REINHOLD ENVIRONMENTAL Ltd.

2015 NOx-Combustion Round Table & Expo Presentations

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Implementation of Co-Firing of Biomass or Natural Gas

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2/23/15

ALSTOM Power Inc. – Thermal Services

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Agenda

- Biomass Background
- Biomass Fundamentals and Technical Considerations
- Natural Gas Background
- Natural Gas Fundamentals and Technical Considerations

Why Co-Fire Biomass?

- Greenhouse Gas Emissions
- Other Environmental Issues

Co-firing Biomass in a Coal Fired Boiler

Greenhouse Gas Emissions

- Biomass is Considered a CO_2 "Neutral Fuel"
- Major Concern in Some Parts of the World

Agenda

Biomass Background

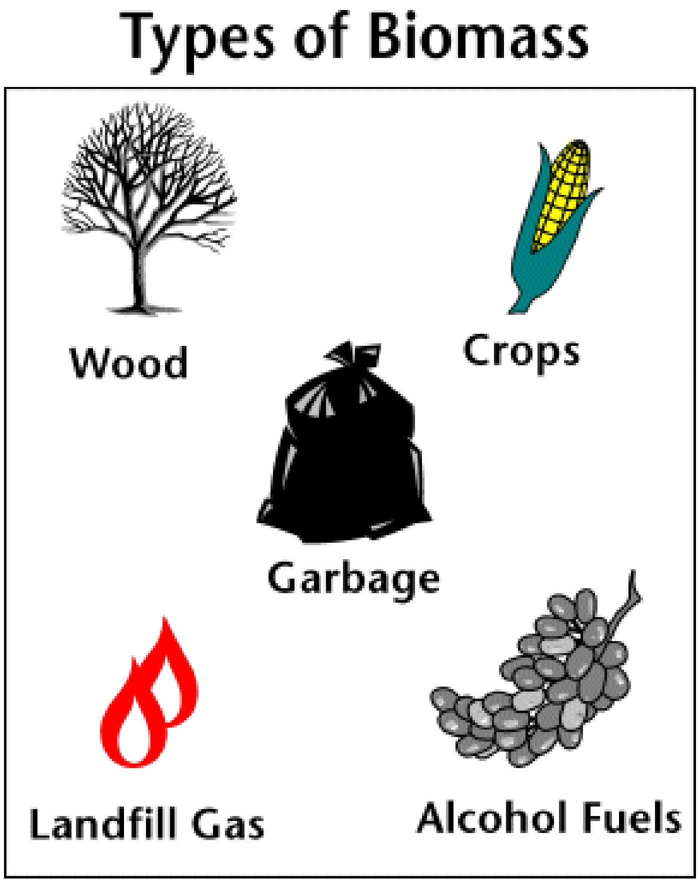
Biomass Fundamentals and Technical Considerations

Natural Gas Background

Natural Gas Fundamentals and Technical Considerations

Biomass Categories

- Untreated wood
  - Fire wood, forest residues, logs
- Agricultural residues
  - Palm kernels, olive pits, sunflower hulls, baggasse
- Treated biomass
  - Pelletized or torrefied products, sawdust, sander dust
- Energy crops
  - Herbaceous crops such as miscanthus, switchgrass
  - Short rotation coppice, including willow poplar
- Waste derived fuels
  - Food industry
  - Sewage sludge, waste derived fuels, RDF, MSW



