REINHOLD ENVIRONMENTAL ®

2026 Reinhold/PCUG Round Table Presentation

Hosted by TVA, Southern Company and Vistra

in the Sonesta Nashville Airport Hotel, Nashville, TN

on June 22-23, 2026

Babcock Power
SERVICES

Gas Co-Firing

June 22, 2026 Presented By: Terence Ake

Vogt Power International — Heat Recovery Steam Gen.
Babcock Power Services — Boiler retrofits & services
Babcock Power Environmental — Emissions Controls
TEi — Condensers, FWH
TEiC — Construction
BTA — Fabrication
Riley Power — Fired Steam Generators
Babcock Power Renewables — Wind Services

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Agenda

- Introduction – Why Add Natural Gas Co-Firing?
- Engineering Approach
- Typical Boiler Performance Impacts
- Equipment Modifications
  - Gas Firing Equipment
  - Fan Evaluation
- Emissions Impacts
  - Changes to NOx, CO, SOx, PM, Hg…
  - Typical AQCS equipment

Introduction

Coal Power – Challenges Facing Electric Utilities

- Environmental
  - Carbon dioxide, coal ash, wastewater
  - Load cycling impact on emissions.
- Fuel Economics
  - Variable coal cost - $/ton, delivery & additives
  - Natural Gas < $4/MBtu.
- Increased Cycling and Operating at Low Load
  - Startup costs
  - Startup time
  - Reliability penalty.

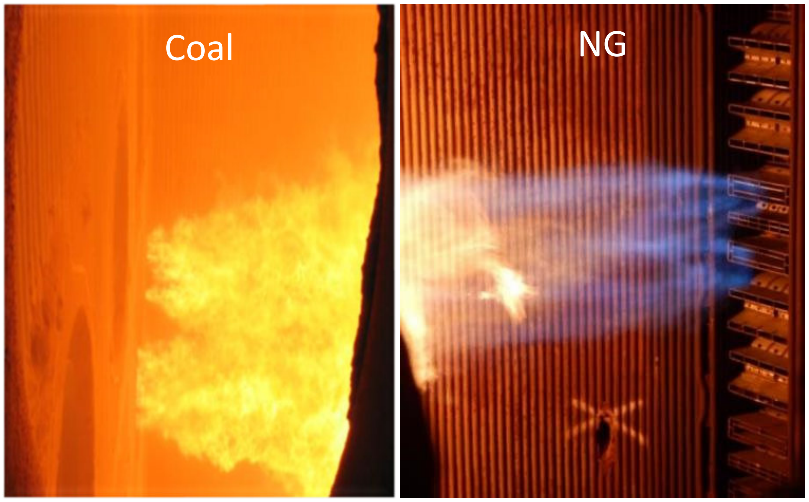
Environmental Drivers

- Good Neighbor Plan
- Mercury and Air Toxics Standards
- Greenhouse Gas (GHG) Standards and Guidelines

Driving conversions despite legal challenges and set-backs.

Natural Gas Firing Benefits

- Lower NOx, CO and CO_2 emissions.
- PM, SOx, and Hg are practically non-existent.
- Better burner turn-down and lower stable load.
- Improved boiler cleanliness (no slagging & fouling).
- No ash to dispose of and/or store.
- Reduced water use.
- Reduced boiler outages.
- Reduced maintenance.
- Increase unit availability and reliability.
- Potential to fire hydrogen.
- Reduction or elimination of coal handling equipment.
- Reduction or elimination of Air Quality Control (AQCS) equipment.



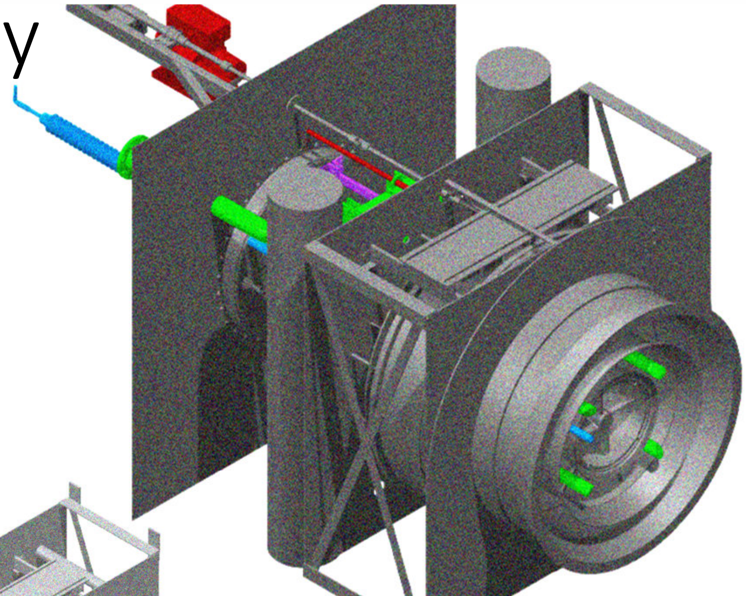
Gas Addition – Maximum Flexibility

Pros:

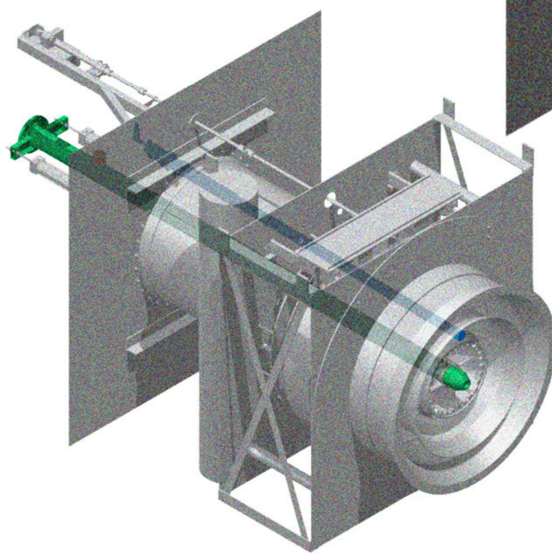
- Firing up to 100% Maximum Continuous Rating (MCR) with either natural gas or coal.
- Retrofit existing coal-fired burners with natural gas or install new Riley Power Dual-Fuel VSII® burners with STS® gas technology.
- Retrofit and new burners can co-fire natural gas and coal together.

Cons:

- More complicated burners (more components in same space).
- Gas components subject to wear.
- If retrofit, there may be restrictions in performance due to existing burner limits.



Dual-Fuel, STS® Manifold



Dual-Fuel, Center-Fired Gas

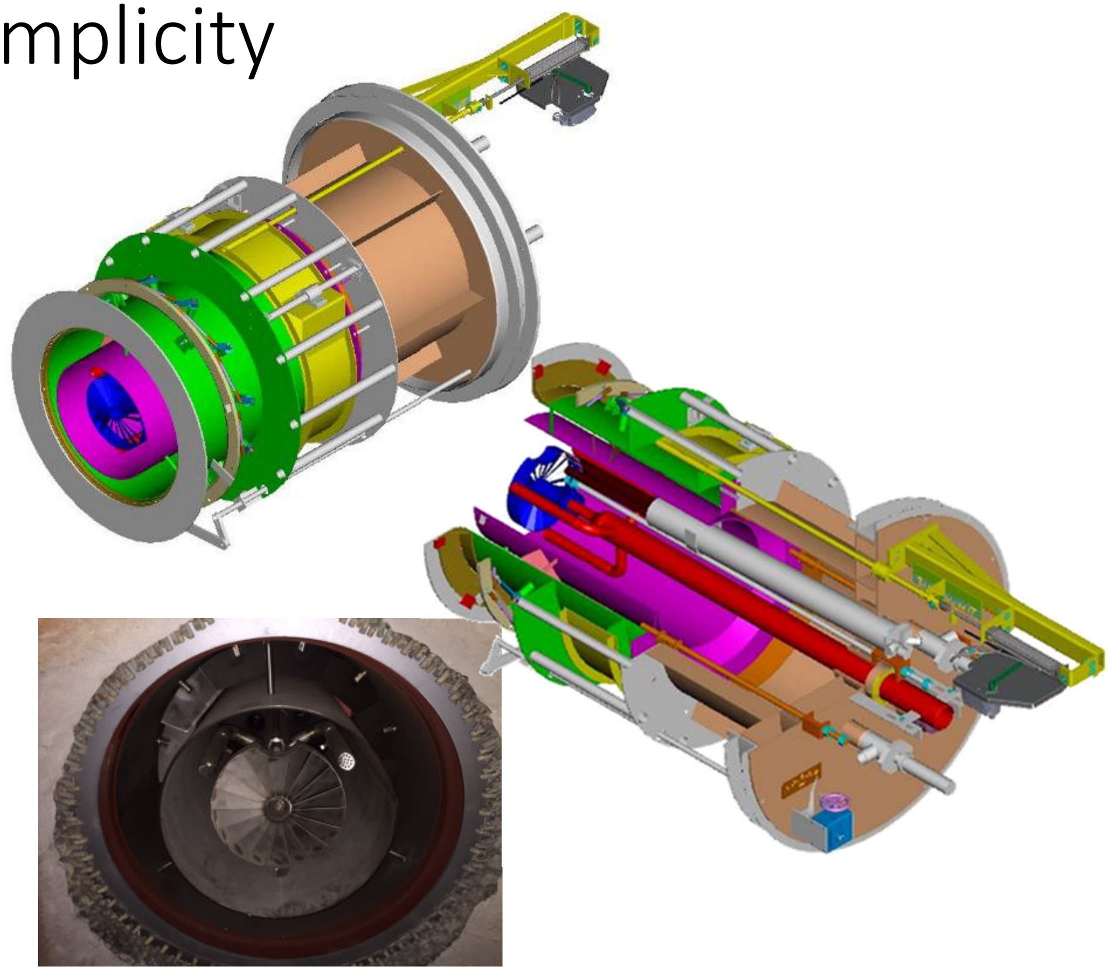
100% Gas Conversion - Simplicity

Pros:

- Reduced maintenance requirements.
- Simplified combustion system operations.
- Reduced backend environmental equipment.
- Simplified burner front.
- Lower auxiliary power due to less operating equipment.

Cons:

- Loss of fuel flexibility.



Performance Engineering Approach

Designing for Co-Firing

- Evaluate fuel and air requirements.
- Determine impacts to boiler performance
  - Steam temperatures
  - Spray flows
  - Metal temperatures.
- Two Methods Used for Analysis
  - Overall envelope calculations – “Basics”
  - Boiler thermal model.

Analysis Methods – Overall Energy Balance "Basics"

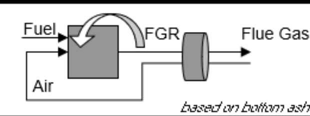
- Establish boiler efficiency (PTC 4.0 methodology).
- Calculate required heat input and subsequent fuel flows.
- Calculate air flows based on fuel flows and excess air.
- Approximate air preheater performance.

Heat input and fuel quantities based on:	PTC 4 Fuel Efficiency Basis	15,521.6	85.28%
		Input, Btu/lb fuel	Effic.

