

REINHOLD ENVIRONMENTAL Ltd.



2016 NO_x-Combustion-CCR Round Table Presentation

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ONE SOURCE • ONE PURPOSE • MANY SOLUTIONS



Boiler Tuning for Emissions & Efficiency Improvements

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Presentation Outline

- Review of environmental regulations
- Tuning unit for emissions & efficiency
 - Preparation required
 - Development of test matrix
 - Test execution
 - Reporting
- Summary



Environmental Regulations

Overview

- Energy producers under ever increasing pressure to comply with environmental regulations
- Discuss two recent developments/rules:
 - Requirement for tuning
 - Clean Power Plan (CPP)



CFR 40 Part 63 Subpart JJJJJ - Rule

What does it say?

- Part of the Boiler Area Source Rule
- Requires the re-establishment of the proper air and fuel mixture to ensure proper combustion
 - Primary goal is to improve boiler efficiency with respect to combustion operations
 - Provide safe and efficient combustion
 - Use of carbon monoxide (CO) as a measure of complete combustion
- Annual testing for units >10 MMBtu/hr input
 - Testing by a qualified, experienced technician
 - Testing performed at high firing rate (i.e., full load)
 - Keep records on site



CFR 40 Part 63 Subpart JJJJJ - Rule

What does it entail

- Preparation
 - Record gathering
 - Current emission limit (NO_x and CO)
 - Instrumentation
- As found observation
- Tune up
- Documentation



Boiler Tuning

Preparation

- Gather and review unit information
 - Drawings
 - Operating instructions
 - Environmental permit requirements
 - NO_x
 - CO
 - UBC
 - Instrumentation required
- As found condition
 - Combustion equipment condition
 - Boiler condition
 - Combustion system operating condition
 - Flame
 - Flue gas composition (O₂, CO, NO_x, etc.)
 - Boiler performance (e.g., flue gas temperature, steam, etc.)
 - Pulverizer condition



Boiler Tuning (cont'd)

Tuning

- Identify issues that prevent optimum operation related to:
 - Equipment
 - Operation
 - Fuel
- Repair equipment if needed
 - Pulverizer, burner, soot blower, etc.
- Develop test matrix
 - Address operational issues identified
 - Flame shape
 - Fineness
 - Fuel flow distribution
 - Flue gas flow imbalance
 - Stoichiometry, etc.
- Gather data



Boiler Tuning (cont'd)

Report

- Indicate the results of the tuning
- Provides recommendations for future operation



Environmental Regulations

Clean Power Plan (CPP)

- Each state is given an average CO₂ emission goal in lbs/MWh to be met by 2030
 - The goal represents a 32% reduction from 2005 CO₂ levels
 - States are also required to show progress towards the 2030 goal in 2022

The EPA suggests that states can meet the goal, using the following strategy:

1. Heat rate improvement for coal/oil units:

- 2.3% - - Texas interconnection
- 2.1% - - Western interconnection
- 4.3% - - Eastern interconnection

2. Redispatch – increase utilization of GTCC to 75% of unit's summer capacity at the expense of steam coal, oil and gas - fired units

3. Expanded use of renewables – meet EPA derived renewable generation target

- Each state is given a potential renewable generation target



Heat Rate Definition

- Heat rate is defined as the energy consumed to generate useful electrical output.

$$\text{Heat Rate (Btu/kWh)} = (\text{Energy Input in Btu/hr}) / (\text{Power Output in kW})$$

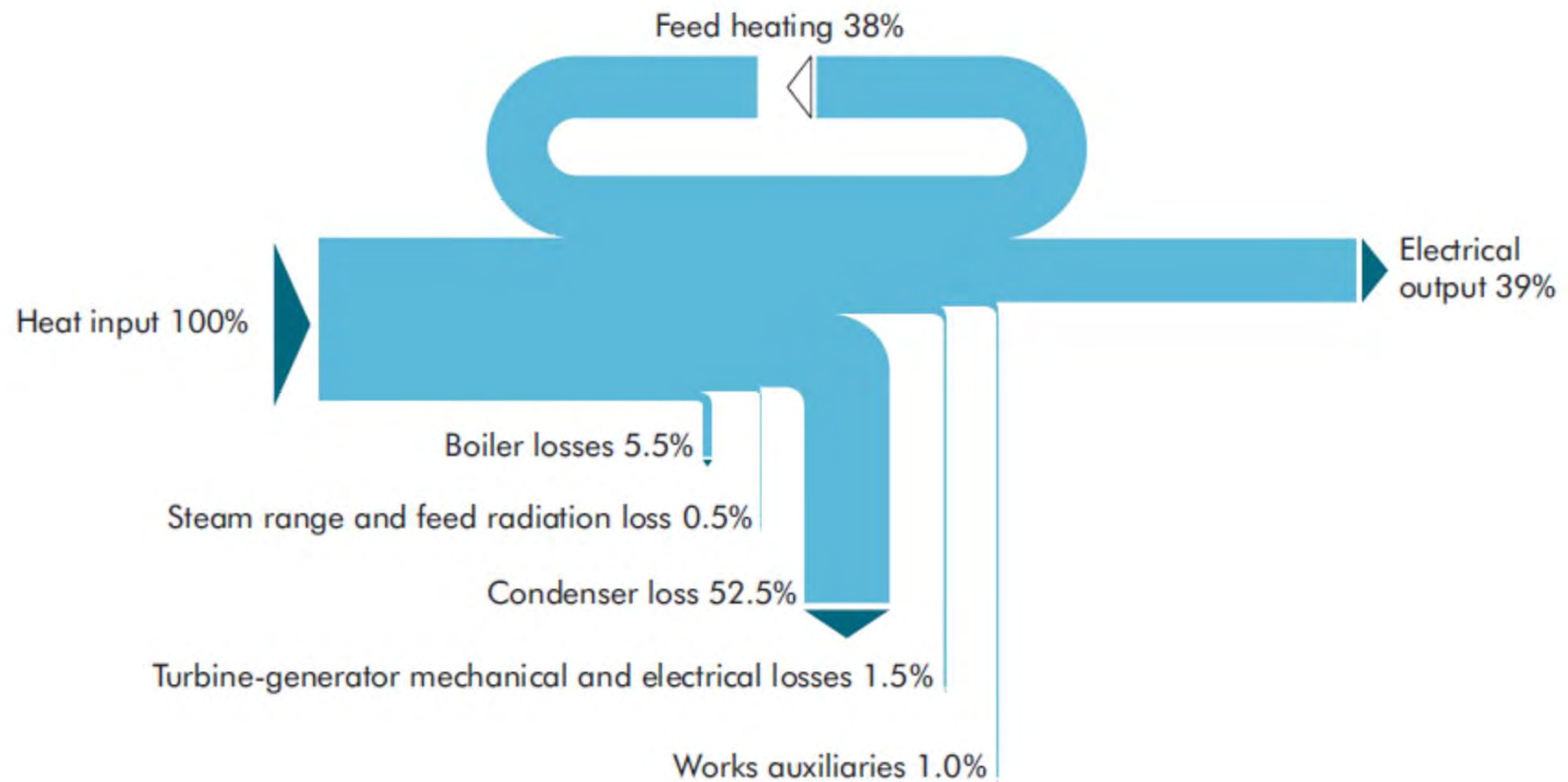
- Heat rate is reported as either “Gross” or “Net”
 - Gross: the output includes all electrical energy generated
 - Net: the output includes only the electrical output sent to the grid
- Another term is Plant Efficiency which is the “reciprocal” of Heat Rate

$$\text{Efficiency (\%)} = ((\text{Power Output}) / (\text{Energy Input})) \times 100$$