Sample Biomass Fuel Types

Pellets

Miscanthus

Straw

Wood chips

Waste wood

Wheat shorts

Sample Biomass Fuel Types

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Logs ~45% H_20

Woodchips ~30% H_20

Pelletized wood ~10% H_20

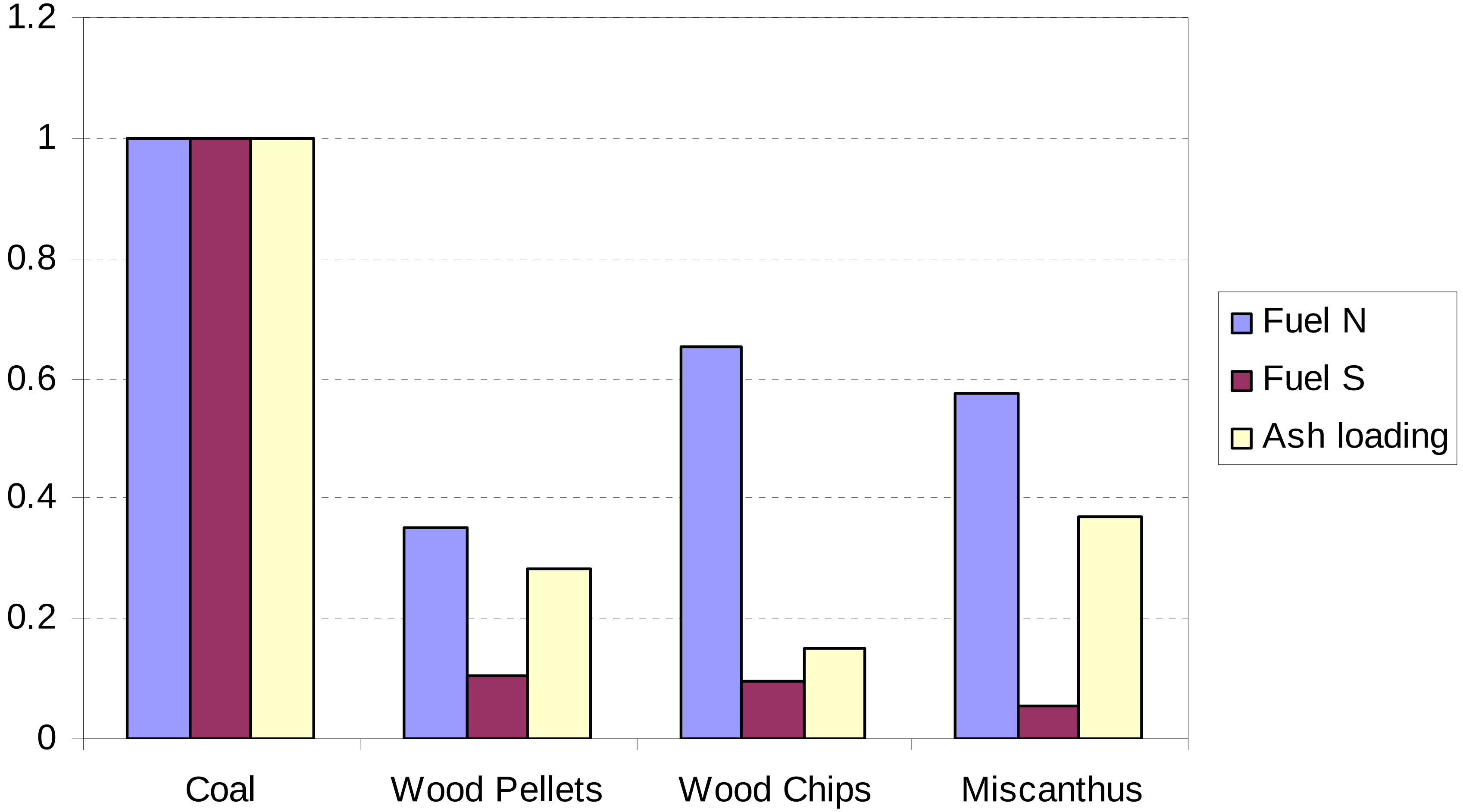
Miscanthus ~20% H_20

Coppiced Willow ~45% H_20

Biomass vs. Coal Fuel and Ash Analyses

FUEL		Coal (Bit)	Coal (Subbit)	Wood Pellet	Coal (Lignite)	50% H_2O Wood
Excess Air		(20% XA)	(20% XA)	(20% XA)	(20% XA)	(30% XA)
Fuel Analysis						
Carbon	%	66.6	50.64	48.23	41.69	21.68
Hydrogen	%	4.7	3.45	5.86	2.8	2.26
Nitrogen	%	1.2	0.7	0.09	0.8	0.15
Oxygen	%	6.8	11.72	36.3	12.71	14.23
Sulfur	%	3.7	0.4	0.01	0.43	0.02
Ash	%	8.5	5.2	1.5	10.74	11.59
Moisture	%	8.5	27.9	8	30.83	50.07
		100.0	100.0	100.0	100.0	100.0
VM	%	38.0	31.0	70.0	27.8	32.2
HHV	Btu/lb	12,000	8,692	7,945	7,154	3,625
Typical XA	%	18	20	20	20	30
Wet Air	lb/MBtu	758.5	767.7	765.2	757.3	745.3
Dry Gas Weight	lb/MBtu	929.9	945.1	936.7	942.7	1008.3
% Change in Fuel Flow (lb/MBtu vs. Bit)	**%**	**100%**	**143%**	**162%**	**164%**	**318%**
% Change in Air Flow (lb/MBtu vs. Bit)	**%**	**100%**	**102%**	**99%**	**100%**	**106%**
% Change in Total Products (lb/MBtu vs. Bit)	**%**	**100%**	**105%**	**104%**	**105%**	**123%**
Boiler Efficiency	%	88.0	85.5	84.0	84.1	68.0
Weighted Total Fuel (Based on B.E. or Q_F)	lb/MBtu	86	127	147	148	356
Weighted Total Air (Based on B.E. or Q_F)	lb/MBtu	1031	1084	1073	1080	1416
Weighted Total P (Based on B.E. or Q_F)	lb/MBtu	1118	1212	1219	1228	1772
% Change in Fuel Flow (vs. Bit)	**%**	**100%**	**147%**	**170%**	**171%**	**412%**
% Change in Air Flow (vs. Bit)	**%**	**100%**	**105%**	**104%**	**105%**	**137%**
% Change in Flue Gas Flow (vs. Bit)	**%**	**100%**	**108%**	**109%**	**110%**	**159%**

Constituent Comparison with Coal on Heat Input Basis



Processed Biomass Fuel Analyses

Pelletized Biomass

- Lower Moisture and Required Storage Volume
- Potential for minimal reduction in boiler efficiency based on current coal fired
- Smaller increase in flue gas flows versus co-firing higher moisture biomass fuels

	Pelletized Wood Biomass	Woodchips Biomass
Proximate Analysis:		
% Moisture	6.00	30.00
% Ash	0.40	1.15
% Volatile	76.30	57.40
% Fixed Carbon	17.30	11.45
Ultimate Analysis:		
% Moisture	6.10	30.00
% Carbon	45.70	35.52
% Hydrogen	5.60	4.19
% Nitrogen	0.20	0.04
% Sulfur	0.01	0.08
% Ash	0.40	1.15
% Oxygen	41.99	29.02
HHV (BTU/lb)	7,900	6,050
lb Fuel/MMBtu	127	165