Gaseous fuel #4:	126,984	lb/hr	46,711	scfm @	0.04531	lb/ft3 @ 60°F, 14.696 psia

Calculated Flow Rates, lb/hr

Fuel	Total	lb/hr	372,324	Bitum coal	245,340
UBC	*% in residue: 4.30%*		996	PRB coal	0
Ash from fuel			22,154	India coal	0
Ash residue, including UBC			23,151	Natural Gas	126,984



based on bottom ash of: 20%

Total Combustion Air lb/hr		5,108,436	**Flue Gas From Combustion**	5,457,609	*Flyash entrained specify distrib. in Resid sheet*	
AH air bypass, incl. TA, boiler infiltration		1,113,639	Flue Gas Recirculation, FGR	0	*lb/hr*	*lb / lb FG*
Hot air recirc, % of TCA	0.0%	0	Flue gas through surfaces	5,457,609	*18,520*	*0.00339*
AH air leak., % of FG in	25.00%	1,364,402	Additional air & moisture	0		
AH Air In	*see air heater section for individual stream details*	5,359,199	AH Flue Gas In	5,457,609	*17,363*	*0.00318*
AH Air Out		3,994,797	AH Flue Gas Out	6,822,012	*16,205*	*0.00238*
add'l downstream infiltr.	*0%*	*0*	*FG w/ additional downstream infiltration*	*6,822,012*	912,712	*CO2 production*
boiler air infiltration (to furn, backpass)		*0*	*FG from furn, w/o boiler air infiltration*	*5,457,609*	*16.724%*	*by wt @ AH in*

not including flyash

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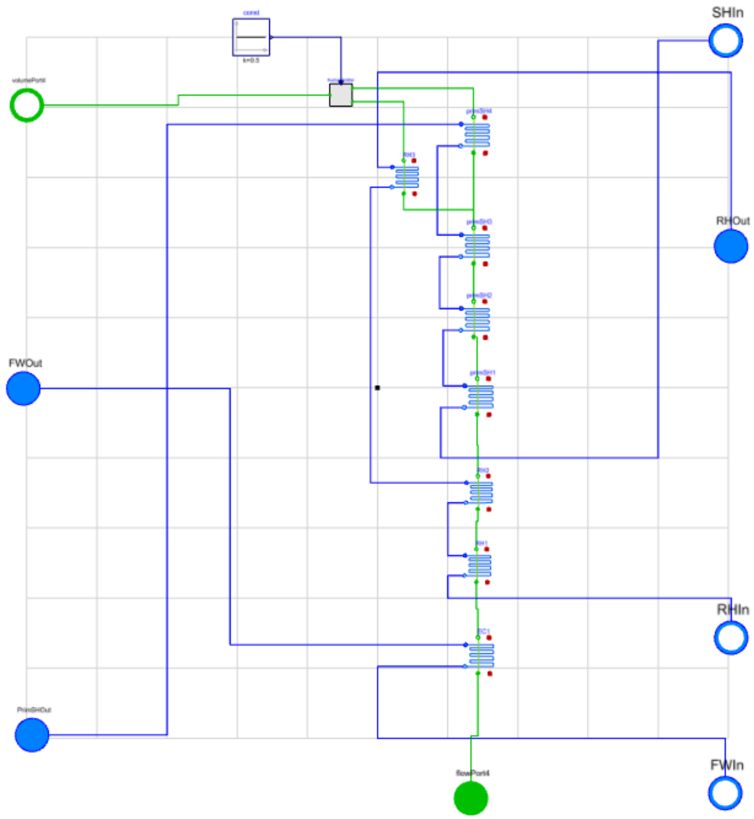
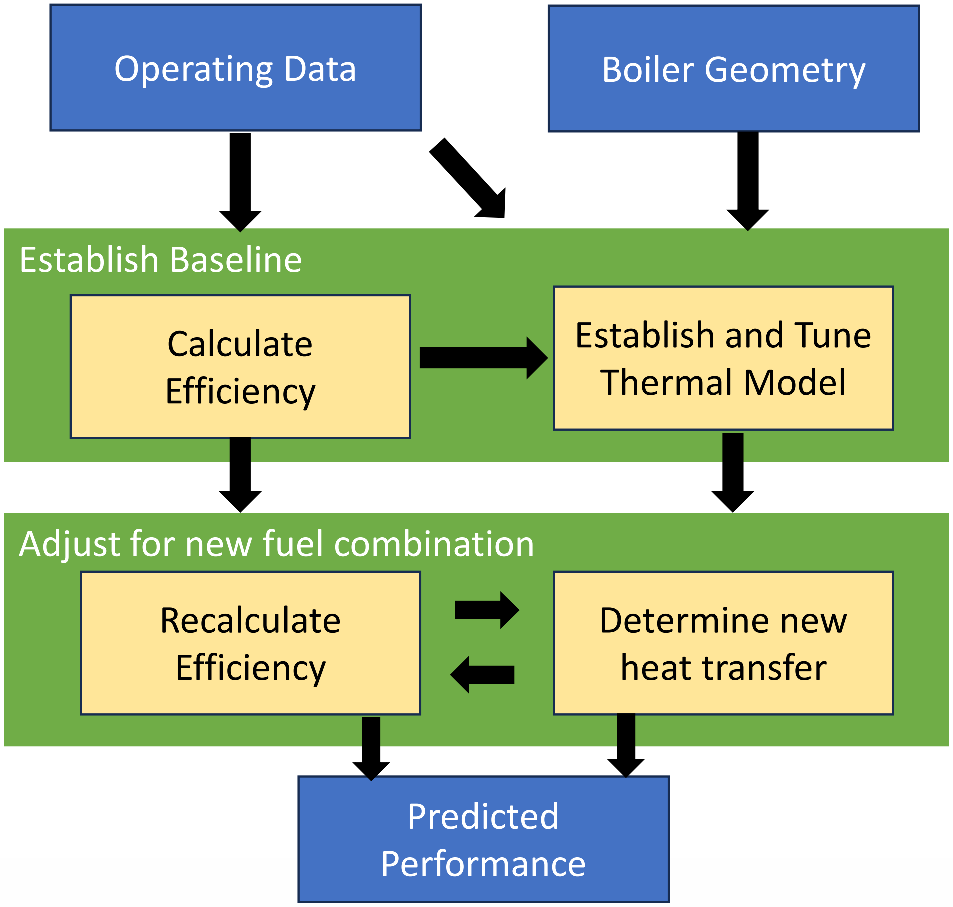
Analysis Methods – Thermal Modeling



- Determine heat absorption by individual surfaces in the boiler.
- Calculate metal temperatures, steam temperatures, and spray flows.
- Improves accuracy of overall efficiency calculations based on exit temperatures of steam and flue gas.

Analysis Procedure

- Coal operating data analysis for
  - Steam Temperatures
  - Flue Gas Temperatures
  - Air Preheater Performance
  - Fuel Analysis.
- Perform "Basics" calculations at several load points.
- Develop a thermal model based on boiler geometry tuned to match operating data.
- Models and calculations then used to predict future cases.



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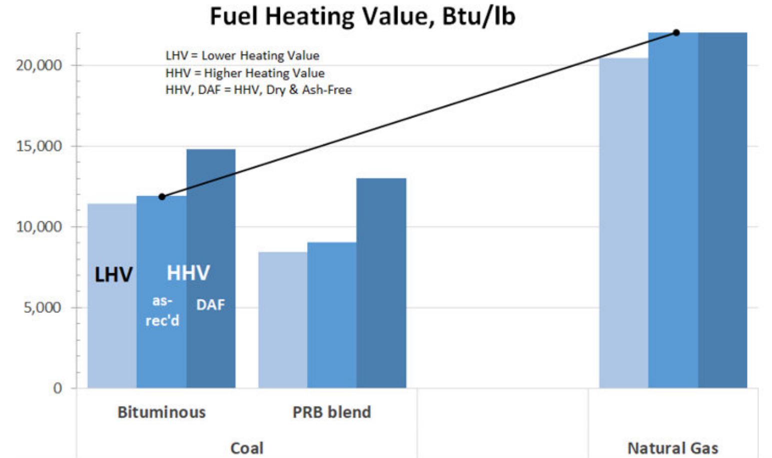
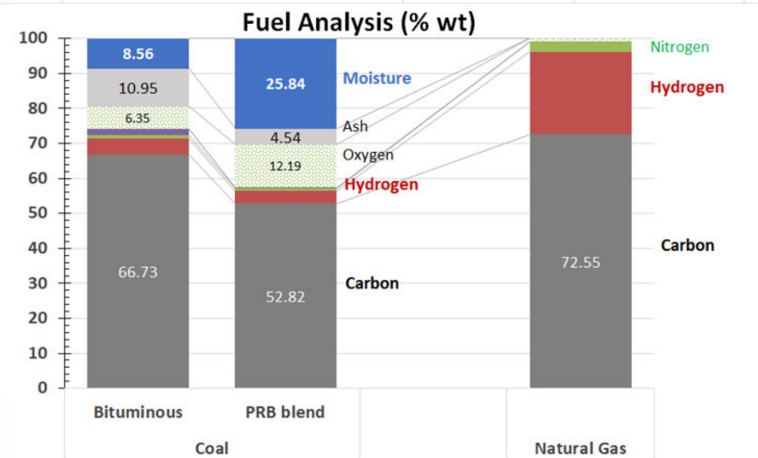
Typical Results – Fuel Comparison

	%Wt (Wet)	Bit Coal	Natural Gas
Carbon	%	64.26	72.82
Hydrogen	%	4.33	23.64
Nitrogen	%	1.32	2.61
Sulfur	%	3.2	0
Chlorine	%	-	-
Ash	%	9.03	0.00
Water	%	10.85	0.00
Oxygen	%	7.01	0.93
Total	%	100	100
Air Requirement	lb dry air /MBtu	740	723
Higher Heating Value	Btu/lb	11,778	22,755