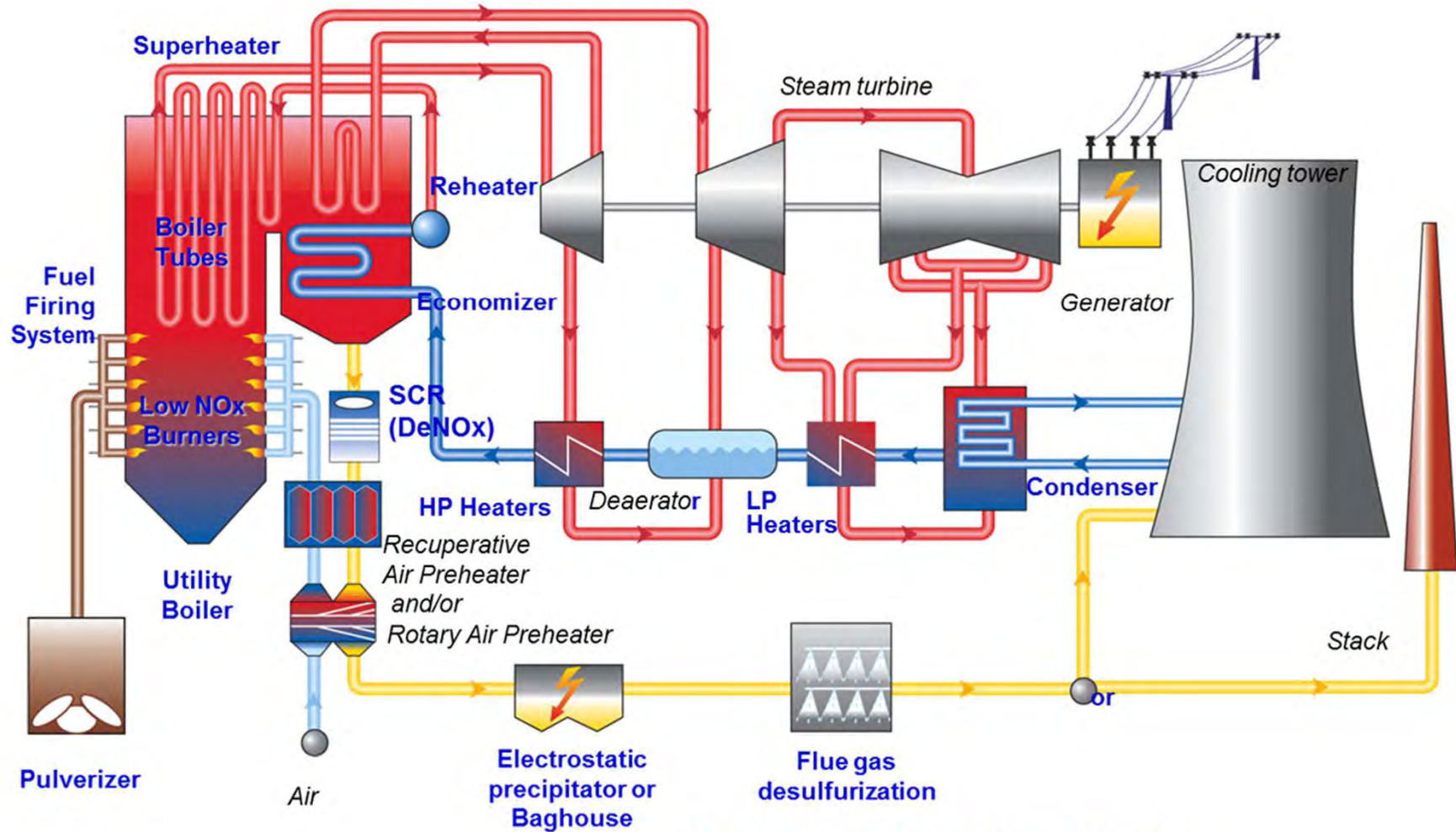
Power Plant

Equipment Impact on Efficiency (* LHV method)





Typical Coal Power Plant



Group Technology labeled in blue

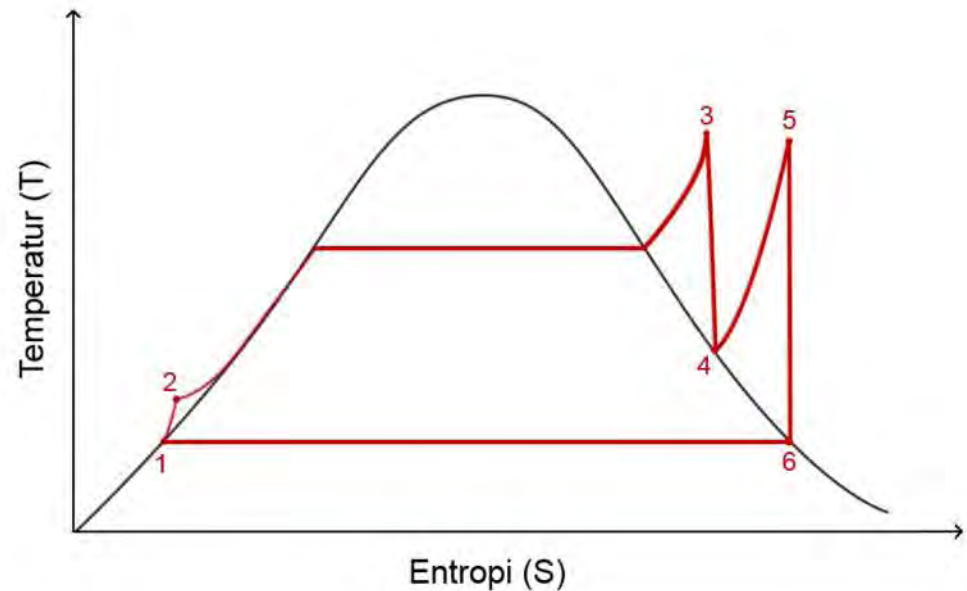


BOILER PERFORMANCE



Heat Rate Basics

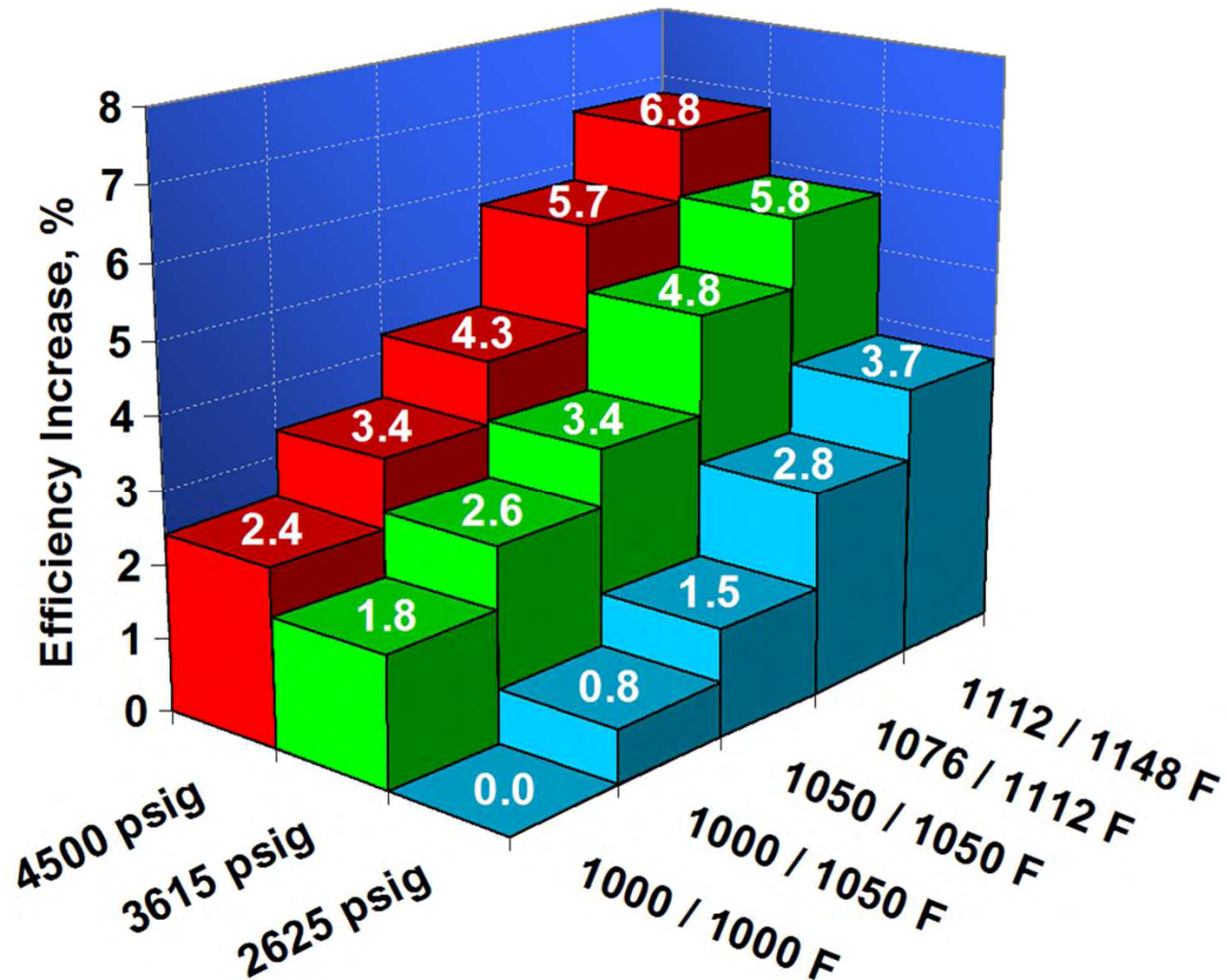
- Rankine thermodynamic cycle is used exclusively in coal power plants
- Process Steps
 - 1-2: Increase pressure of condensate, then increase temperature through economizer
 - 2-3: Increase energy by adding heat to get water to steam and superheated steam
 - 3-4: Expand steam through HP turbine
 - 4-5: Reheat steam through Reheater
 - 5-6: Expand steam through IP and LP turbine
 - 6-1: Condense steam in condenser





