to the power grid.

Some Definitions (Cont.)

- **Plant Efficiency - a**nother way of ranking performance is the reciprocal of **Heat Rate**:
  - **Plant Efficiency**, (%) = Power Output/(Energy Input) x 100 in consistent units.

In this presentation Heat Rate and Plant Efficiency are used interchangeably. When improvement changes are given in percent they are the same. A typical coal-fired power plant has a heat rate of 10,000 Btu/kWh or an Efficiency of 34.14%.

- **Capacity Factor** - the total output over a period of time divided by the total output over that time if it were running at full output the entire time.

Overview of the S&L Report

- The S&L report is a good report that describes power plant heat rate reduction opportunities.
- The report is specific to full-load operations and does not address the impact on power plant heat rates from cycling loads. Typically, cycling increases the power plant heat rate.
- The report was published in 2009 and many changes that it discusses have already been implemented by the electric power sector.

Overview of the S&L Report (Cont.)

- The report did not address whether some of the modifications discussed could trigger New Source Review (NSR).
- EPA added the findings from each section of the report and it is clear that adding each of the improvements to a total was not the intent of the report.
- The report does not look in detail at the impact of different coals (Bituminous, Powder River Basin (PRB), and Lignite) and boiler types in its power plant heat rate reduction analysis. Heat rate improvements on tangential-fired boilers are not applicable to cyclone units.

Steam Turbine and Condenser

Heat Rate Potential and Order of Magnitude Cost: Units 200 MW – 900 MW

Type of Upgrade	Estimated Heat Rate Improvement (from baseline), %	Cost of Hardware (M$ est.)
HP (high-pressure)	1.5 – 2.5	6.0 - 8.0
HP/IP	1.5 – 3.0	7.0 – 8.5
IP (intermediate-pressure)	0.2 - 0.5	7.0 - 8.0
LP (low-pressure)	0.5 - 2.0	7.0 - 9.5
Valves	TBD	TBD
Condenser	0.2 - 0.5	Unit Specific
Totals	**2.2 - 5.5**	**Unit Specific**

A 5.5% heat rate improvement is achievable through application of steam turbine and condenser technology upgrades on some older units. The above improvements may not be additive.