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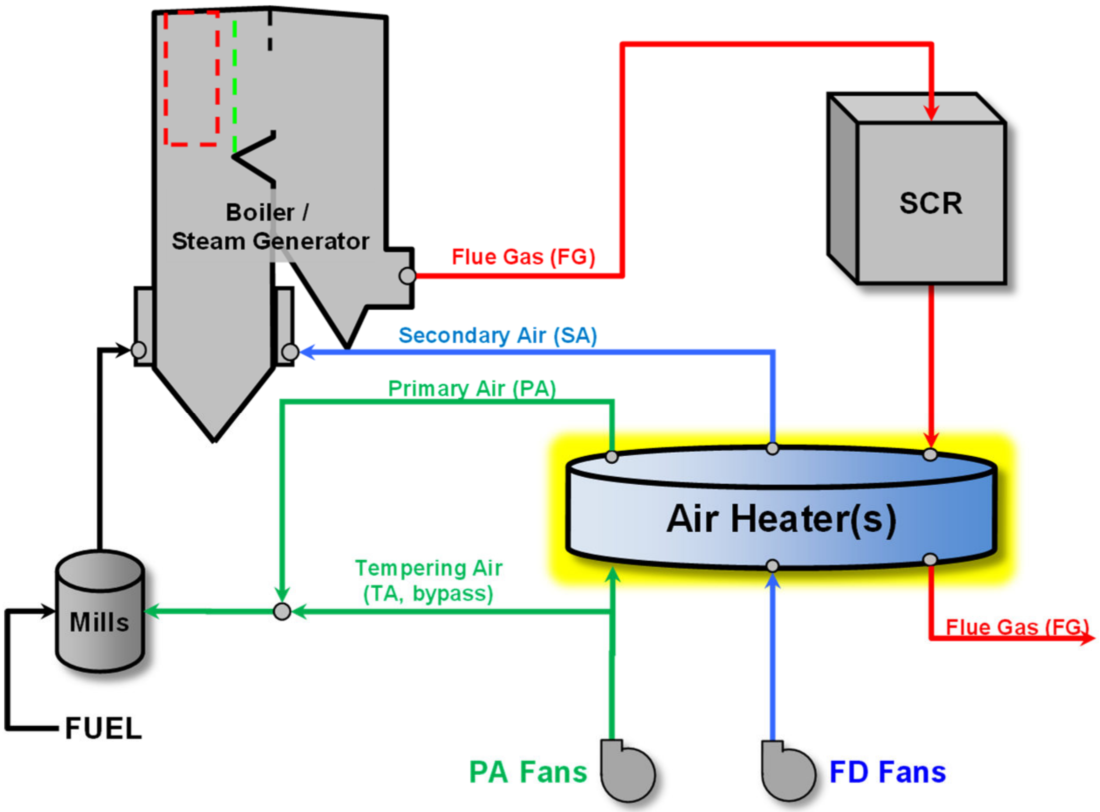
Typical Results – Combustion Air Distribution



- Excess Air
  - 20% firing coal
  - 10% natural gas.
- No primary air for 100% natural gas.
- May need to direct primary air to secondary air or retip forced draft air fans for 100% natural gas.

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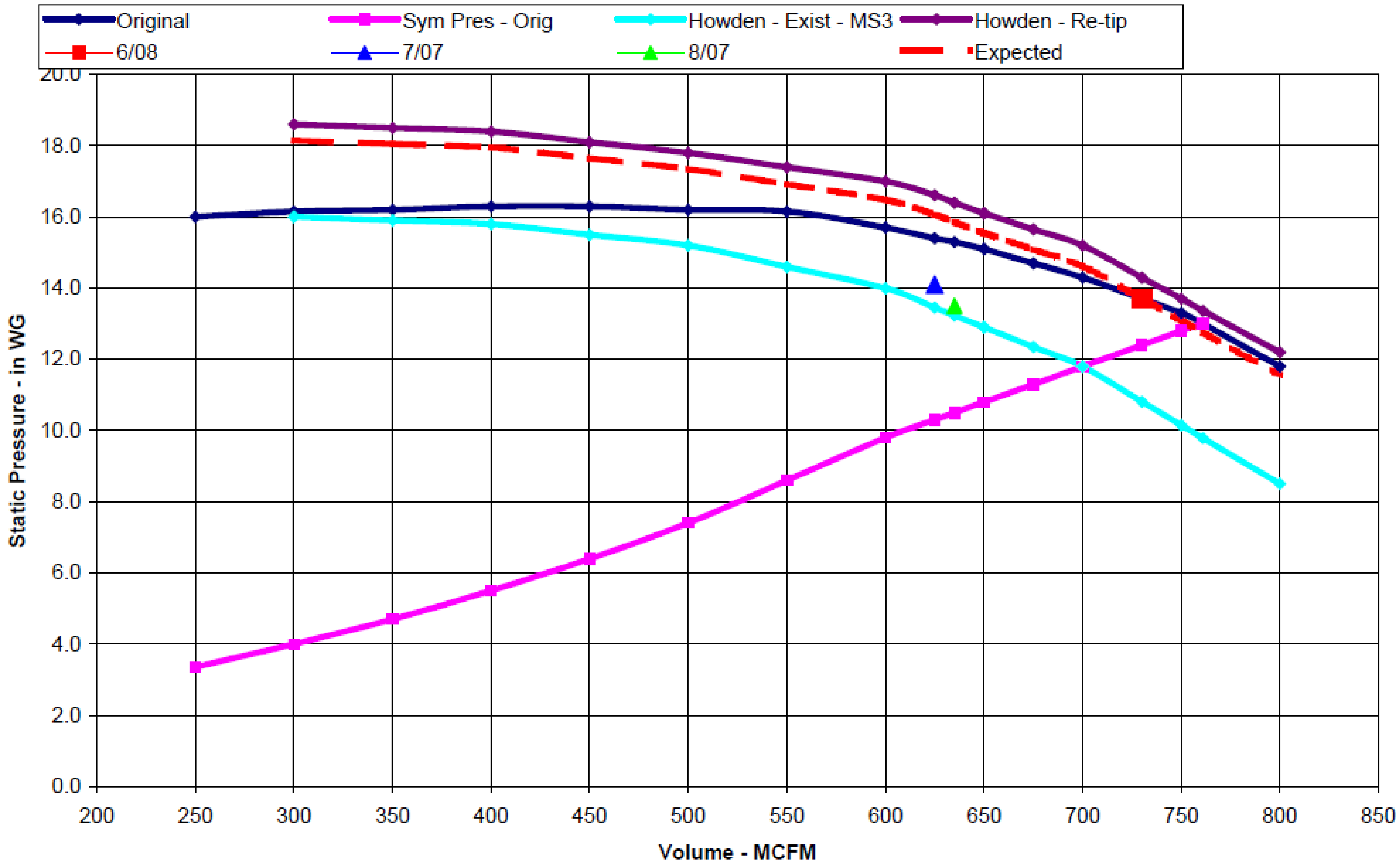
Typical Results – Fan Evaluation



- New load points on existing fan curves.
- Fan tipping and duct alterations.
- New fans or supplemental fans.

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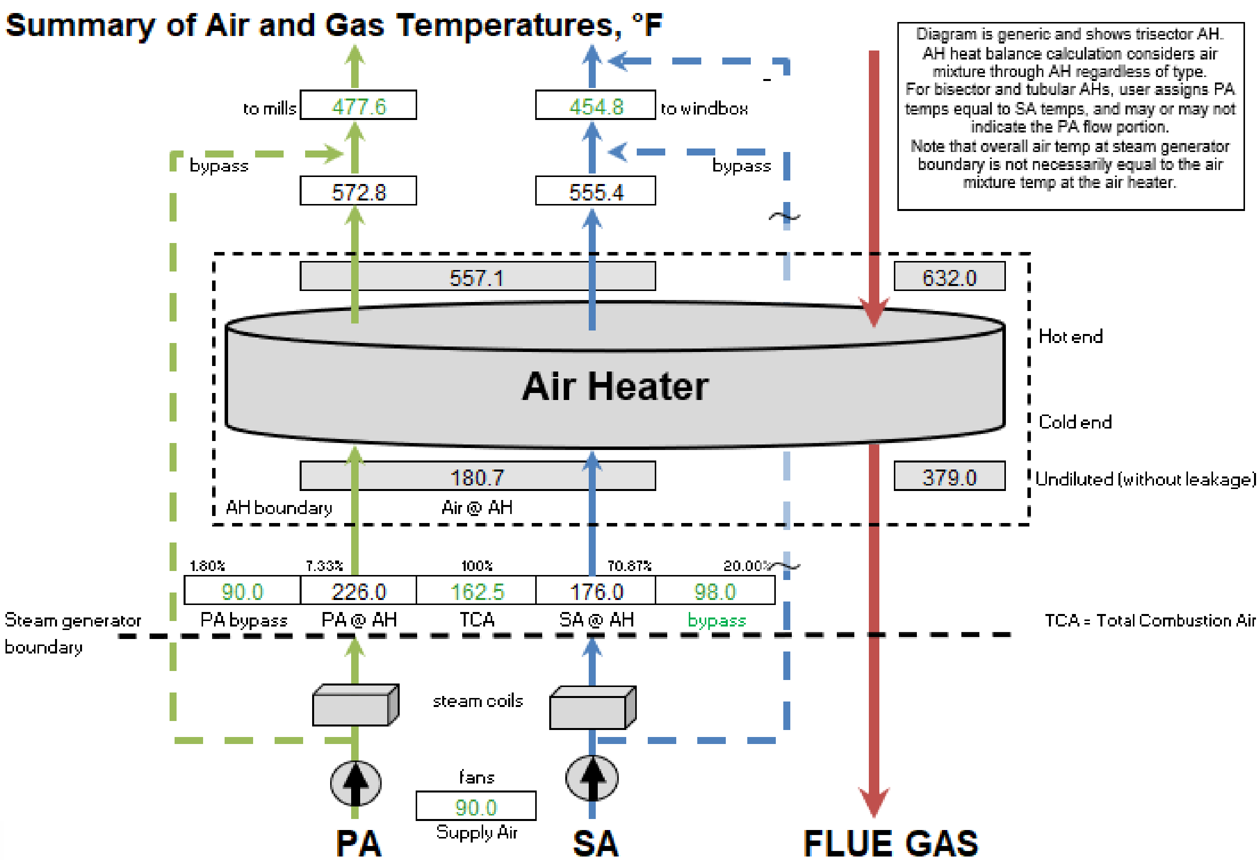
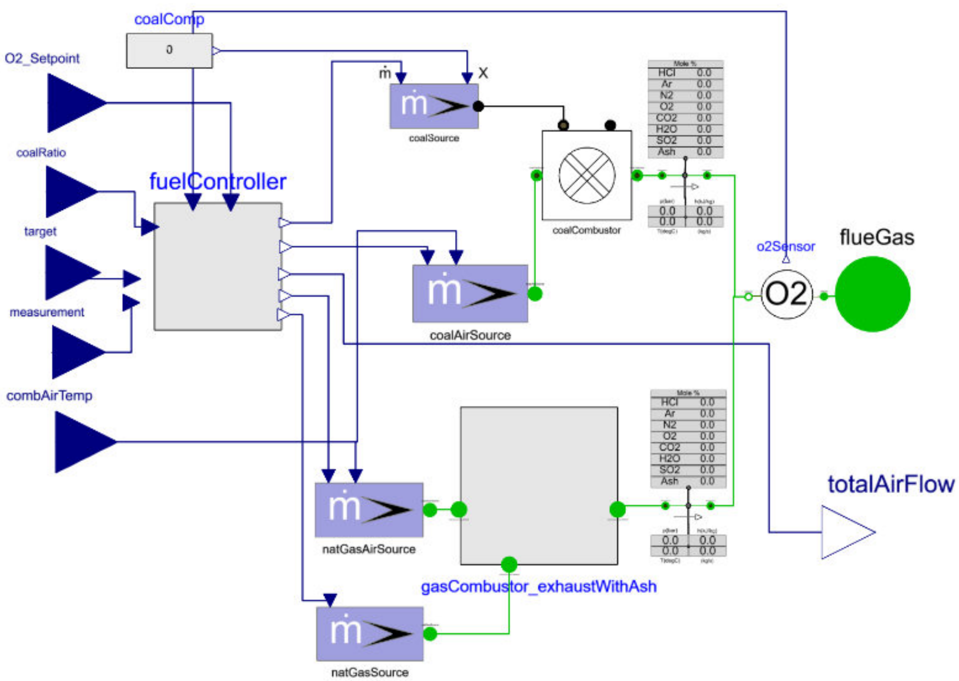
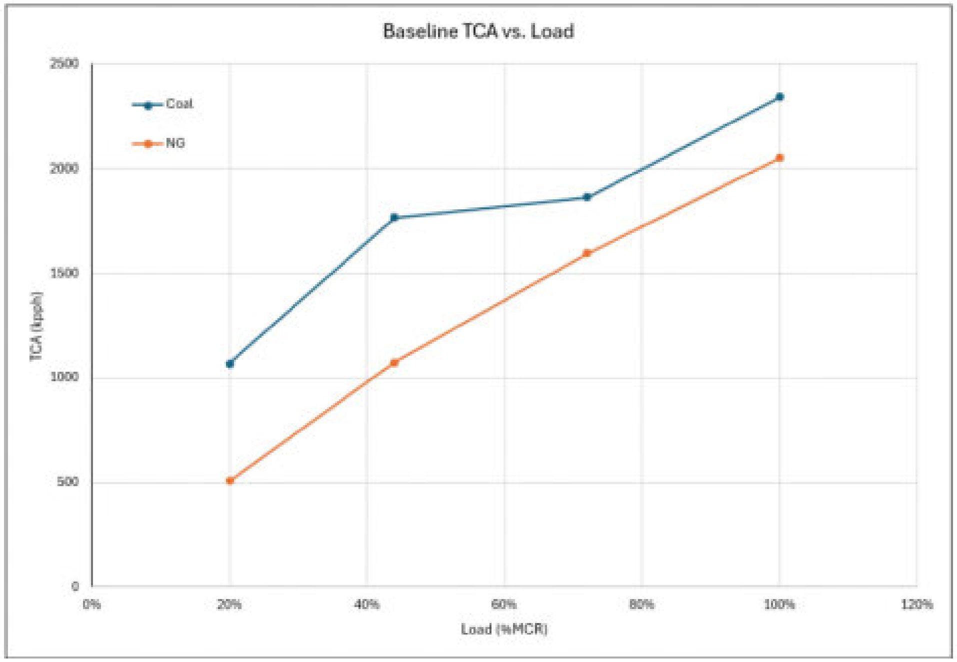
Typical Results – Air Preheaters