Boiler Design - Impact

Steam Conditions Play a Role





Heat Rate

Heat Rate Impacts

- Weather
- Fuel
- Boiler design
 - Boiler efficiency
- Turbine design
 - Turbine efficiency
- Condenser
- Cooling water
- Equipment out of service
- Unit operation/dispatch



Impact of Plant Operation on Heat Rate

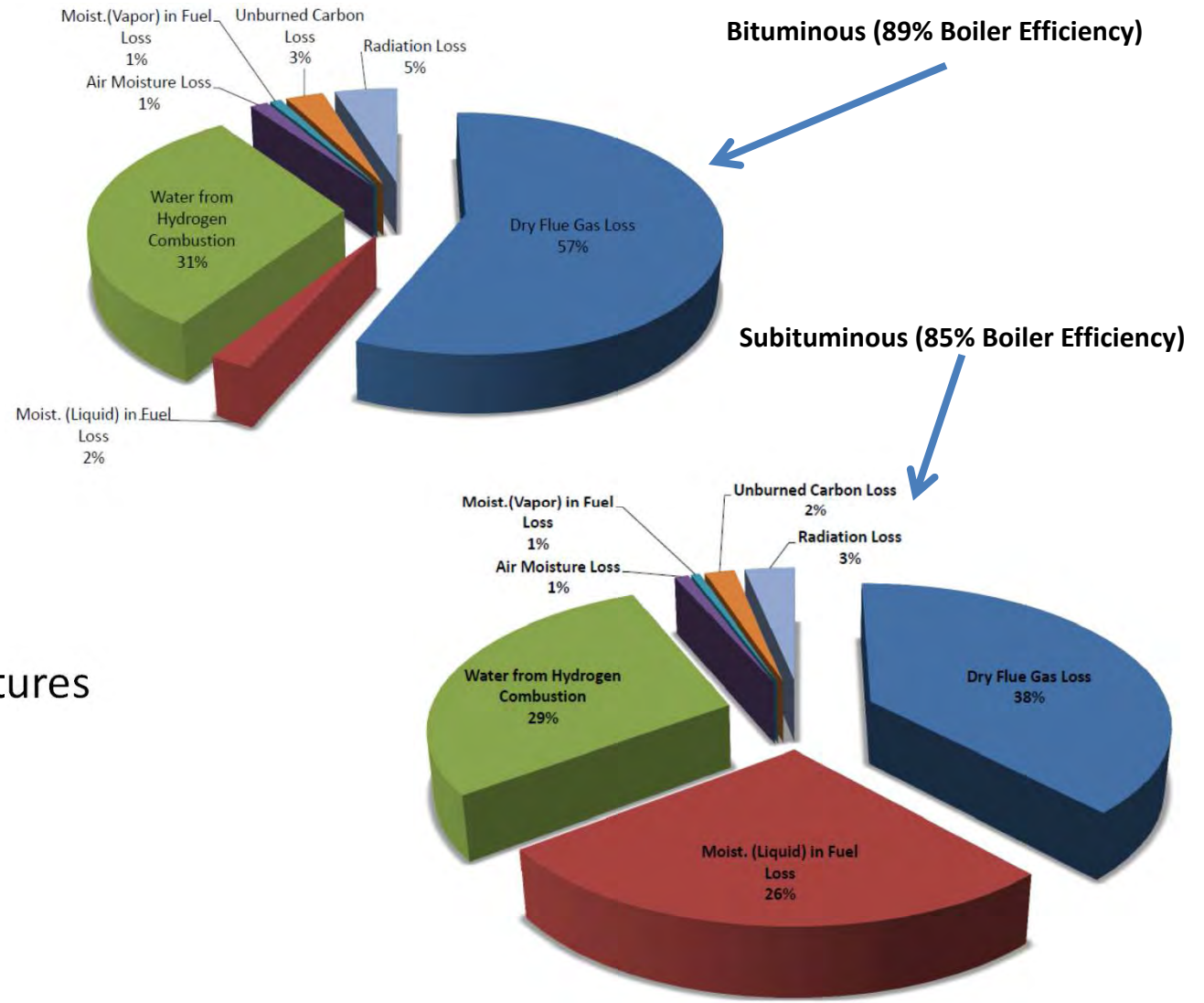
| Parameter | Change | Heat Rate Improvement, % |
|-----------------------|-------------|--------------------------|
| Superheat Temperature | + 10 °F | 0.17 |
| Reheat Temperature | + 10 °F | 0.16 |
| Reheat Spray | - 2 % | 0.4 |
| Condenser Press. | - 0.5 in Hg | 0.6 |
| Excess Oxygen | - 1% | 0.2 |
| APH Exit Gas Temp. | - 10 °F | 0.2 |



Coal Properties

Coal Properties Impacting Boiler Efficiency

- Heating value
- Moisture content
- Hardness
- Reactivity
- Ash chemistry
 - Alkalis
 - Calcium
 - Iron
 - Fusion temperatures





Impact on Boiler Efficiency

- Dry gas loss
 - Quantity and temperature of flue gas
 - Excess air
 - Maintain proper exit gas temperature
- Hydrogen and water in fuel
 - High hydrogen fuels
 - High moisture fuels
- Unburned carbon
- Flame length
- Boiler degradation
 - Surface fouling
 - Air preheater leakage
 - Pulverizer performance
 - Off design fuel
 - Heating value, Moisture content
 - Hydrogen content
 - Slagging/fouling characteristics
 - Sulfur content



Impact of Burner Parameters

Emissions

- Air and fuel flow
 - Near and far field burner stoichiometry
 - Flame length
 - Emissions (NO_x, UBC, CO)
 - Steam temperatures
 - Combustible losses (CO and UBC)
- Fuel moisture
 - Efficiency
 - Emissions
 - Pulverizer capacity
- Coal fineness
 - Emissions (NO_x, CO, UBC)



AS FOUND CONDITION TESTING



As Found Condition Test

- Could substitute operating data if there is enough data
- Use test to identify areas requiring attention:
 - Operational
 - Equipment
- Combustible losses identified as high CO and UBC
 - Fineness
 - Excess air
 - Flame length
 - Burner stoichiometry
- Steam temperatures
 - Excess air
 - Slagging fouling
 - Feedwater heaters



Tuning Test

Develop Matrix

- Matrix should address areas of deficiencies identified during the as found testing or review of existing operating data
- Typically you test impact of:
 - Excess air
 - Burner air register adjustments
 - Stoichiometry (e.g., OFA flow)
 - Pulverizer operating conditions
 - Fineness



Pulverizer System

Key Parameters Influencing NO_x Emissions & Efficiency

- Primary Air (PA) Flow Balance to burners
- Coal Flow Balance to burners
- Coal Fineness
- Primary Air to Fuel Ratio
- Mills in or out of service
- Effects on CO and UBC are more pronounced than NO_x emissions





Pulverizer System

Primary Air Flow Measurement

- Implement proper PA flow characterization
- Integrated with burner design
- Optimize the Primary Air / Coal Ratio throughout boiler load range
- Input for PA flow control
- Diagnosis for abnormal mill operation
 - Pluggage
 - Burner line layout
 - Erosion





Pulverizer Systems

How do you measure PA flow?

- Clean Air Basis
 - Coal pipe traverses with std. pitot probe and Mill Off Line
 - Primary Air Duct traverse with a s-type probe with the mill in operation
 - Airflow measuring devices such as Venturi, Pitot Array, ETC.
- Dirty Air Basis
 - Coal pipe traverses using dirty air probe with mill operating
 - On-line permanent/semi-permanent probe system
- LNB Requirements
 - Typically $\pm 15\%$ or less





Coal Feed Balance

- Typically mill to mill coal flows should be maintained within $\pm 5\%$
- The raw coal size entering the mill must be maintained to ensure proper and steady throughput.
- Mill and Feeder maintenance is essential to ensuring peak performance.