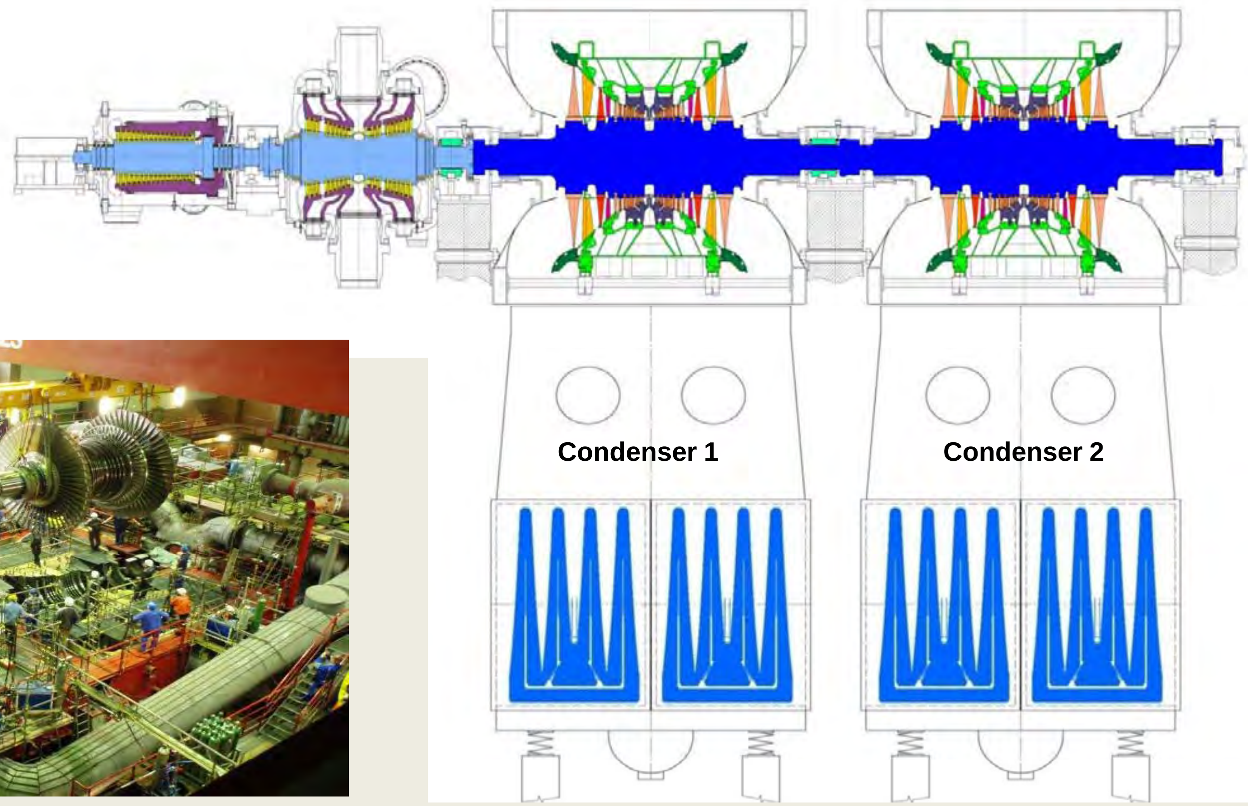
Heat Rate Reduction Optimization

Example: Ibbenbüren Coal Plant, Germany

Extended upgrade scope: all turbine sections + condenser + BoP

6% efficiency improvement achieved through extended scope

- **In service: 1985 – upgraded in 2009/10**
- **Nominal Rating: 752 MW**



Ref: John Walsh and Dr. Roland Sommer, "Modernizing of Steam Turbines and Condensers at Ibbenbüren Coal-Fired Power Plant" *VGB PowerTech* (2012)