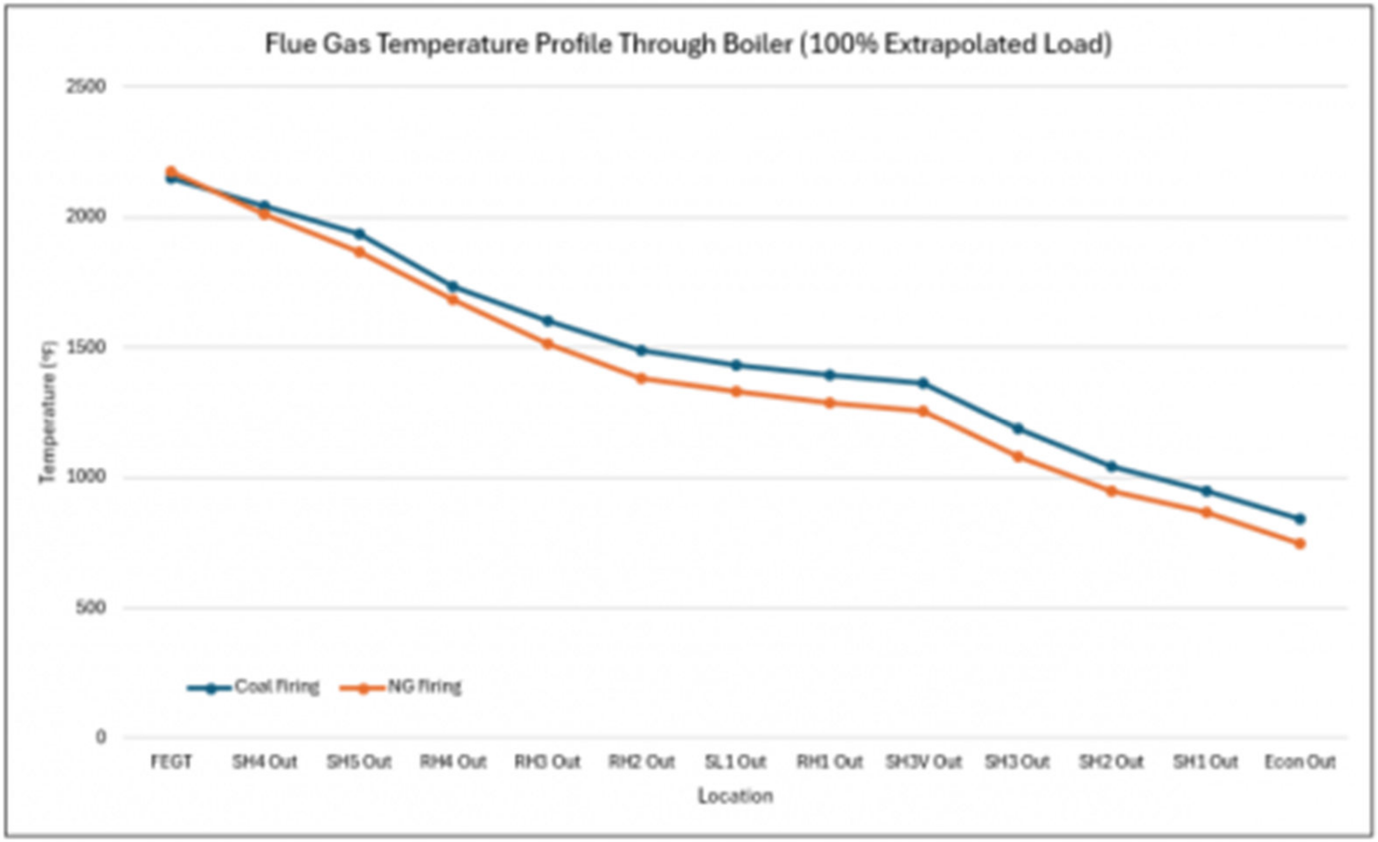
- Minimal change for trisector air heaters.
- Damper upgrade for separate primary and secondary air heaters.
- Air leakage may change.

Typical Results – Combustion Air Adjustments





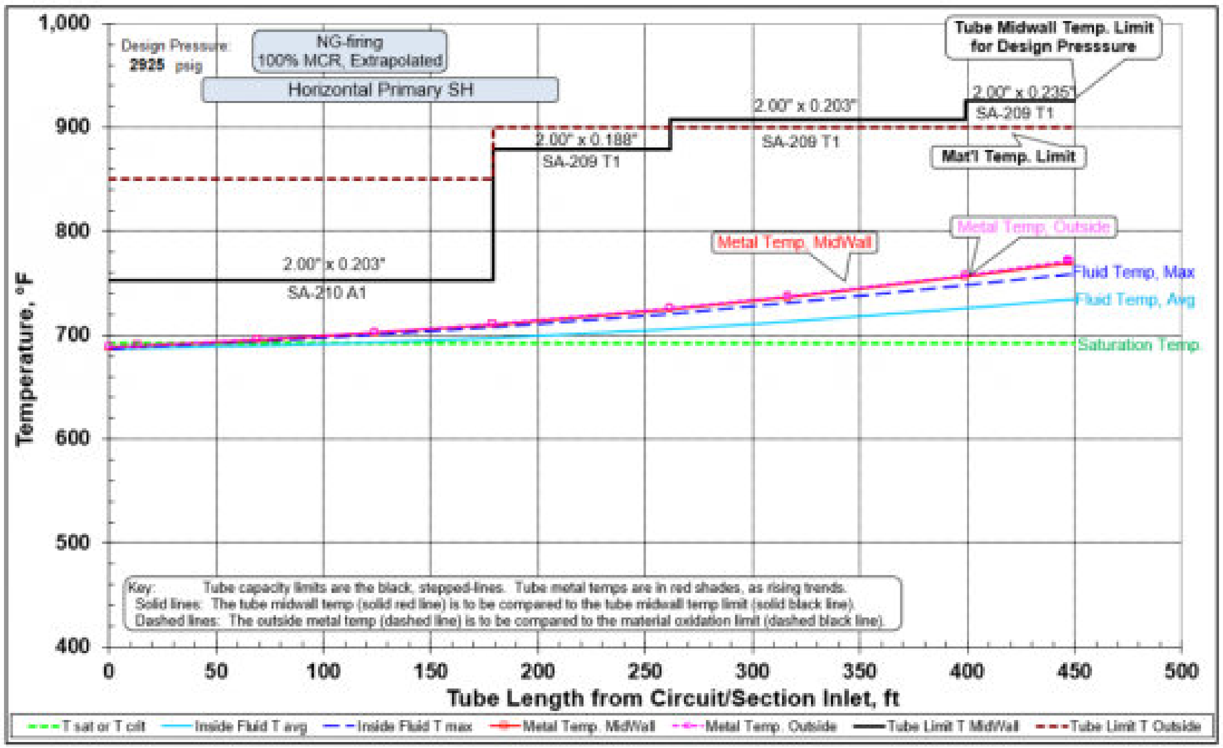
Typical Results – Steam Temperatures



- Furnace absorption
- Tube cleanliness
- Excess air.