Coal Line Balance

Impact on Emissions & Performance

- Pre NSPS burners could maintain good repeatable performance with variations of $\pm 20\%$
- LNB typically require a coal pipe-to-pipe distribution of $\pm 15\%$ or less
- To achieve the best possible combustion emissions less than $\pm 5\%$ deviation pipe-to-pipe coal flow is ideal

How do you Balance Flow?

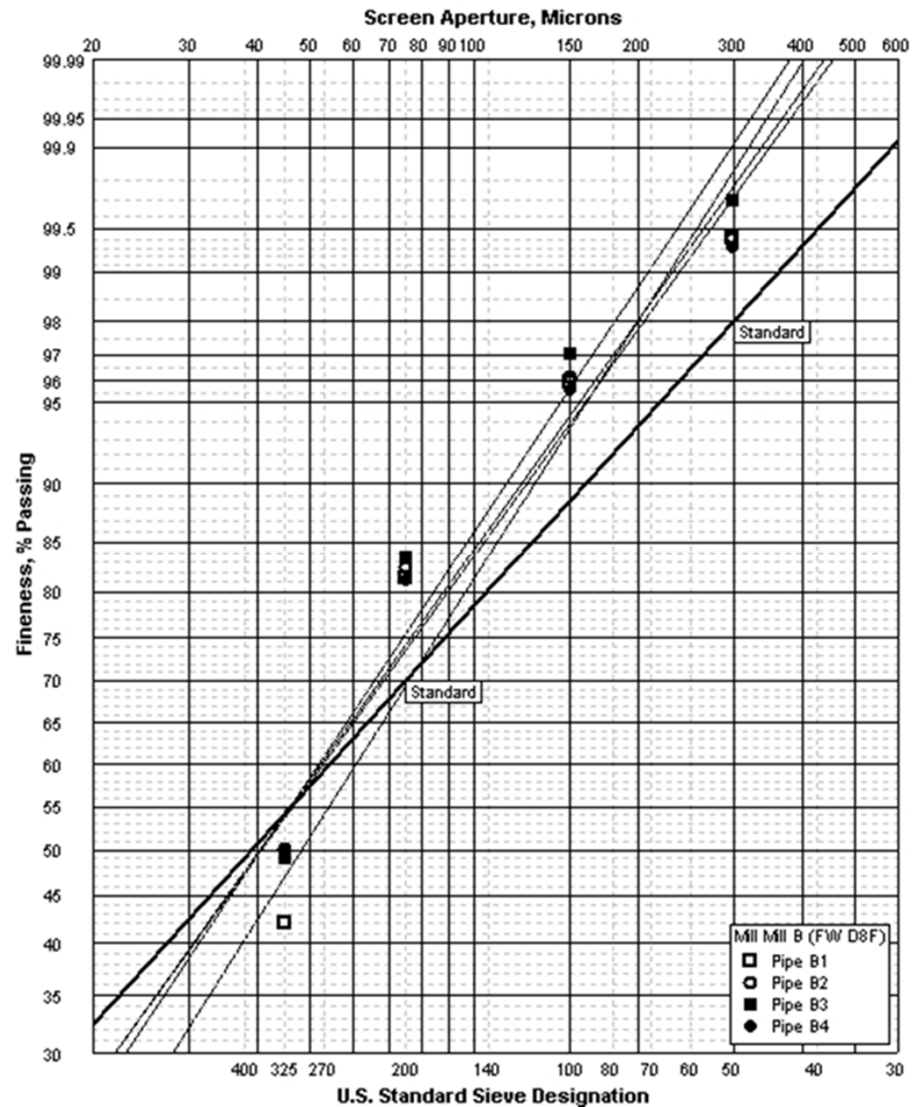
- Utilize coal balancing devices with on-line adjustment
 - Variable orifices
 - Coal Flow distributors
 - Classifier Adjustments
 - Classifier Inlet or Outlet distribution devices
 - Dynamic Classifiers



Coal Fineness

Basics

- Rosin-Rambler Plots
- Minimum fineness requirement
- 98% passing 50 mesh
- 70% passing 200 mesh
- Average Mill Fineness versus Coal Pipe fineness
- One coal pipe with poor fineness can have an effect on emissions

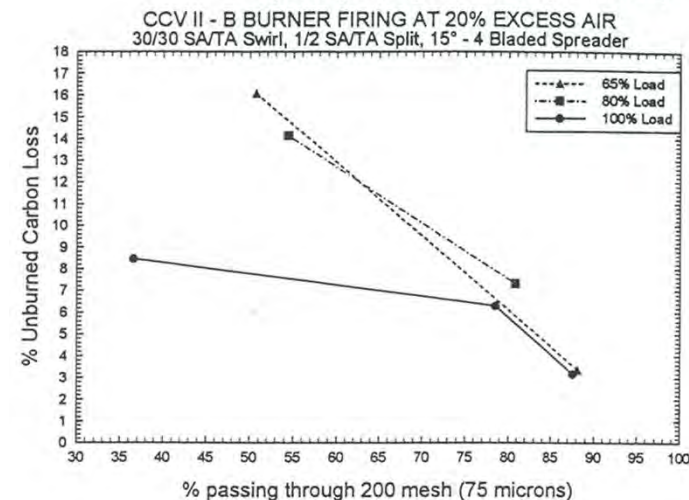
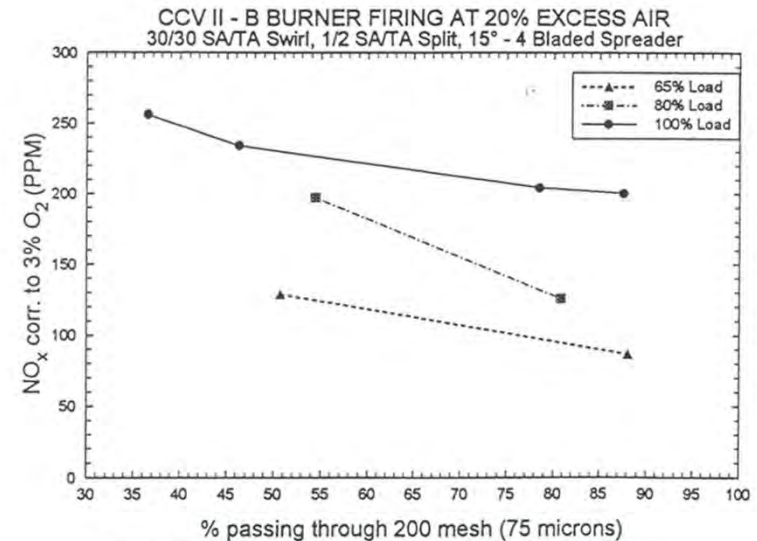




Coal Fineness

Impact on Emissions & Performance

- Coal fineness impacts Unburned Carbon (UBC, LOI) in ash
 - UBC is directly proportional to the fineness.
 - Small particles burn faster
- Maintaining the coal fineness over time is critical
- Coal particle size distribution directly effects emissions
 - Bituminous coal fineness is more critical
 - PRB (subbituminous) not so critical





EFFECTS OF BOILER SYSTEM CONDITIONS



Burner Air Register

- The operating functions of the Air Register are important to maintaining good low NOX emissions
- Controls the airflow balance from burner to burner
- Directs the secondary air entering the furnace and mixing (spin/swirl) with the coal.
- Controls the total secondary air to the burner
- Controls the w/f dP
- Swirl vanes need to be functional to support optimization for significant fuel variations over time
- Air modulation control is important to ensuring local burner zone stoichiometry can be controlled





Burner Condition

Fuel Side

- Ensure that flame side equipment is in good condition
 - Flame stabilizers
 - Coal distributors
 - Flame rings





Effects of Heat Absorption on Emissions

- Low heat absorption in the burner zone increases the local temperature and raises NO_x
- Reduced heat absorption in the radiant pendants increases fouling potential which can affect emissions
- Use of wallblowers and sootblowers are important to maintaining the furnace conditions for controlling peak temperatures
 - Especially on PRB coal firing
- Low economizer inlet water temperature can increase the firing rate



TUNING THE LOW NOX BURNERS

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Detailed Planned Approach

- Understand the goals of the testing
 - Is lowest NOx emissions the goal?
 - Is lower UBC or CO emissions the goal?
 - Is furnace conditioning the goal?
- Prioritize the goals for success
- Schedule req'd. unit loads for testing
- Schedule testing times but be aware of potential delays