Boiler/Turbine Cycle Optimization: Ibbenbüren Coal Plant, Germany

Site Assessment

General Status Quo Inspection

Integral Boiler/Turbine Modernization Study

Customer Requirements Detailed Inspection of Defined Areas

Integral Boiler/Turbine Cycle Optimization

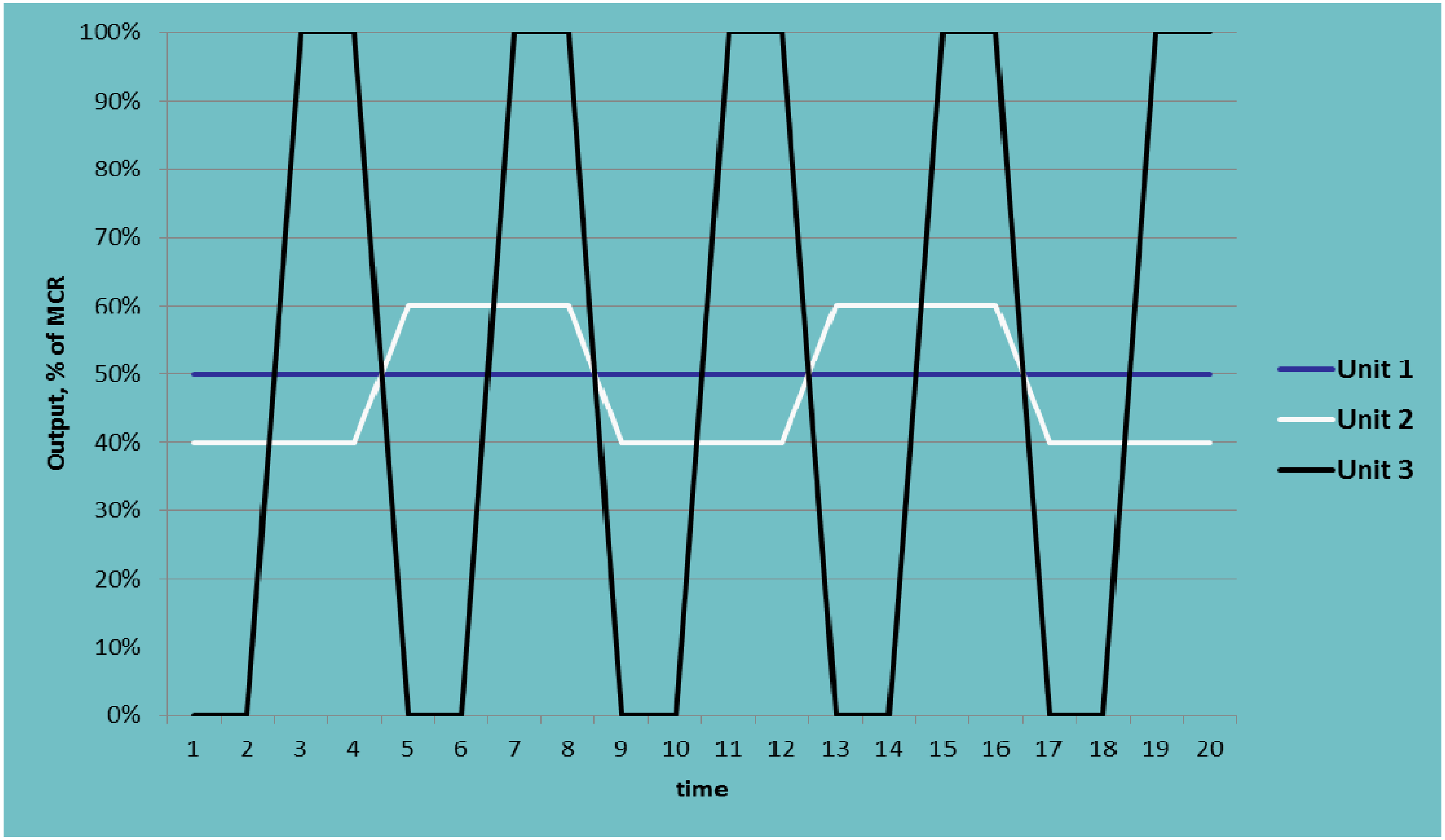
	Before Optimization	*After Optimization*
Live Steam	524 °C (972 °F)	534 °C (993 °F)
Reheat Steam	527 °C (981 °F)	538 °C (1000 °F)
Mass Flow	618 kg/s (4.905 mpph)	640 kg/s (5.079 mpph)
Cooling Water	26 °C (79 °F) 10953 kg/s (86.9 mpph)	21 °C (70 °F) 15100 kg/s (119.84 mpph)