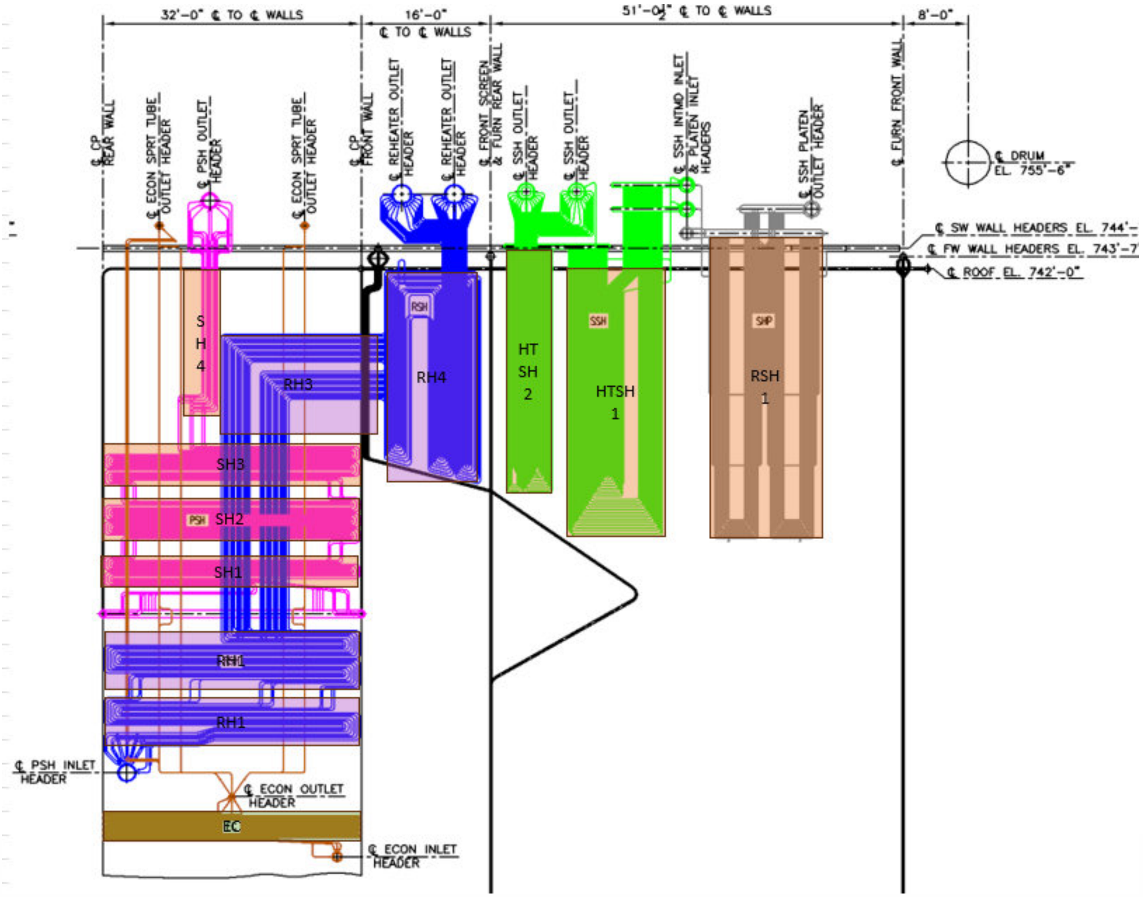
- Co-firing steam temperatures similar to coal up to 50% natural gas.

Typical Results – Metal Evaluation



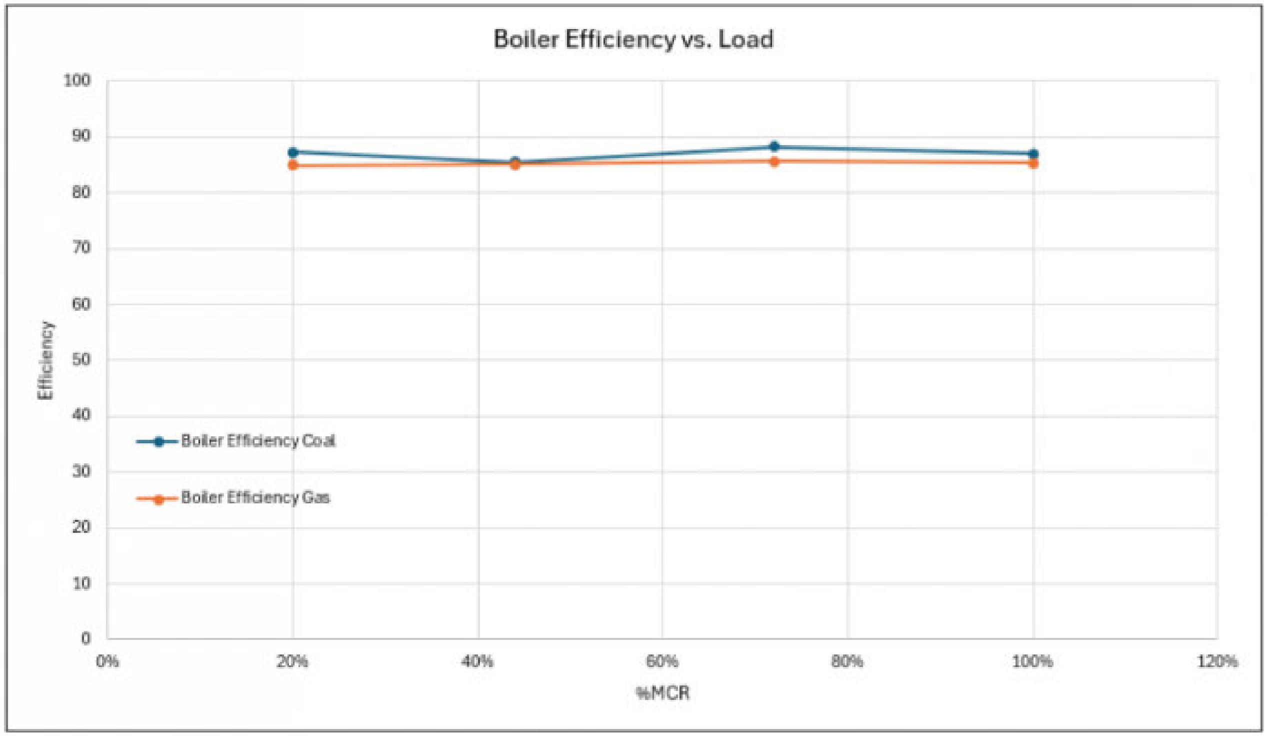
- Mid-wall temperature of tubes are compared to code values for material strength.
- Assume tube are in good condition (not end of wear cycle).
- In rare cases, tubes may be modified to prevent failure.

Typical Results – Surface Adjustments



- Superheater, reheater, or economizer surface may be added or removed to improve performance.
- Air heaters may be modified to improve energy recovery.

Typical Results – Boiler Efficiency



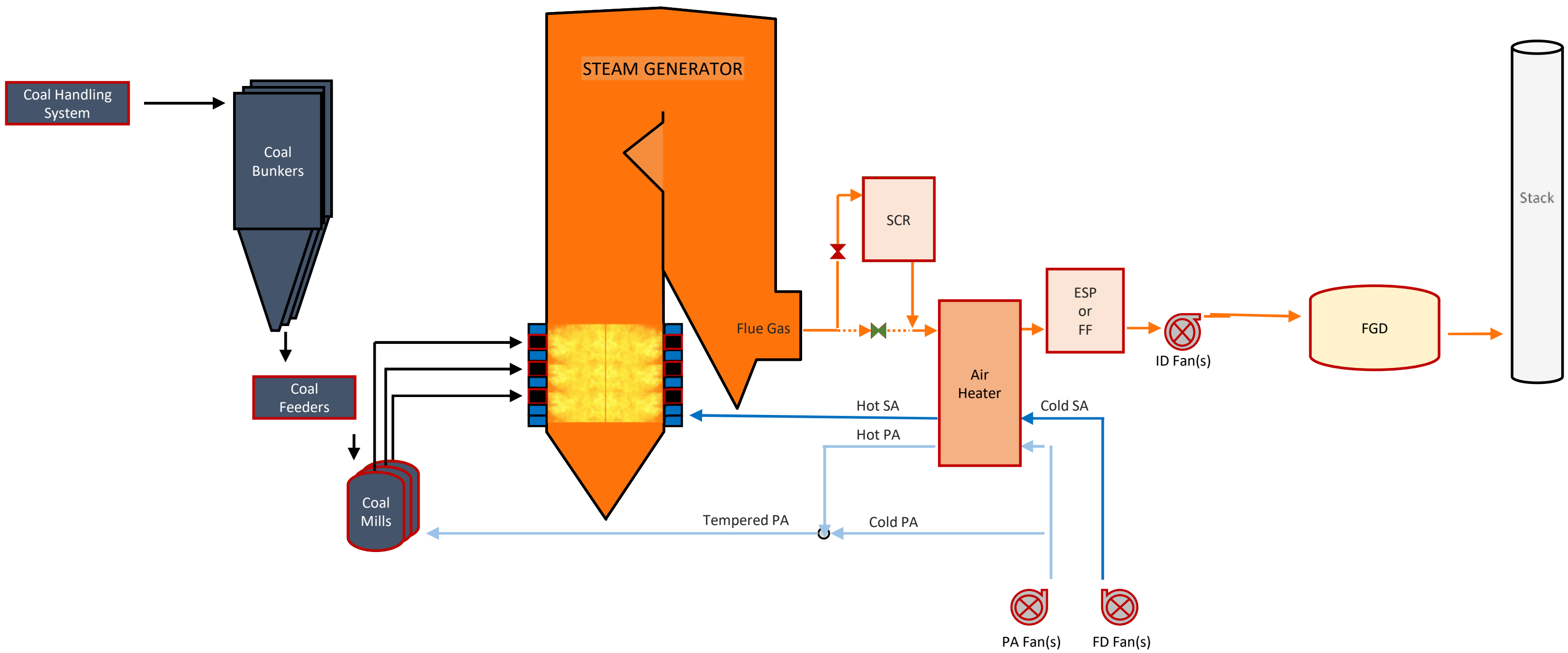
- Calculated by Power Test Code (PTC) 4 – Loss Based Calculation.
- Slight reduction firing 100% natural gas due to higher flue gas moisture (net loss of energy due to unrecovered latent heat).

Fuel Equipment Selection

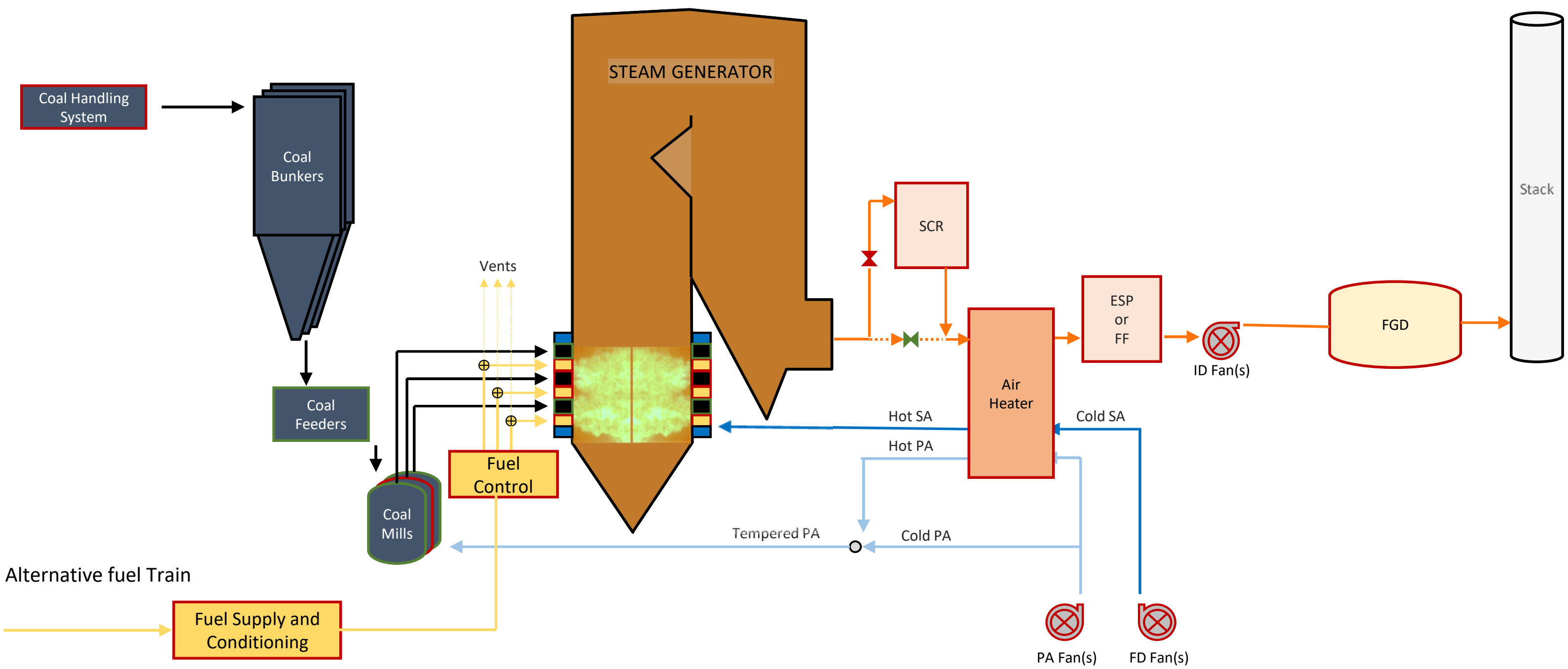
Gas Addition Equipment Overview

- Major components:
  - New Burners or Burner Modifications
  - Gas Skids
  - Gas Piping
  - Fuel Yard.
- Safety Considerations:
  - Risk Analysis
  - Hazardous Area Classification.