Detailed Planned Approach (cont'd)

- A Test Matrix with a logical progression of tests designed to achieve the goals of the testing.
- Emissions sampling location and grid equipment
 - Portable analyzers versus a test truck
 - Test time versus cost



Typical Tuning Test Matrix

| Test # | Unit Load) | Windbox Dampers (°closed) | Swirl Vane (°) | BRN Air Balnce | % O ₂ wet | OFA Damper Bias | Flame Length Adj | Data and Samples Required ⁽¹⁾ |
|--------|------------|-----------------------------|----------------|----------------|----------------------|--------------------|------------------|--|
| 1 | MCR | As Found | 20 | As Found | 3.1 | 100/100 | 1 | BR, B, FO, G |
| 2 | | Bias per ⁽²⁾ 2.1 | | | | | | BR, B, FO, G |
| 3 | | | | | | | | BR, B, FO, G |
| 4 | | | | | | | | BR, B, FO, G |
| 5 | | | | | | | | BR, B, FO, G |
| 6 | | 30 | | | | | | |
| 7 | | 35 | | | | | | |
| 8 | | OPT | OPT | Bias per 2.3 | 2.7 | Balance | OPT | BR, B, FO, G |
| 9 | | | | BR, B, FO, G | | | | |
| 10 | | | | 2.6 | | | | BR, B, FO, G |
| 13 | | | | OPT | | | | BR, B, FO, G |
| 14 | | | | | | 2.5 ⁽³⁾ | BR, B, FO, G | |
| 15 | | | | | | 4 | BR, B, FO, G | |
| 16 | INT | | | | | OPT | ALL | |
| 17 | LOW | | | | | OPT | ALL | |

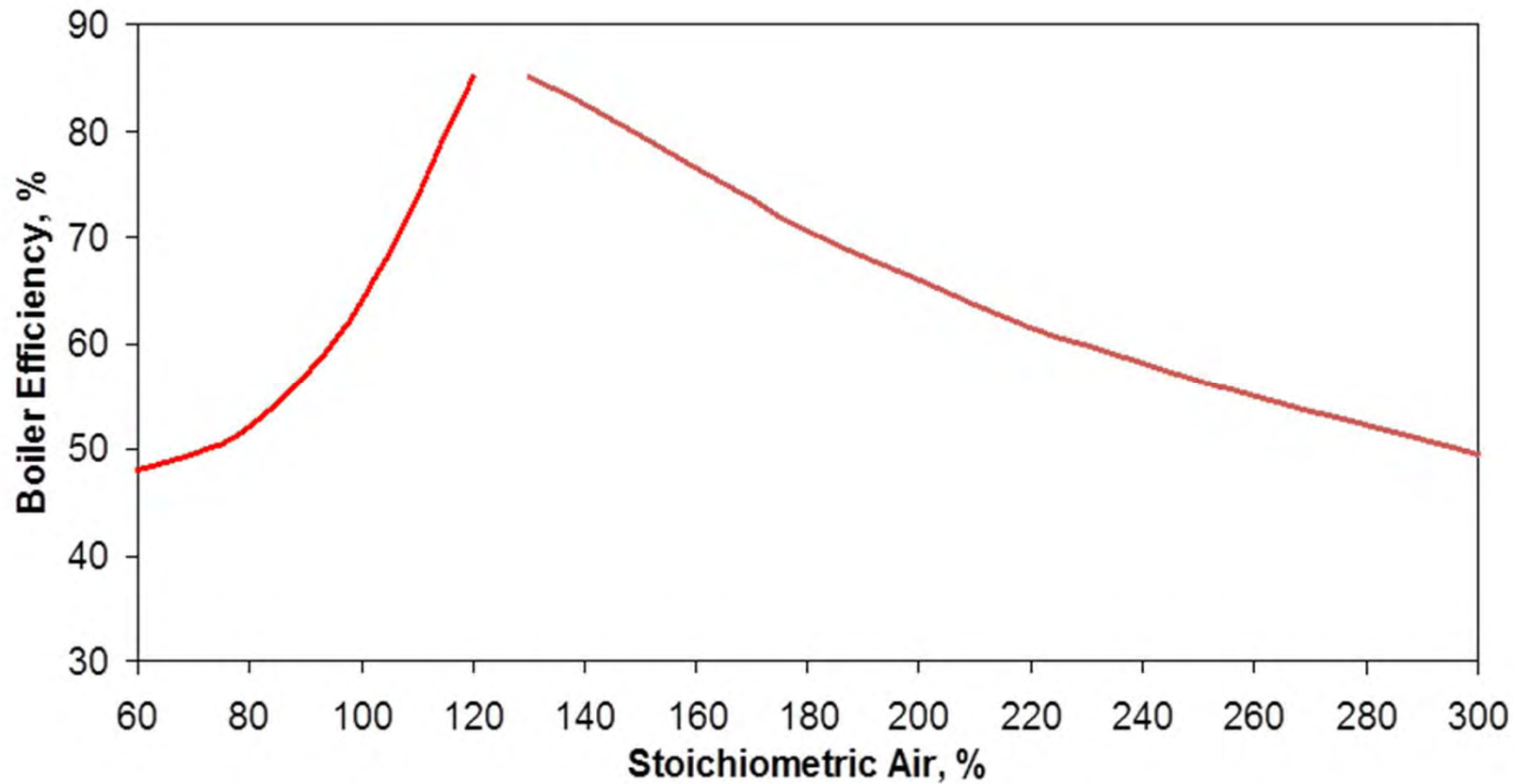


Boiler Operation/Tuning for Low Emissions

- Reduce the amount of excess air to the furnace as much as possible to achieve lowest NO_x while maintaining low CO and % UBC.
- Windbox to Furnace Differential Pressure should be optimized according to furnace and burner type and fuel being fired (~4.0 – 4.5” W/F dP seems best)
- Coal flow distribution to the furnace should be balanced to ±15%, PA distribution to ±10%.
- Balance air distribution to burners