Cost / Benefit

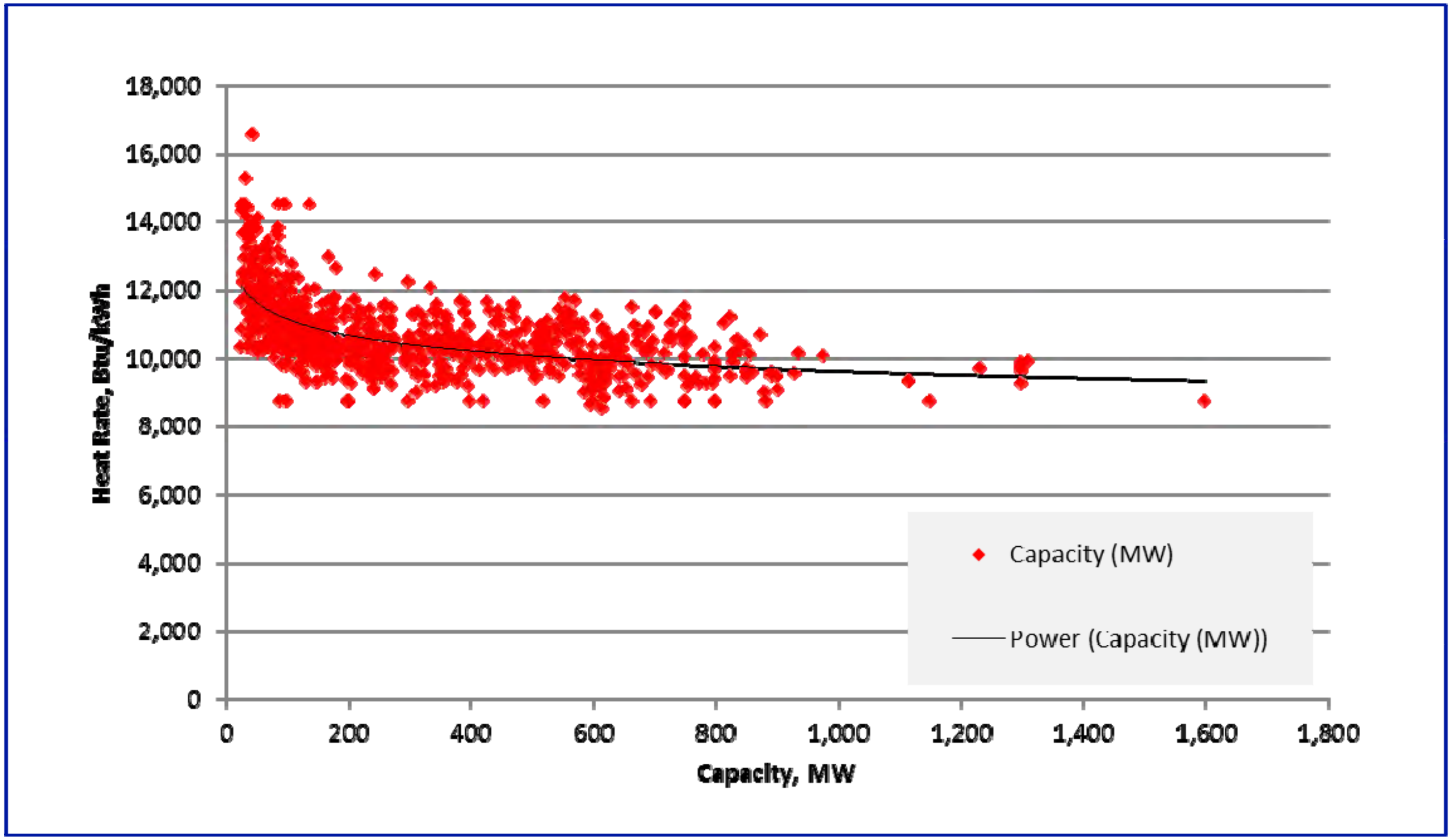
Positive Customer Decision

Award / Project Kick-off for Optimized Integral Boiler/Turbine Cycle Modernization

Units 1, 2, and 3 all have 50% capacity factor although their operation is very different.