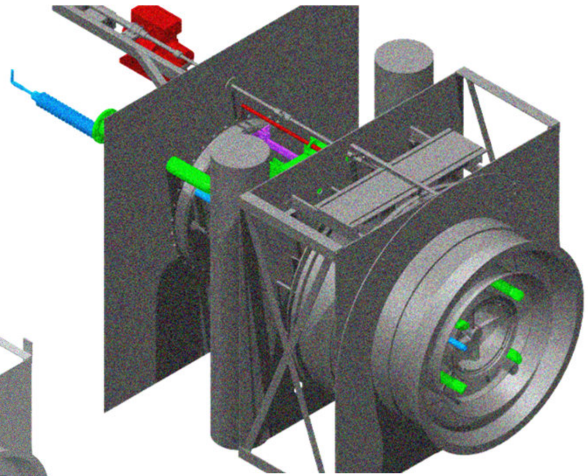
Typical Pulverized Coal Boiler



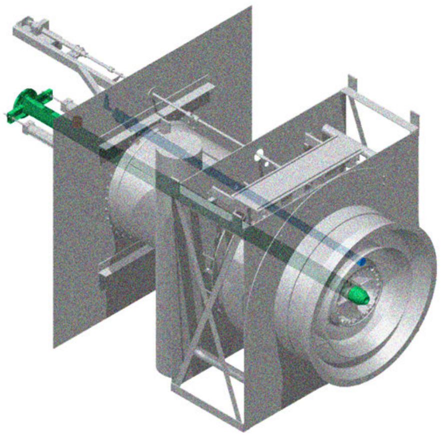
Co-Firing Coal + Nat Gas



Gas Equipment – Flat Wall Burners



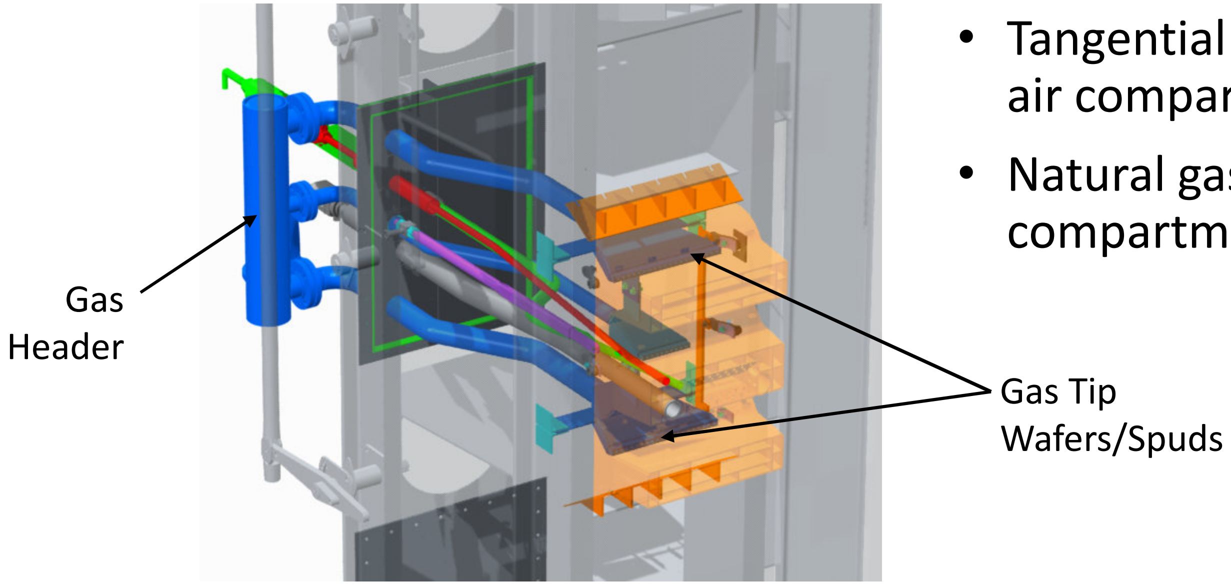
Dual-Fuel, STS® Manifold



Dual-Fuel, Center-Fired Gas

- Wall fired dual fuel burners consist of a standard central coal pipe and either a central gas nozzle or multiple gas tips in the secondary air register.
- Gas piping can be retrofit into many existing burner designs.
  - Burners must be in good condition.
  - May require maintenance or replacement in some cases.
- New burners may improve emissions performance in some cases.

Gas Equipment – Tangential Burners



- Tangential burners consist of coal and air compartments.
- Natural gas tips can be added to air compartments in between coal levels.

Gas Equipment - Scanners

- Flame scanners must work for both coal and natural gas.
- Add new UV scanners or replace existing scanners with UV/IR scanners.

RapidEye IS Plus Series UV/IR Scanner

Gas Equipment - Ignitors

- Natural gas can be used as a new ignition source.
- It can replace existing oil ignitors, or it can be added as a supplemental ignitor depending on plant preferences.

Gas Equipment – Riley Power Direct Spark Ignition

- Class III – Special Ignitor
  - Main fuel is directly ignited using a retractable HESI (High Energy Spark Igniter).
- Cost Savings:
  - Eliminates equipment: igniter scanners, fuel trains, cooling air systems, etc.
  - Decreases maintenance & spares costs.
- Ease of troubleshooting.
- High turndown.
- Ease of boiler warmup.
- Riley Power's patented dual-fuel direct-spark technology allows a unit to use main gas burner as the ignition source for coal while also allowing up to 100% heat input on either coal or natural gas.

Gas Equipment – Flow Control Skids

- Typical arrangements include elevation control or total unit control.
- Block and bleed stations (safety shutoffs) are placed at each burner as required by NFPA.

Gas Equipment - Fuel Yard

- May consist of:
    - High Pressure Gas Regulating Skid
    - Gas Heater(s)
    - Gas Filtration.

Questions For Your Gas Supplier

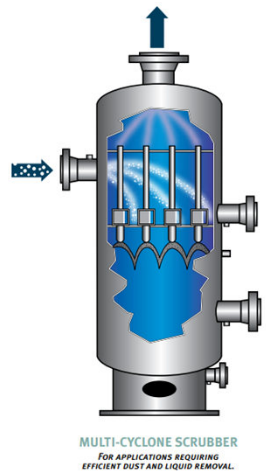
- What equipment will be provided at plant boundary?
- What quality natural gas is guaranteed by your Tariff/Contract?
- Location of tap/lateral on pipeline?

Gas Equipment - Filtration

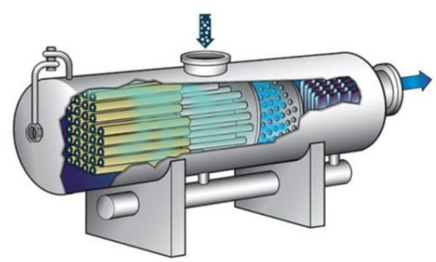
Filter Skid

Used when the gas supplier provides filtration at the metering station.

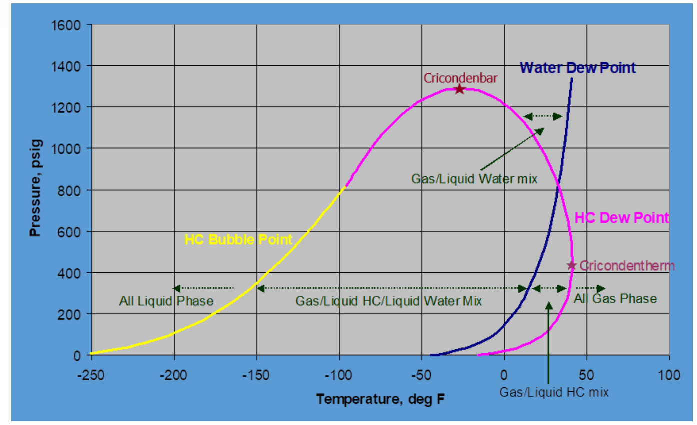
Cyclone / Knock Out Tank



Coalescing Separators



Gas Equipment - Heating



Questions For Your Gas Supplier

- What is the delivery pressure?
- What is the hydrocarbon dewpoint?

Why Heat Your Natural Gas

- Joule-Thomson Effect
  - Conservative Estimate:
    7°F for every 100 PSI of Pressure Drop
  - Modeling/Experience: 5°F/100 PSID
- Hydrocarbon dewpoint control
- Icing Control
  - Internal & External

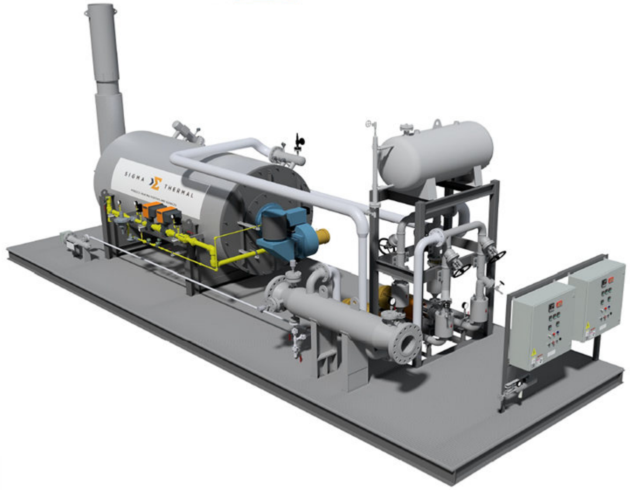
Technology

- Water Bath
- Indirect Fired Thermal Fluid System

Fuel Equipment - Gas Heating

Water Bath Heater

- Pros:
  - Historic usage in plants
  - Simplicity
  - Low Maintenance.
- Cons:
  - Low Thermal Efficiency: ~80%
  - Limited turndown
    - Governed by burner turndown & Bypass Flow Control Valve
  - Large glycol volume.