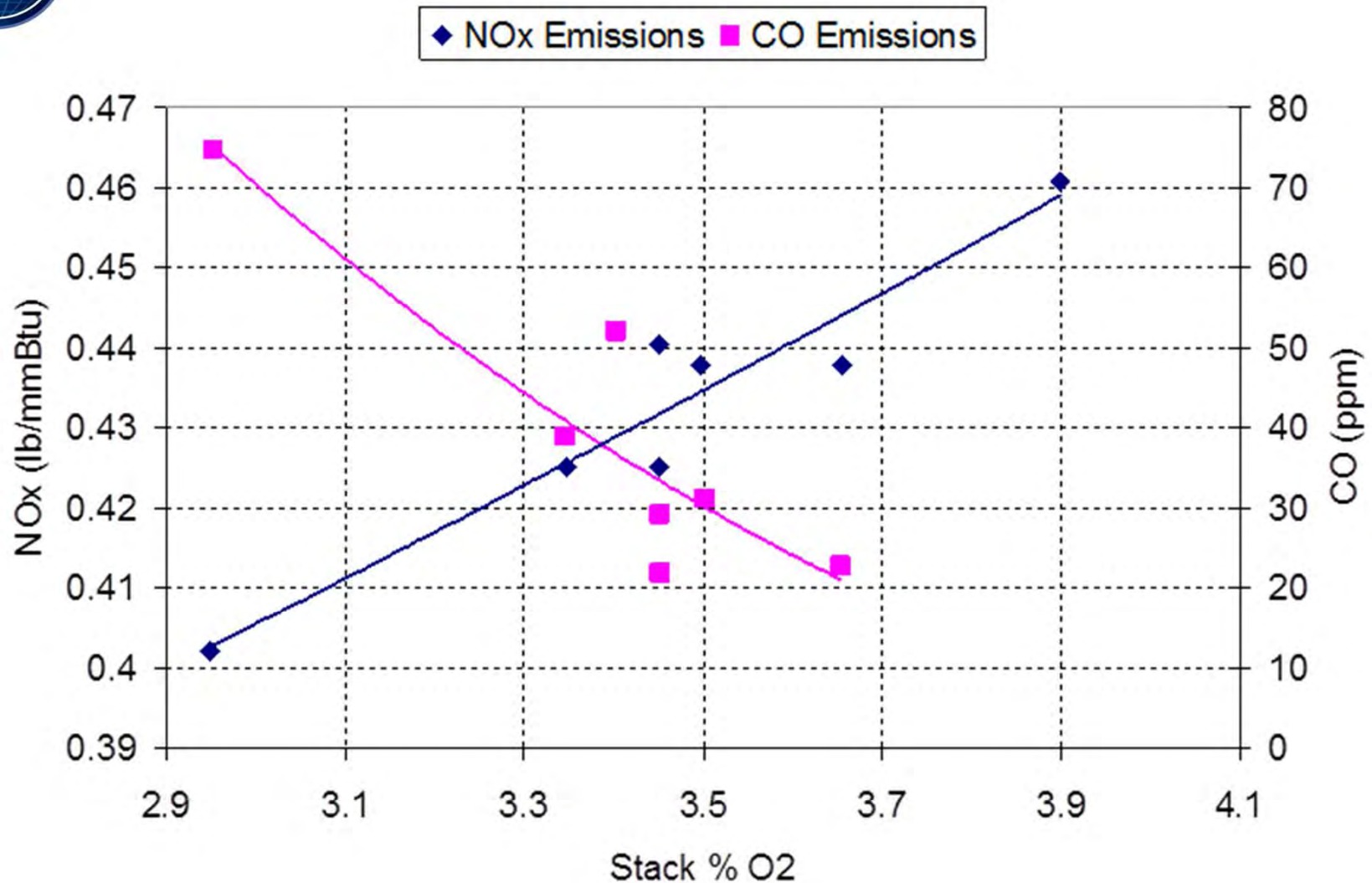


Impact of Excess Air on Emissions



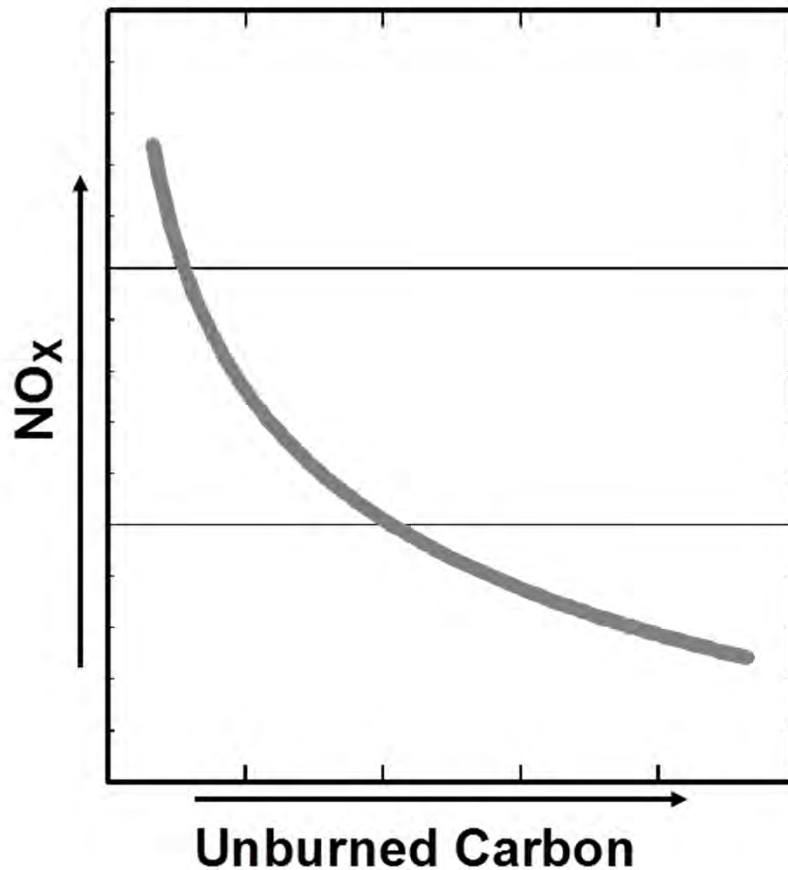


Impact of Excess Air on CO and NOx





Relationship of NO_x and UBC



- Coal properties
 - Coal Rank
 - FC/VM Ratio
- Coal fineness
- Operating conditions
 - Excess O₂
 - Boiler load



Optimization Strategies – Fuel Side

Fuel Side

- Primary Airflow Balance
 - Mill testing to determine the current airflow balance and identify any deficiencies
 - Install balancing devices as required to correct the airflow within +/- 10%
 - Confirm balance with testing on the mill
 - Good primary airflow balance can help minimize CO while achieving low NOx emissions



Optimization Strategies

Combustion Air Side

- Secondary Airflow Balance
 - SA balance begins at the FD Fan
 - Varying approaches can be utilized to improve the balance entering the burner
 - Divided windbox versus common windbox designs
 - Individual burner air balancing
 - Airflow measurement devices for assisting with balancing
 - CFD modeling of windbox and upstream ductwork
 - Economizer outlet grid O₂ measurement
 - Good Air distribution improves furnace conditions, decreases CO and NO_x emissions and lowers UBC



Optimization Strategies

Overfire Air

- Overfire Airflow Balance
 - Overfire Air system designs vary, but have some similarities
 - From the Windbox
 - From the Main Secondary Air Feed
 - From Booster Fans
 - Balance from port – to – port improves overall furnace distribution
 - biasing may be required depending on the furnace conditions
 - CFD modeling of the WB & Furnace for distribution and mixing
 - Balancing the low NOx Burners first with OFA closed can better isolate the OFA tuning.



Summary

- Careful review of current operating conditions
 - Characterize and operate the boiler within the known design ranges whenever possible
- Inspect combustion, fuel delivery and pulverizer equipment and repair if necessary
 - Maintain mill system at or near design conditions (PA & Coal Distribution, fineness, A/C)
 - Maintain the low NO_x burner on both the primary and secondary sides to ensure reliable long term performance
- Air and Fuel Balancing is key to any low NO_x burner optimization program.
- Documentation of the optimization testing is critical to reducing test time for any future testing.



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2. “Opportunities to Improve the Efficiency of Coal-Fired Power Plants”, NETL Workshop Report, July 2009
3. “Coal-Fired Power Plant Heat Rate Reductions”, S&L Report SL-009597, Jan. 2009
4. “Increasing the Efficiency of Existing Coal-Fired Power Plants”, Congressional Research Service, Report 7-5700, Dec. 2013
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6. “Standards for Steam Surface Condensers”, HEI 11th edition, 2012



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THANK YOU



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CONDENSER PERFORMANCE



Efficient Condenser Operation

Condenser Performance Impacts

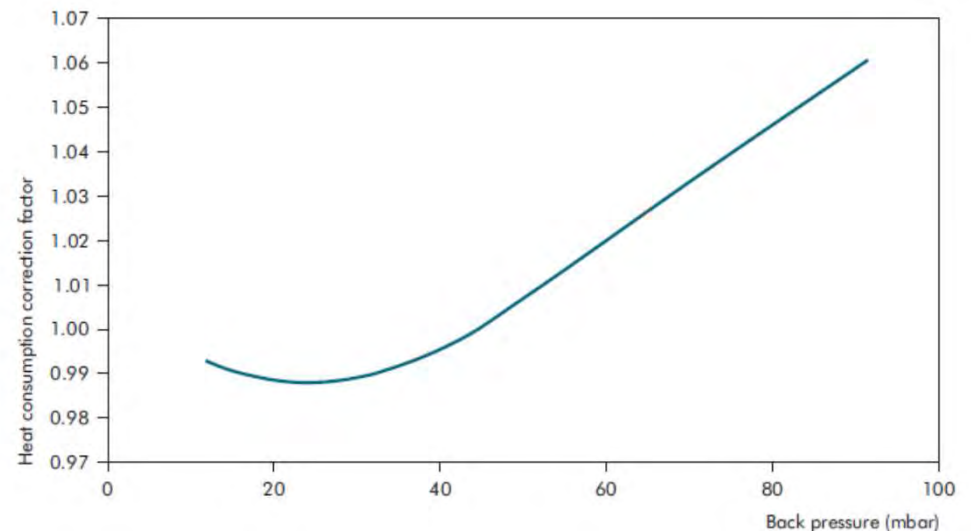
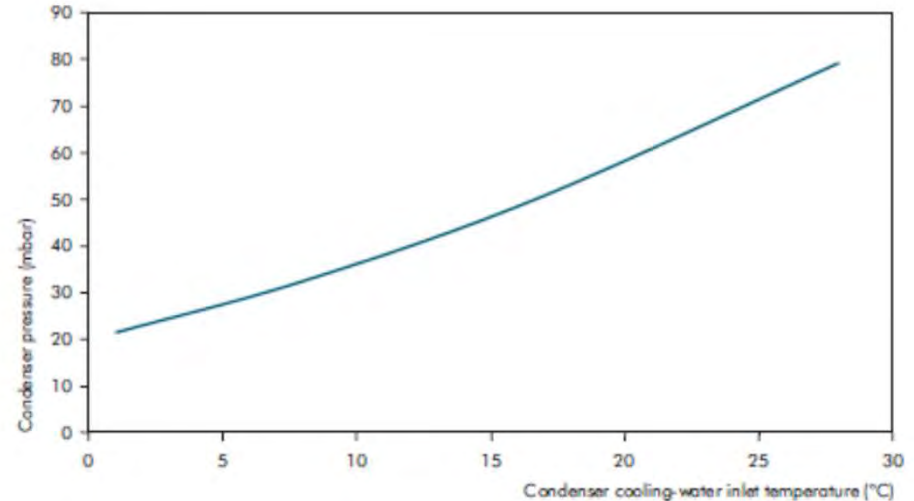
- Cooling water inlet temperature
- Heating load
- Circulating water flow
- Tube fouling
- Air in-leakage