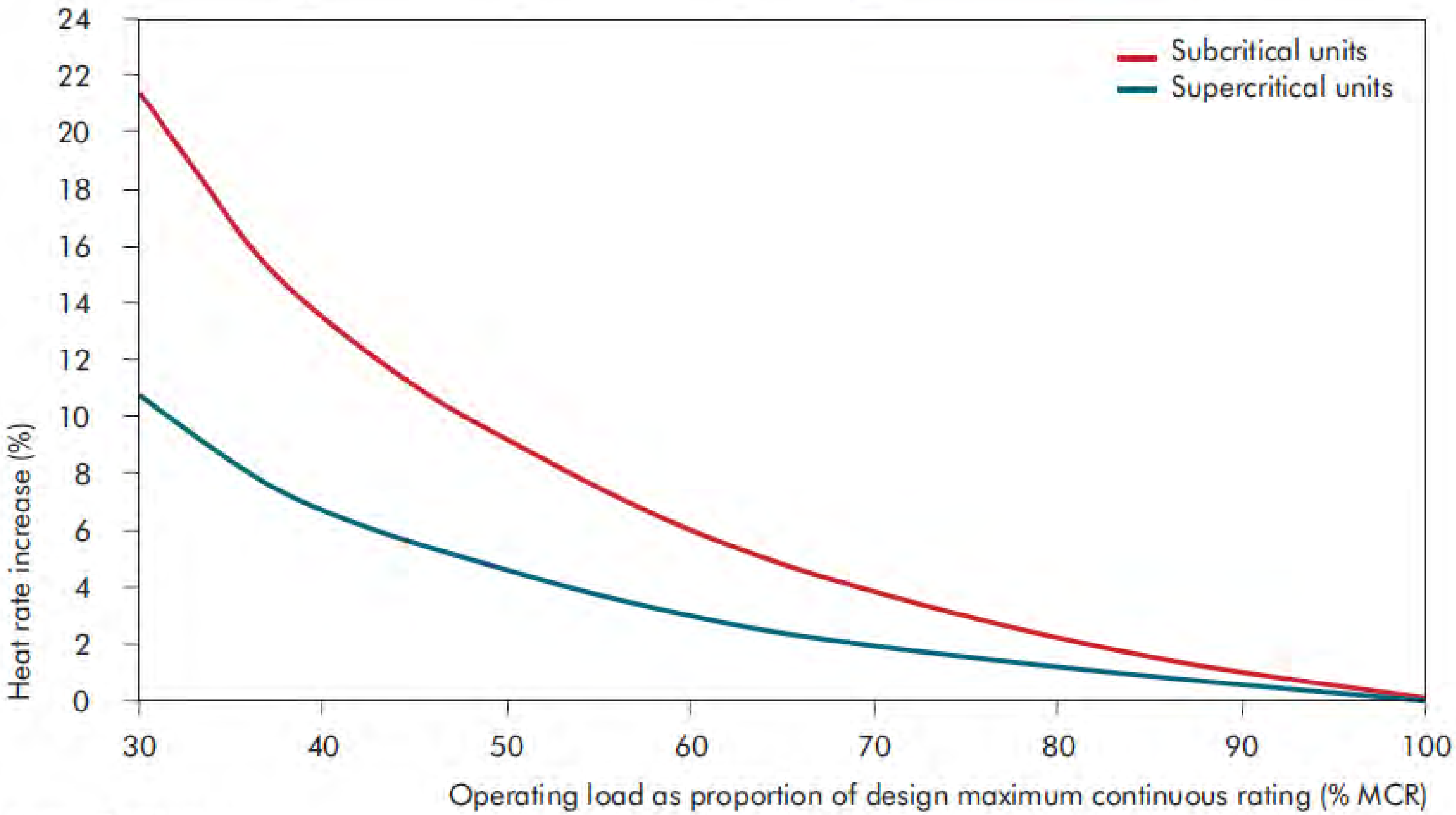


Effect of capacity on net heat rate



Effect of part load on heat rate

Impact is greater when load is changing



Source: E.ON UK plc.

FDS Upgrades– 500 MW PC Boiler

Component	Upgrade	Benefits
Feeder	New Feeders	Improved Flow Control
Pulverizer	Dynamic Classifiers	Increase Fineness (X50 Mesh) & Capacity (~5%)
Coal Pipes	Coal-air flow	Improved Flow Control
Burner Modernization	LNBs & OFA	Improved combustion Reduced NO_X & UBC; <NH_3
Boiler Control System	Neural Network	Improve Boiler Efficiency, NO_X & Fan Power; <NH_3

Impact on Excess Air → Combined effects of above upgrades reduced the Excess Air 6.7%, which results in 0.34% in boiler efficiency, and 15% reduction in fan power. Lower excess air also reduced NO_x emissions slightly.

Full-Load Performance Impact

- Full-Load Excess Air in Operating Units
  - Typical OEM design guarantees → 18%-20%
  - Common fleet PRB coal operating units → 16.4% (3% O_2)
  - Top fleet PRB coal units → 13.3% (2.5% O_2)
  - Bituminous coal units typically higher
- Potential Full-Load Efficiency Improvement (PRB Unit)
  - 16.4% → 13.3% → 3.1% decrease in excess air
  - 0.16% efficiency (heat rate) improvement
  - Comparison: S&L Heat Rate Improvement – Not Listed
  - Comparison: NETL Heat rate Improvement 0.15% – 0.84%

Part-Load Performance Impact

- Reduced Load Operation has Big Impact on Excess Air
  - Pulverizers (2:1 turndown) and associated burner elevations removed from service at lower loads
  - Out-of-service burners still require cooling air
  - Lowering flows reduces air penetration into boiler affecting thermal and emissions performance
- Excess Air Commonly Exceeds 20% at Reduced Loads
  - 13.3% - 16.4% → 20% → 3.6% - 6.7% increase in excess air
  - 0.18% - 0.34% efficiency (heat rate) deterioration
- Excess Air Can Approach 50% at Minimum Load
  - 13.3% - 16.4% → 50% → 33.6% - 36.7% increase in excess air
  - 1.68% - 1.84% efficiency (heat rate) deterioration