Alstom's Biomass Experience

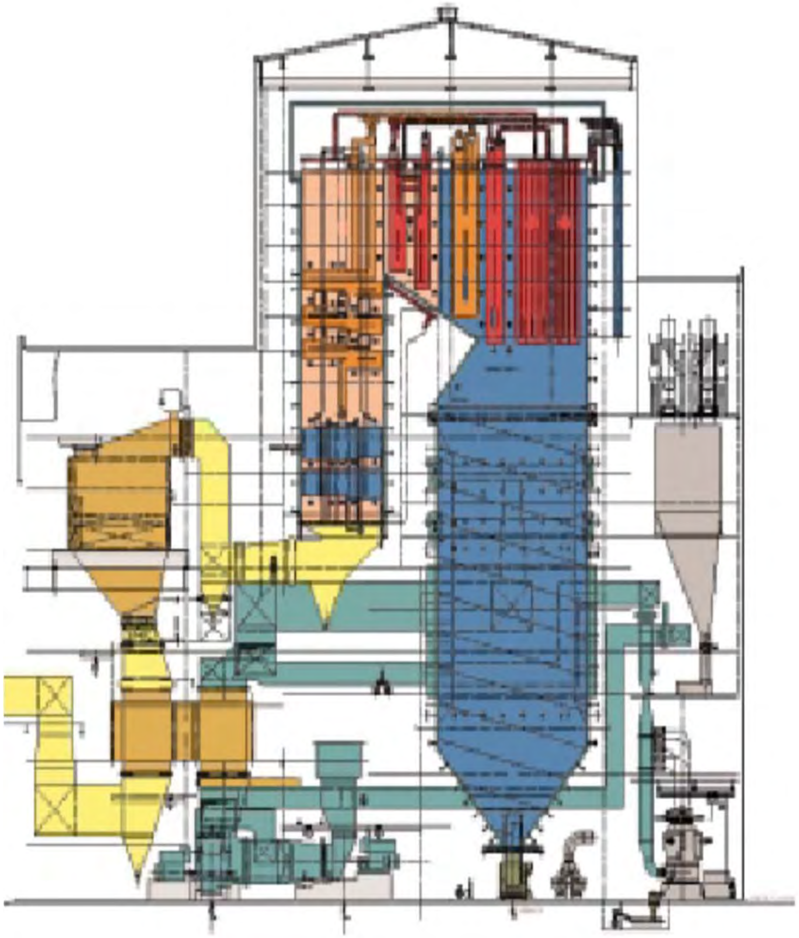
- Suspension Firing
  - Direct injection
  - Using Mills to reduce particle size
- Stoker Firing

Key Parameters Effecting Technology Choices

- Fuel Sizing
- Fuel Constituents
- Fuel Fired Quantity & Variability
- Physical Constraints
- Performance Constraints
- Economic Constraints
- Environmental Constraints

Suspension Fired with Pulverized Coal

- Typ. Can Co-fire 5% to 25% Biomass
- Typ. Moisture Range of 10% to 30%
- Requires Finer Particle Sizing
- May Require Dump Grate (depending on size of fuel being fired)