Cooling Water Impact

- Probably the most significant impact on condenser performance
- Once through system there is generally no control on temperature
 - Provides best heat sink
- Closed loop system cooling tower performance plays a significant role
 - Ensure that all cooling tower cells are in service at peak temperature periods
- Ensure that condenser pressure matches the turbine supplier's "curve" for the heat load and temperature





Condenser Inefficiency

Heat Loading

- Increasing heat load increases condenser pressure
 - Normal operation it is associated with unit load increase
- Heat load increases other than unit load increase then:
 - Isolation issues such as startup drains, bypass lines or emergency drains send excess steam to the condenser
 - Turbine efficiency has degraded – more steam for same MW
 - Increase in turbine flow passing exceeds condenser design limitations

Circulating Water Flow

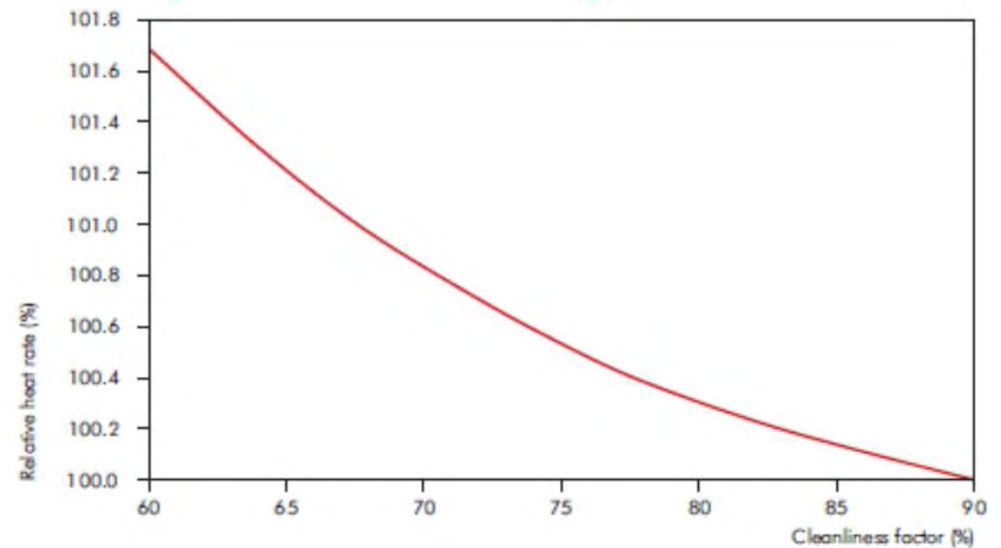
- Decreased water flow through condenser results in increased water temperature
 - Circulating pumps out of service
 - Discharge valves fully open



Condenser Inefficiency (cont'd)

Tube Fouling & Scaling

- Significant impact on condenser performance
- Scaling/fouling of the tubes maybe present if cooling water flow is normal and terminal temperature difference (TTD) is high
- Fouling is typically from organic growth attaching to the water side
 - Chemical treatment of water reduces growth in a closed system
 - Mechanical cleaning of section(s) for once through system
- Scaling is typically caused by impurities in the water
 - Accelerated if pH in circulating water is high
 - Also accelerated through heating and some evaporation in cooling tower
 - Scaling can be reduced with proper blowdown and acid injection to maintain proper pH
 - In an once through system mechanical clean is only option





Condenser Inefficiency (cont'd)

Air In – Leakage

- Presence of air reduces the vacuum draw increasing pressure and efficiency loss
- Air in-leakage can occur through gland seals and through piping/components under vacuum
- Common items that cause leakage:
 - Inadequate turbine shaft sealing (low seal steam pressure)
 - Vacuum breaker leaks
 - Air leaking expansion joints
 - Various under vacuum components
 - Condenser and hot well instrumentation
 - Heater drains
 - Steam traps and drains
 - Condensate pump shaft seals
 - Flash tanks



Impact on Condenser Efficiency

- Any of the areas below causes the heat rejection to be less efficient causing an increase in condenser pressure:
 - Cooling water inlet temperature
 - Heat load
 - Circulating water flow
 - Tube fouling
 - Air in-leakage
 - Condenser degradation



Condenser Regaining/Improving Performance

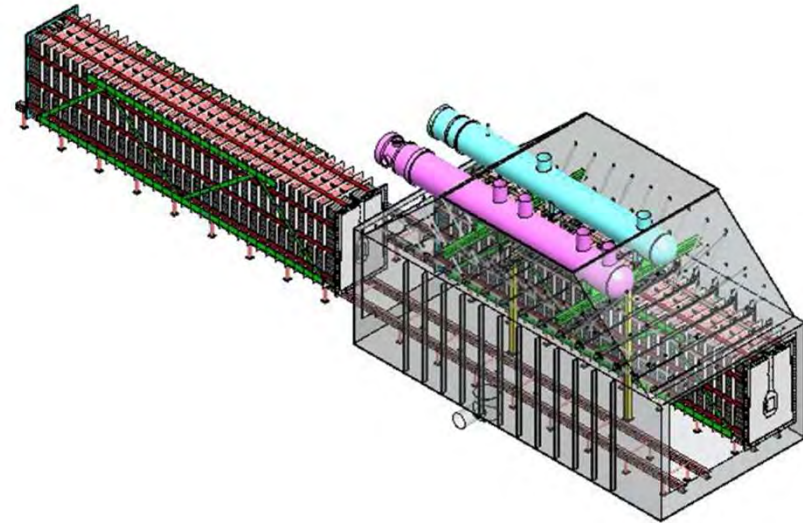
Module vs Retube

| | MODULE | RETUBE |
|---------------------|--|--|
| Capital Cost | <ul style="list-style-type: none"> • Higher Initial Cost | <ul style="list-style-type: none"> • Lower Initial Cost |
| Reliability | <ul style="list-style-type: none"> • Designed to Current HEI Std • Revised Support Plate Spacing • Optional Tube to Tubesheet Welding • Tube and Tubesheet Compatibility | <ul style="list-style-type: none"> • Tube to Tubesheet Compatibility? <ul style="list-style-type: none"> • Field Rolled Tube Joints • Tubesheet Ligament Damage |
| Performance | <ul style="list-style-type: none"> • Improved Back-Pressure • Maximized Water Flow • Increased Output | <ul style="list-style-type: none"> • Unchanged/Degraded Performance |
| Design | <ul style="list-style-type: none"> • Increased Effective Surface Area <ul style="list-style-type: none"> • Advanced Tube Layout • New Support System • New Tubesheets • New Waterboxes (Option) • Improved Deaeration | <ul style="list-style-type: none"> • Retain Existing Surface Area <ul style="list-style-type: none"> • Possible Tube Vibration • Need for Tube Staking • New Tubesheets (Option) • New Waterboxes (Option) |
| Installation | <ul style="list-style-type: none"> • More Complex Installation • Longer Duration* | <ul style="list-style-type: none"> • Less Complex Installation • Shorter Duration* |
| Quality | <ul style="list-style-type: none"> • Shop Based Quality & Control • OEM Manufacturing Experience • Single Source Engineering • Manufacturing (and Installation) | <ul style="list-style-type: none"> • Field Based Quality & Control <ul style="list-style-type: none"> • Field Based Work • Multiple Sources |



Condenser Summary

- **Costs**
 - MW Gain vs. No Gain
- **Bundle Configuration**
 - Packed Bundle vs. Liberal Steam Lanes
- **Desired Performance**
 - Retube- Same or Less
 - Module- Same or More
 - MW Gain?
- **Outage Duration**
 - <500 MW → Retube
 - >500 MW → Modules
- **Vibration**
 - Intermediate Support Plates vs. Staking
- **Material Compatibility**
 - Tubes and Tubesheets
 - Rolled Only vs. Rolled and Seal-Welded Tube to Tubesheet Joints



- **Tubesheet Pattern**
 - Moline vs. Lahr (Drawing Available?)
- **Retube Unknowns**
 - Tubesheet Condition
- **Shop vs. Field**
 - Tube to Tubesheet Joints
- **Performance Guarantee**
 - Retube → No
 - Module → Yes!