Negative Impact of Boiler Operating Conditions

Parameter	Change	Heat Rate Negative Impact*, %
Main Steam Temp.	- 10 °F	0.17
Hot Reheat Temp.	- 10 °F	0.16
Main Steam Press.	- 1%	0.06
Feedwater Temp.	-10 °F	0.27
SH Spray Flow	1% of steam flow	0.025
RH Spray Flow	1% of steam flow	0.4
Aux. Steam Flow	0.5% of cold RH	0.35
O_2	+ 5%	0.2
APH Exit Temp.	+10 °F	0.25

** Assumed a 10,000 Btu/kWh net heat rate;*

Fuel Switch or Co-firing

Fuel	Heat Rate Improvement	CO_2 Reduction, %
PRB Coal	0	0
Bituminous Coal	+1.3	8
Bit. Coal/24% NG	-0.9	9
PRB Coal/37% NG	-0.15	17

NOTE: *It is assumed that stack temperatures are equal. For stack temperatures to be equal boiler surface modifications may be required.*

Combustion Optimization with Neural Networks

- Results achieved through optimal mixing of fuel and air through model predictive control (MPC), adaptive neural networks and condition-based rules
  - NOx reductions of 10% - 15%
  - CO controlled to desired limit
  - Better ramping and load-following performance
  - Reduced opacity excursions
  - Better control of UBC
  - Better adherence to fan and mill amp limits
  - Improved situational awareness and process insight
  - Avoided tail-chasing behavior

Intelligent Sootblowing

- Published results:
  - 0.96% heat rate improvement
    - 650 MW, Tangential Fired, PRB coal
    - 12 hour test at full load
  - 0.77% heat rate improvement
    - 550 MW, Wall Fired, PRB coal
    - Multi-month average net daily heat rate
    - ISB a major contributor, but probably not the only contributor

Air Heater Function and Design

- **Design Criteria**
  - Designed in concert with economizer to maximize boiler efficiency by minimizing flue gas outlet temperature from the boiler
  - Air outlet temperature set by coal drying requirements
  - Gas outlet temperature set high enough to avoid corrosion and plugging due to condensation of moisture and/or acids
  - Pressure drop set to minimize fan power requirements
  - Gas outlet temperature needs to be high enough to support operation of Dry Scrubber /Baghouse if so equipped

Factors Impacting Air Heater Performance & Heat Rate

- **Increase in air leakage** due to degradation of the sealing surfaces or failure of air heater tubes from corrosion or erosion (Fan Power/Thermal Performance)
- **Loss of thermal performance** due to loss of heating surface from corrosion and/or pluggage of heating surface (Thermal Performance). Each 10 degree increase in AH gas outlet equals ~ 0.25% loss in heat rate
- **Increase in pressure drop** due to ash deposition on heat transfer surfaces (Thermal performance/ Fan Power)
- In most cases cannot improve heat rate more than design

Selective Catalytic Reduction (SCR) Improvements

- S&L Report states that additional surface area can be added to economizer to gain heat rate improvement.
- Over 50% of the coal-fleet has SCRs.
- Adding surface area to the boiler would interfere with the SCR operations. This eliminates a large percentage of the MW capacity that may capable of this type of heat rate improvement.

Flue Gas Desulfurization (FGD) Improvements

- Venturi Units - Almost all of the venturi units have been removed, therefore, there can be no system-wide improvements.
- Application of VFD recycle pumps is not practical for most installations
- Oxygen-air blowers are a potential source of power savings and should be evaluated further

Electrostatic Precipitation (ESP) Power Reductions

- Since the report was written in 2009, there have been a number of ESPs that have already been upgraded with modern voltage controls to meet the MATs rule. EPA should survey the industry to determine if this is an option that can be added to the list of improvements.

What Triggers NSR for an Existing Unit?

Definition: A Physical modification or change in method of operation that results in a net emissions increase over the significance levels.

What Has Triggered NSR?