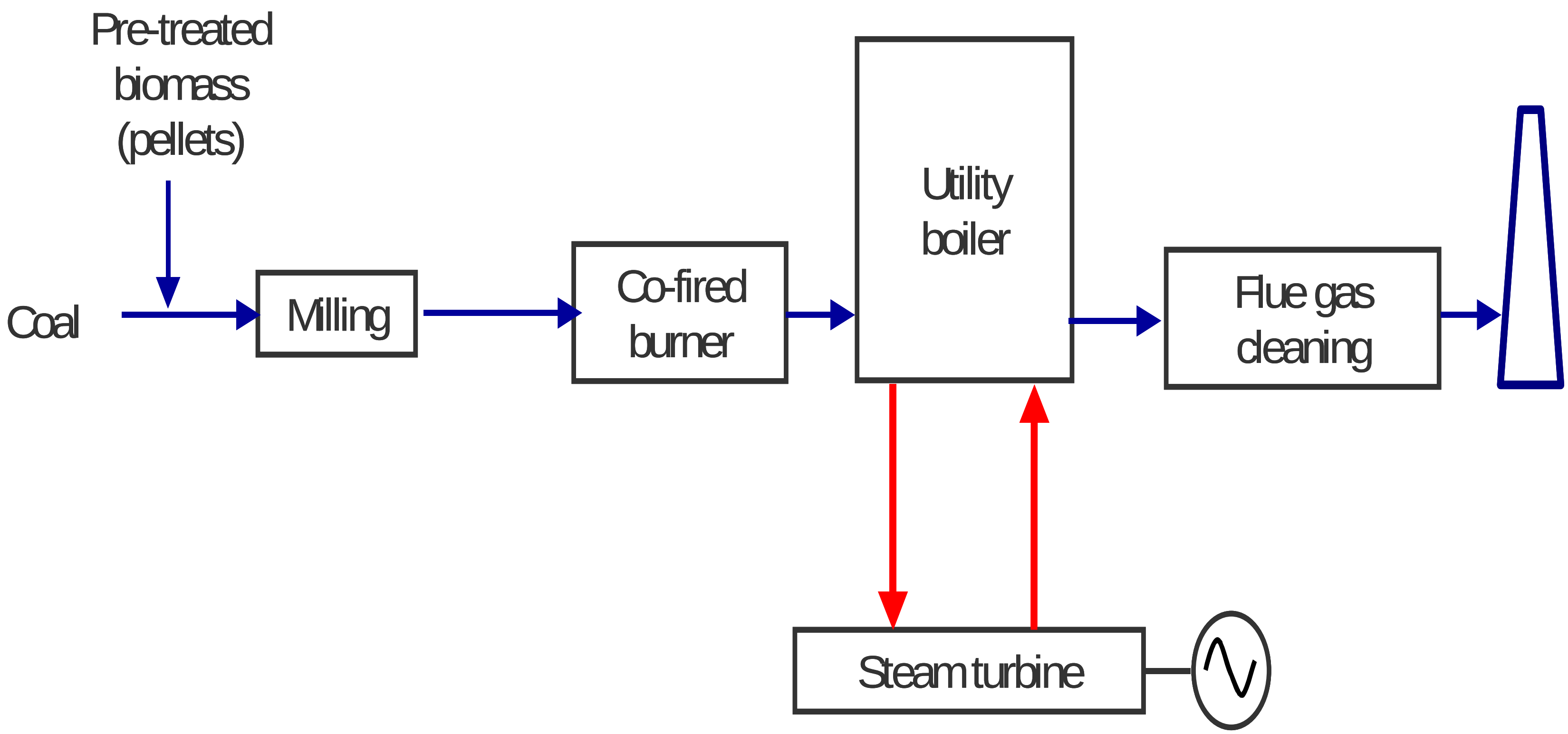


Options for Biomass Co-Firing

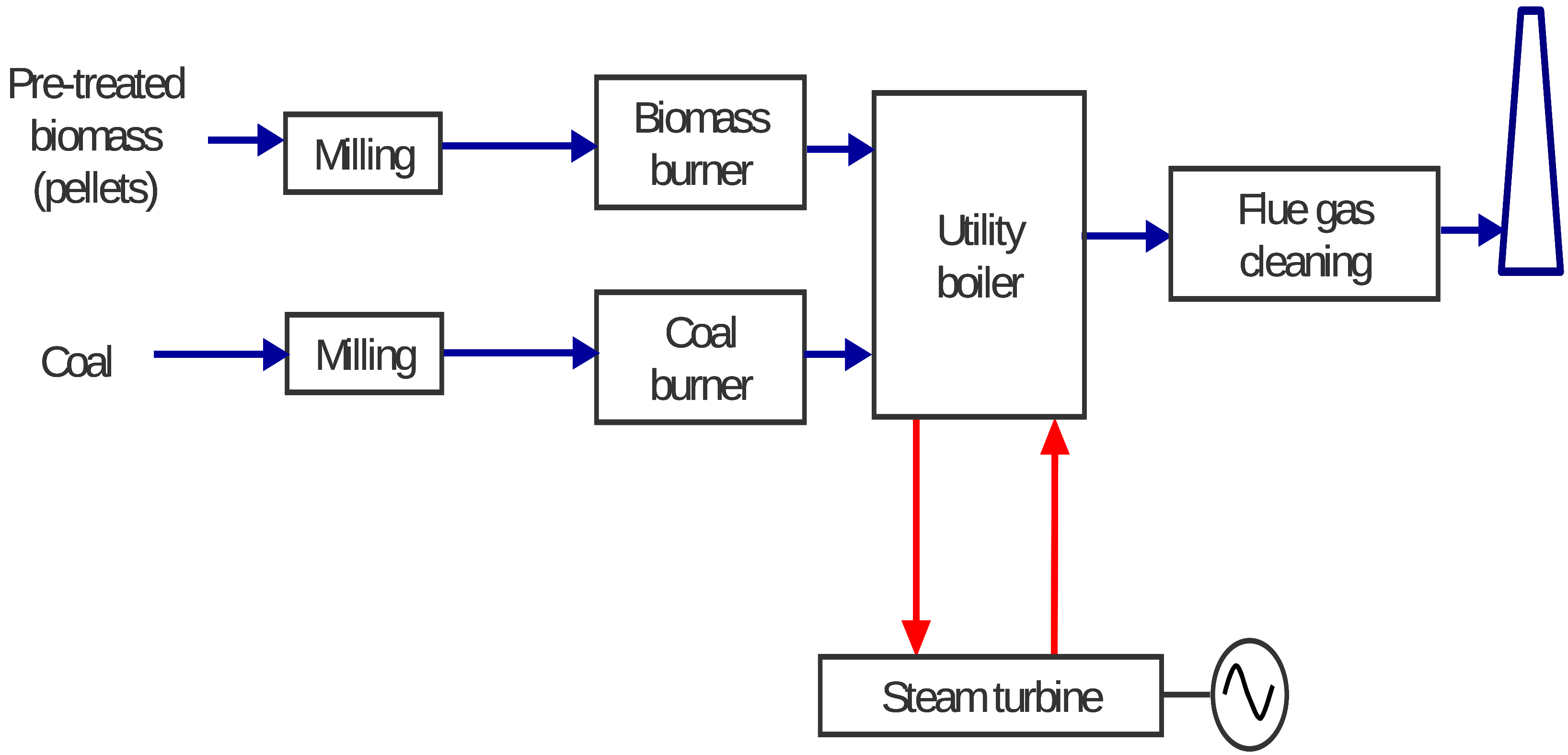
Principally, there are two main methods for firing biomass within an existing coal boiler:

- Co-Milling
  - Generally limited by fuel type up to <10%
- Dedicated co-firing
  - Experience up to 20^{+}% with dedicated mills

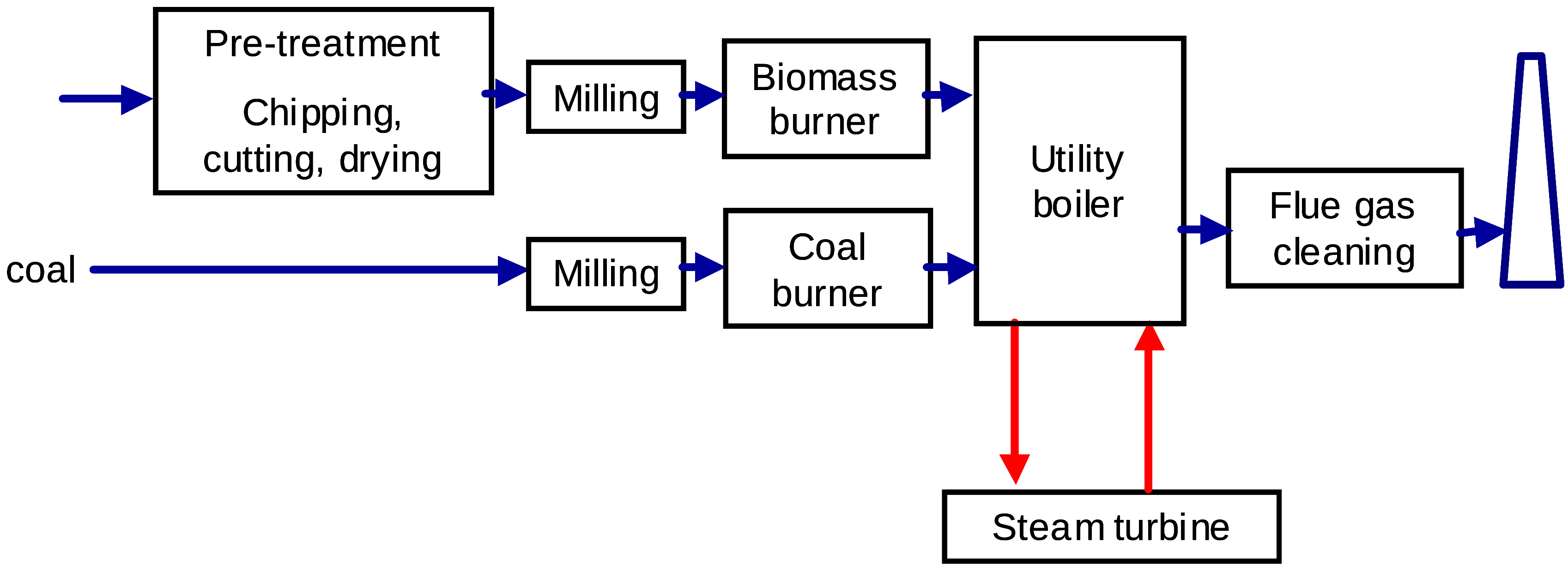
Biomass Pellets Firing System Design Concept #1