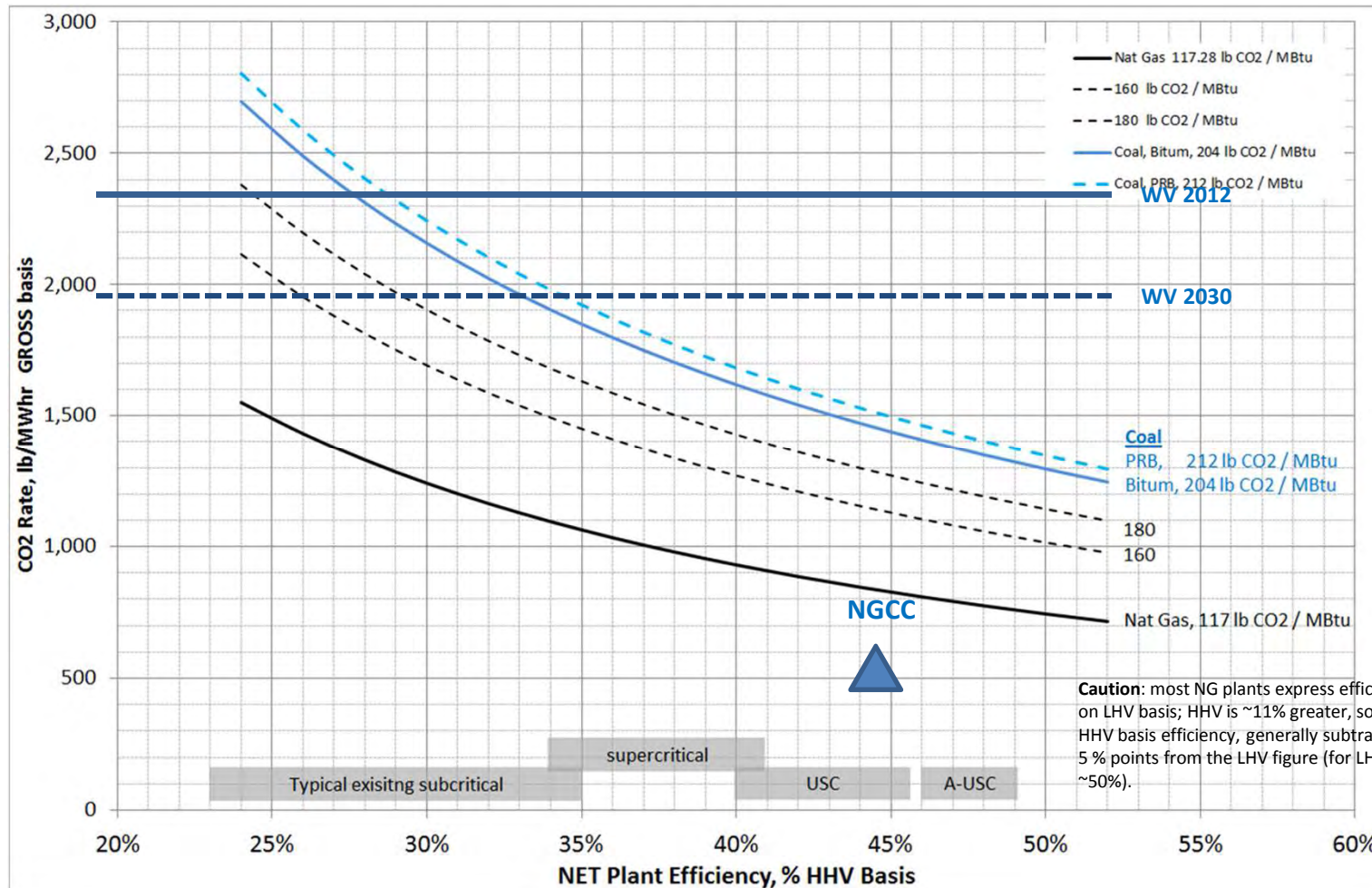
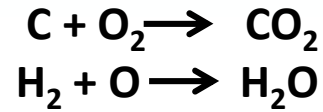


Conclusion

- Opportunities exist to improve a plant's heat rate through modifications and upgrades to:
 - Fuel
 - Boiler
 - Turbine
 - Condenser
 - Ancillary equipment (fans, feedwater heaters, etc.)
- ***What is achievable in terms of overall improvement greatly depends on the plant's original design and the current operating condition of each piece of equipment***



Production of CO₂





Example B

Background:

350 MWg

Steam Flow 2,534,000 lb/hr

PRB

Original Boiler Mfr: **CE / Alstom**

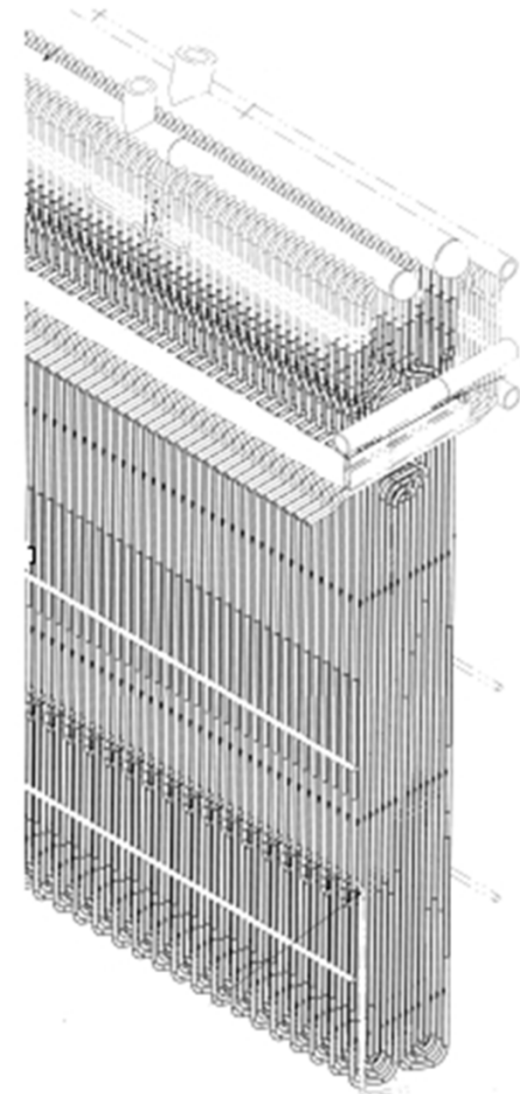
Objectives:

- Optimize Superheat Steam Temperature
- Simplify Metal Selection

Enhancements:

- Added additional surface to HTSH to restore steam temperature to 1,005 °F
- Unique alternating element design (saw tooth) to reduce slagging potential.

| Parameter | Pre-Modification | Post-Modification |
|------------------------|------------------|-------------------|
| Burner Tilt | -15° | -7° |
| Reheat Steam. Temp. | 953 °F | 959 °F |
| Superheat Steam. Temp. | 977 °F | 1,000 °F |
| SH Spray | 0 lbs/hr | 26,600 lbs/hr |





Example C

Background & Objectives:

- 700 MW capacity (OEM: Foster Wheeler)
- Increase cavity spacing
- Fuel: PRB Coal
- Increase sootblowing capabilities
- Regain SH, RH design temp.
- Reduce radiation from furnace to finishing SH
- Reduce ash carryover to AH
- Improve heat transfer in AH

Scope:

- RH, primary SH, and economizer surface modifications
- Add new sootblowers, relocate existing sootblowers
- Add new LPA screen
- Replace airheater baskets
- Boiler nose arch modifications

Results:

- Increased boiler efficiency
- Improved plant heat rate (approx. 1%)
- Reduced SH, RH & AH fouling (improved reliability)

| | <u>Before</u> | <u>After</u> |
|-------------------|---------------|--------------|
| Boiler Efficiency | 84.75% | 85.10% |
| SH Steam Temp. | 980 F | 1,005 F |
| RH Steam Temp. | 980 F | 1,005 F |