- New Low NO_X Burner Replacements
- Non "Routine" modifications and repairs (economizer, steam turbine, air heater, feedwater heaters)
- Efficiency improvements (economizer, steam turbine, air heater, feedwater heaters)
- Re-dispatch that is coincidental to repairs
- Fuel conversions

An Example of Triggering NSR

- Proposed new Low NO_X Burner replacements
  - A 500-MW with new LNBs lowers NO_X but increases CO from 100 ppm to 110 ppm
  - CO increase is over 250 tpy above CO significance threshold of 100 tpy
  - NSR would be required for CO increase

Is the Modification a Physical or an Operational Change?

- Excludes routine maintenance, repair and replacement (RMRR) activities
- “Routine” is not defined
  - Landmark court case, 1990, Wisconsin Electric Power Company (WEPCO) v. Reilly.
  - Determined RMRR by “nature & extent, purpose, frequency, and cost”
  - No single factor is dispositive (conclusive)
  - No activity is categorically exempt

So, What Has Triggered NSR?

- New construction (new burners)
- Non "Routine" modifications and repairs (economizer, steam turbine, air heater, feedwater heaters)
- Efficiency improvements (economizer, steam turbine, air heater, feedwater heaters)
- Re-dispatch that is coincidental to repairs
- Fuel conversions

Other Heat Rate Improvements Used by EPA & Projects that Have Triggered Notices of Violation

Activity	Assumed Heat Rate Improvement		NSR NOV Project Identified by EPA*	Potential Non-NSR Heat Rate Improvement	
	S&L (Btu/kWh)	NETL (percent)		S&L (Btu/kWh)	NETL (percent)
Economizer Replacement	50 - 100	2.1	Yes	0	0
Neural Network	50 - 100	0.2 - 2.0	No	50 - 100	0.2 - 2.0
Intelligent Sootblowers	30 - 90	0.1 - 0.65	No	30 - 90	0.1 - 0.65
Air Heater/Duct Leakage	10 - 40	0.16 - 1.5	Yes	0	0
Lower Acid Dewpoint (Trona)	50 - 120	0.3 - 1.5	No	50 - 120	0.3 - 1.5
Steam Turbine Upgrades	100 - 300	0.84 - 2.6	Yes	0	0
Clean Condenser	30 - 70	0.7 - 2.4	No	30 - 70	0.7 - 2.4
Boiler Feed Pump	25 - 50	Not listed	No	25 - 50	Not listed
Fan replacement/VFD	30 - 150	Not listed	No	30 - 150	Not listed
Misc. AQCS upgrades	0 - 65	Not listed	Yes	0	Not listed
Cooling Tower	0 - 70	0.2 - 1.0	No	0 - 70	0.2 - 1.0
Other	0 - 20	Not listed	No	0 - 20	Not listed
Ash Removal System	Not listed	0.1	No	Not listed	0.1
Combustion system optimization	Not listed	0.15 - 0.84	No	Not listed	0.15 - 0.84
Feedwater heaters	Not listed	0.2 - 2	Yes	Not listed	0.2 - 2
Flue Gas Moisture Recovery	Not listed	0.3 - 0.65	No	Not listed	0.3 - 0.65
Coal Drying	Not listed	0.1 - 1.7	No	Not listed	0.1 - 1.7
Reduce slagging	Not listed	0.4	No	Not listed	0.4
Steam Leaks	Not listed	1.1	No	Not listed	1.1
Total	375 - 1,175	6.95 - 20.54		215 - 670	3.85 - 14.34

** Some additional activities not specifically flagged in this column to trigger NSR could still trigger NSR. For example, for steam leaks that are significant enough that require significant replacement of parts could trigger NSR.*

Summary

- Power plant heat improvements is a proven method for reducing CO_2 emissions.
- The amount of heat rate improvements depends on:
  - Plant location, design, age and size
  - Coal type, cooling system type, type of APC equipment
  - Electric grid dispatch
  - Time of year/weather
  - O&M practices
- Only by changes in legislation and rulemaking can the NSR issue be resolved.

Summary (cont.)

- Increased use of renewables will increase the cycling duty of coal fired plants resulting in a degradation of their heat rate
- Most of the anticipated 60 - 88 GW of smaller, older coal fired plants to be shut down by 2020 are less efficient units but where most of the heat rate improvements can be made.
- 6% Efficiency Improvement? Not likely!

Questions?