Indirect Fired Thermal Fluid System

- Pros:
  - Large turndown/Increased Flexibility
    - Burner Turndown, Glycol Temperature Setpoint, Glycol Flow Through HX
  - High Thermal Efficiency: ~87%
  - Only about ~4% of the required volume of glycol compared to Water Bath Heater.
- Cons:
  - Increased equipment
  - Increase maintenance.

Gas Equipment –
Gas Regulation & Overpressure Protection

Questions For Your Gas Supplier

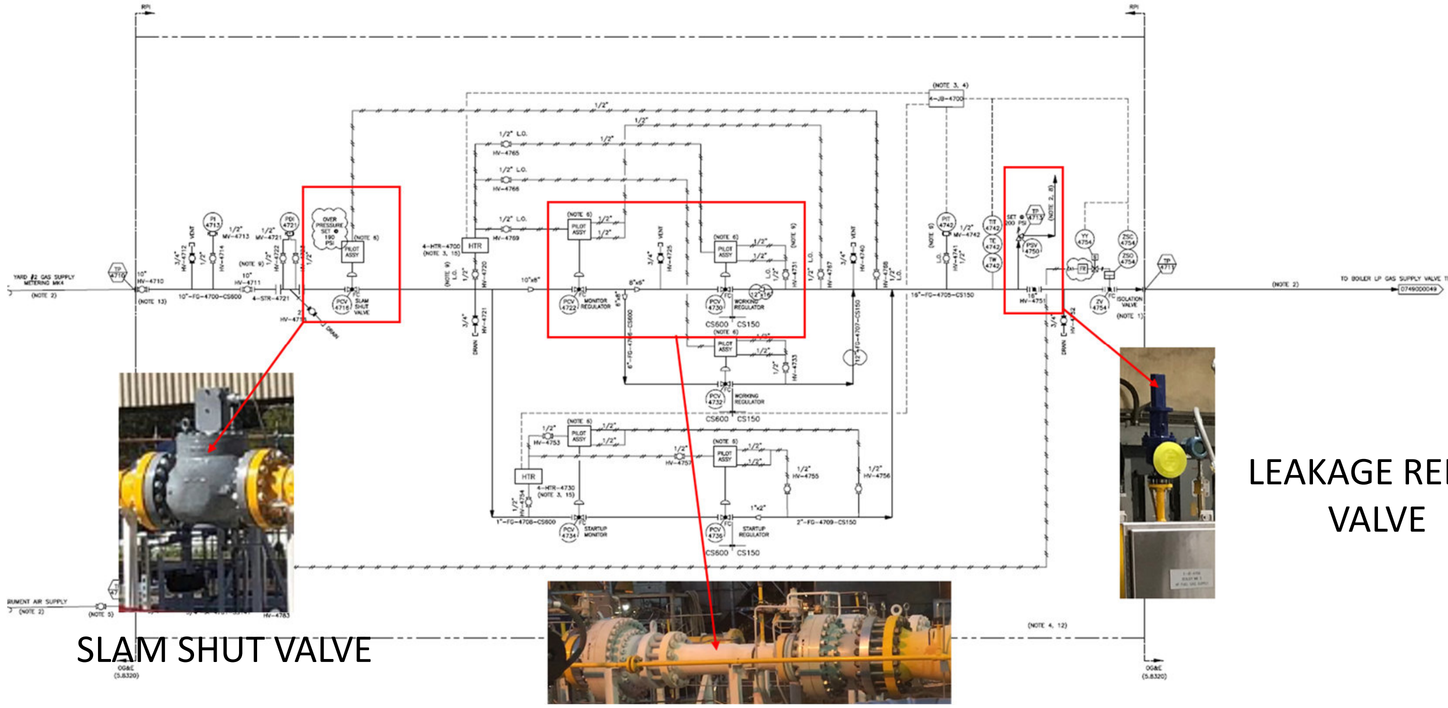
- What is the delivery pressure range?
- What is the design pressure of the pipeline/lateral?

ASME B31.1 122.8.1.D(1)

- A full System Relief Valve

OR

- Slam Shut Valve
- Tandem Pressure Regulators (Worker Monitor)
- Leakage Relief Valve.



SLAM SHUT VALVE

TANDEM PRESSURE REGULATORS
(WORKING MONITOR)

LEAKAGE RELIEF
VALVE

Safety Considerations – Process Hazard Assessment

- Identify ways process can deviate impacting:
  - Personnel
  - Resource
  - Property damage.
- Rank deviations based on likelihood and impact.
- Develop safeguards to mitigate the deviations to acceptable levels.
- Guiding Documents:
  - OSHA 29CFR1910.119 PSM:
  - IEC 61882 Hazard and operability studies (HAZOP studies)
  - NFPA 497
  - API RP 500.
- Activities
  - Ventilation Study
  - Hazardous Area Drawings
  - Hazardous Area Report
  - Locate Gas Detectors
  - Modify Equipment.

Risk Assessment 5 x 5 Matrix

Risk Likelihood	Severity: Catastrophic A	Critical B	Moderate C	Minor D	Negligible E
5 - Frequent	5A	5B	5C	5D	5E
4 - Likely	4A	4B	4C	4D	4E
3 - Occasional	3A	3B	3C	3D	3E
2 - Seldom	2A	2B	2C	2D	2E
1 - Improbable	1A	1B	1C	1D	1E

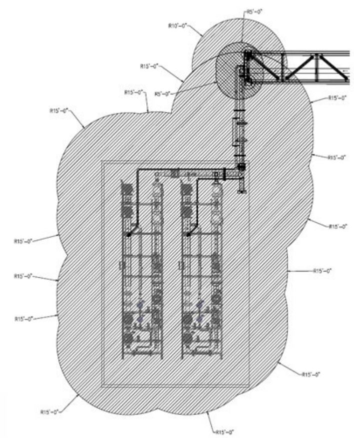
Risk Likelihood Definitions

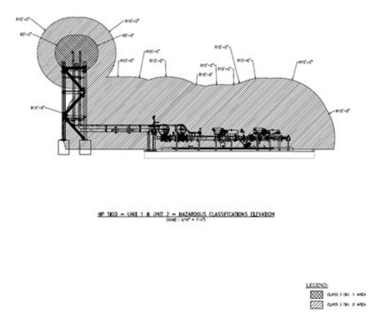
Likelihood	Chance of event	Value
Frequent	1 in 100	5
Likely	1 in 1,000	4
Occasional	1 in 10,000	3
Seldom	1 in 100,000	2
Improbable	1 in a million	1

Assessment Values	Meaning	Accountable Organizations
5A, 5B, 5C, 4A, 4B, 3A	Unacceptable - requires immediate action.	Risk Review Board and VPs of relevenant departments.
5D, 5E, 4C, 3B, 3C, 2A, 2B	Manageable under risk control and mitigation.	Managing Directors and Risk Review Board.
4D, 4E, 3D, 2C, 1A, 1B	Acceptable after review of the operation. Continued tracking and recorded action plans are required.	Managing Directors and relevant organization levels.
3E, 2D, 2E, 1C, 1D, 1E	Acceptable - continued data collection and analysis for improvement is required.	Department Managers and relevant organization levels.

Severity of Occurrences

Severity	Impact to...: Personnel Safety	Resources	Work Performance	Property Damage	Reputation	Value
Catastrophic	Multiple deaths	Institutional resources required	System-wide shutdown Operation suspension	Large environmental impact Equipment destroyed	Uncontrollable public relations events	A
Critical	Serious injury or death	Institutional resources required	Major operational disruptions	Medium environmental impact Moderate equipment damage	Loss of confidence	B
Moderate	Moderate to life impacting injuries	Additional resources required	Significant delays	Small environmental impact	Damaged	C
Minor	Minor injuries	Moderate impact	Modest delays	No environmental impact Slight equipment damage	Potential damage	D
Negligible	No injuries	No impact	No delays	Minor	No impact	E





Impact on Emissions

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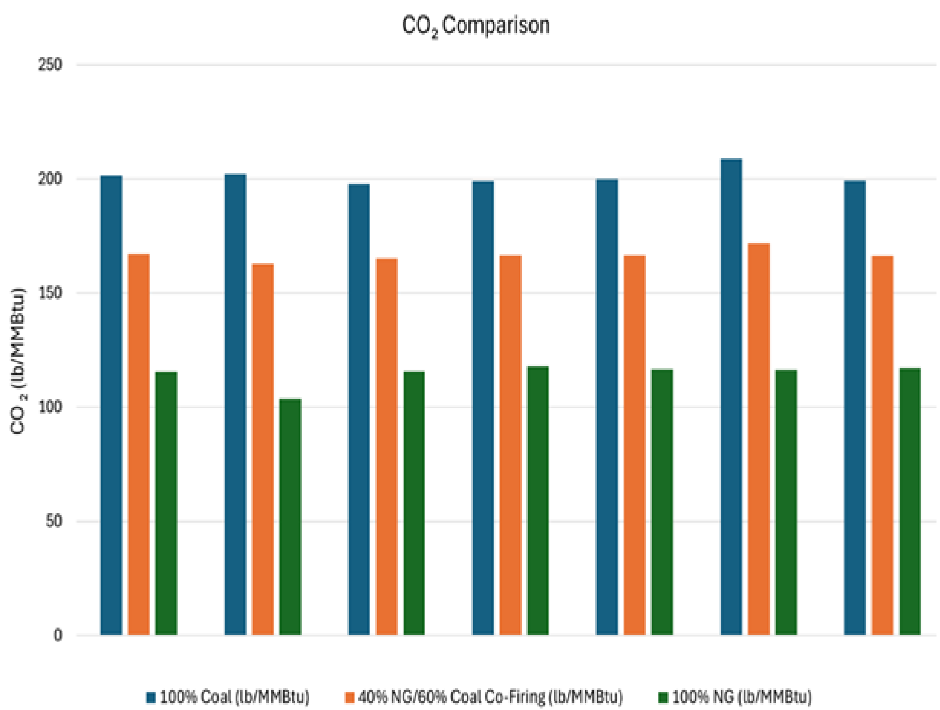
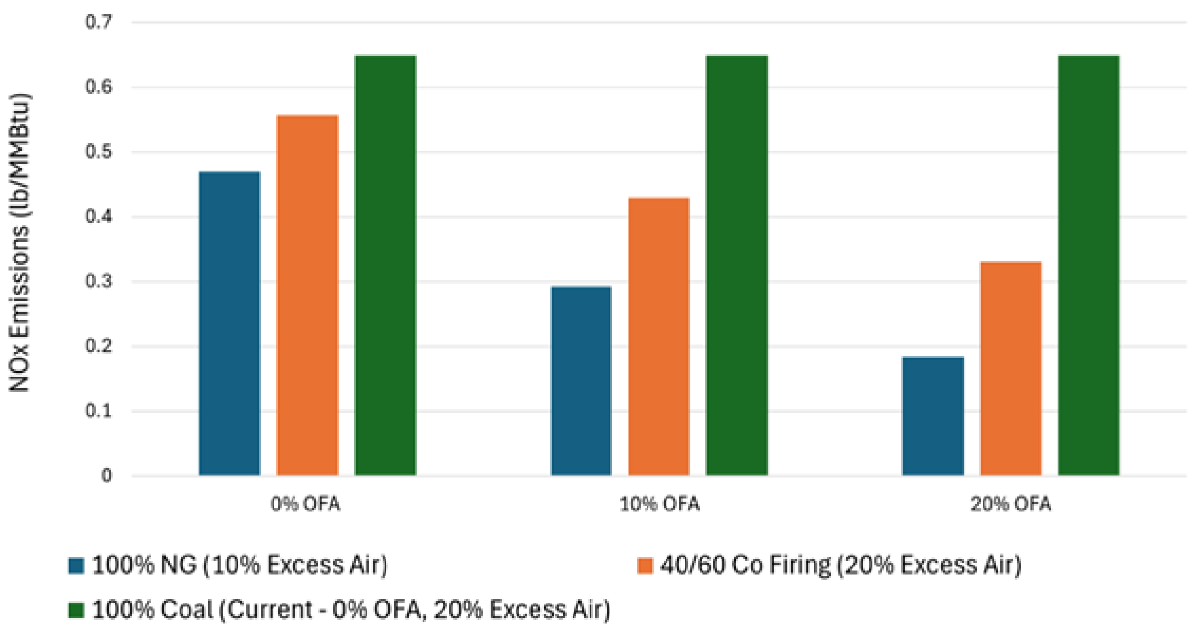
Emissions – CO_2

- Reduced CO_2 emissions firing natural gas instead of coal.
- Proportional reduction when co-firing natural gas with coal.
- Gas conversion or addition are low-cost methods to reduce CO_2.

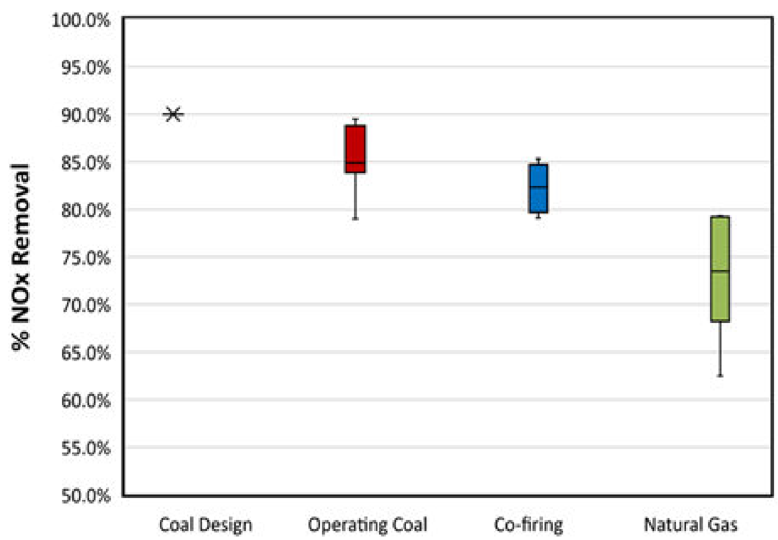


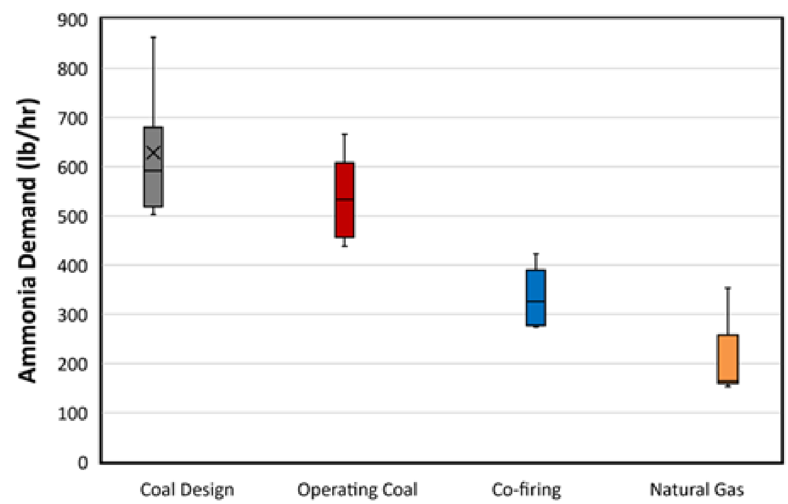
Emissions – NOx



- NOx emissions are impacted by
  - Excess air
  - Overfire air (OFA)
  - Combustion air temperature
  - Flue Gas Recirculation (FGR)
- Firing natural gas typically reduces NOx.
- Co-firing also reduces NOx, but to a lesser extent, and impacted by air conditions like coal.

Emissions – Impacts to SCR systems





- If NOx permit limit is reduced, SCR ammonia demand may not change significantly.
- If limit is not changed, ammonia demand significantly reduces.

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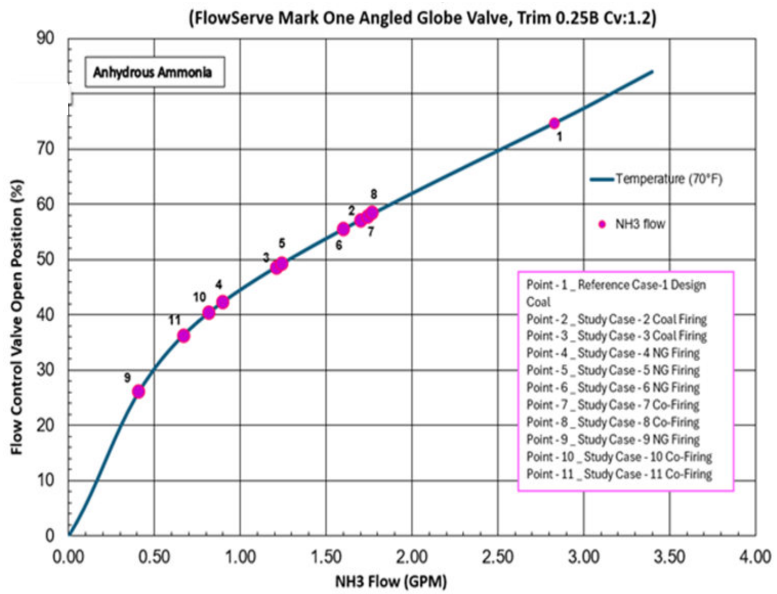
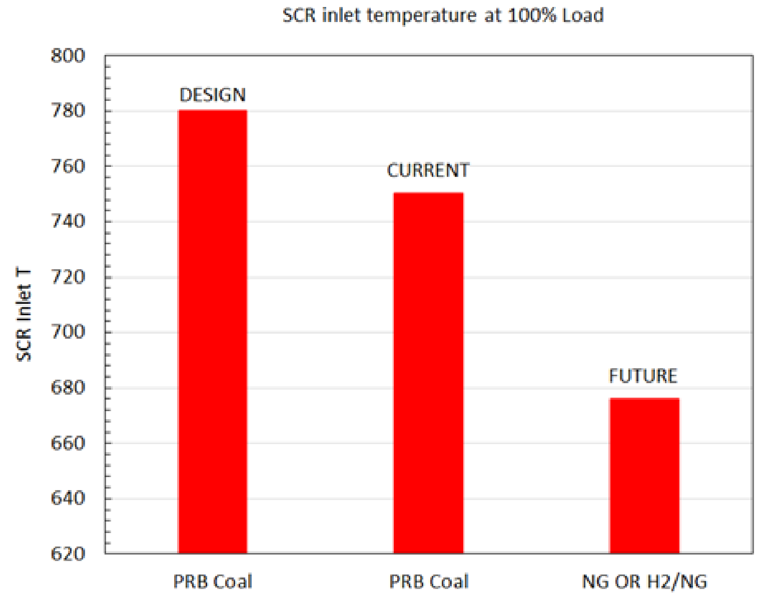
Emissions – Impacts to SCR systems

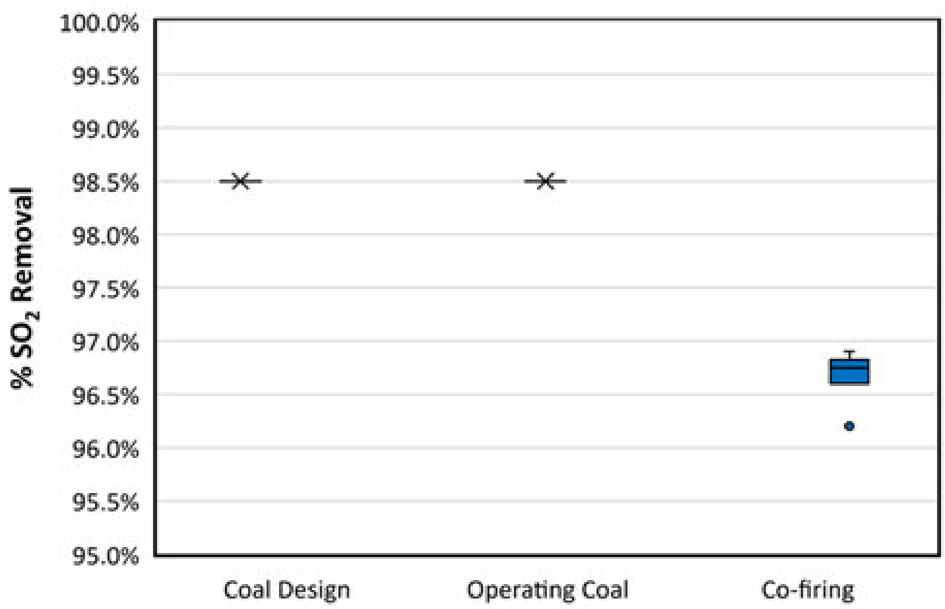




- Reduced ammonia demand may require ammonia pressure setpoint change or new ammonia flow control valve and flow meter.
- Catalyst activity not impacted by lower inlet temperatures when firing natural gas due to no ammonia bisulfate formation.
- Catalyst life will be extended due to reduced catalyst poisons (heavy metals, arsenic, calcium binding, etc.)

Emissions – Flue Gas Desulfurization and other Air Quality Control System Impacts

- SO_2 and SO_3 emissions reduced in proportion to natural gas and near zero for 100% natural gas:
  - FGD systems remain in service when co-firing
  - Reagent demand based on permit levels.
- Particulate Matter and Mercury reduce in proportion and near zero for 100% natural gas.
- Auxiliary equipment loads reduced:
  - Air compressors for instrument and service air
  - Service and process water supply systems
  - Steam and condensate handling
  - Waste water treatment.
- Some of AQCS may be eliminated fully for 100% natural gas:
  - Dry sorbent injection
  - Powdered Activated Carbon injection
  - Spray Dryer Absorbers
  - Baghouses or Electrostatic Precipitators.



Any Questions?