Biomass Pellets Firing System Design Concept #2

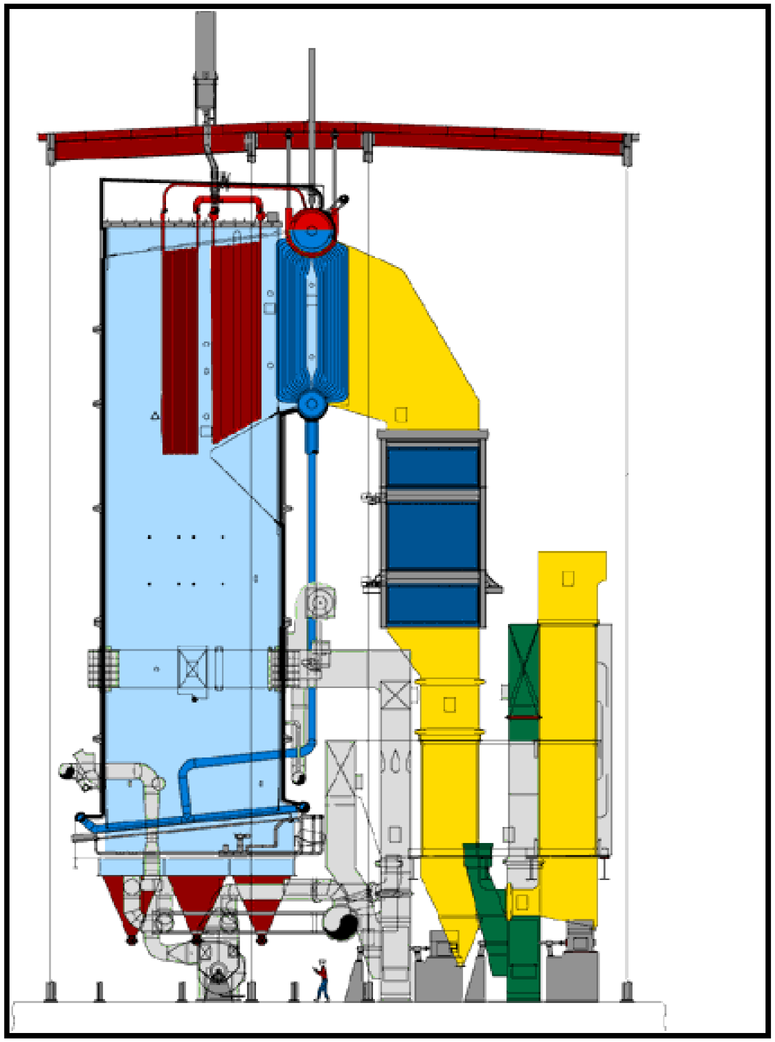


Biomass Firing System Design Concept #3



Spreader Stoker Fired

- Designed to Fire 50 to 100% Biomass
- Can Co-fire Oil, Gas, PC or Stoker Coal
- Can Handle Coarse Material (4" top size)
- Can Handle Wet Material (~55% moisture)
- Uses Belts, Drag Chains and Feed Screws
- Use Gravity Feed Chutes and Air Assisted Spreaders



Co-Firing with Biomass: Key Issues & Challenges

- Local Regulations
- Transport & Storage of Volatile Fuel
- Volume of Material Due to Low Heating Value & Lower Density
- Site Constraints
- Dust Emissions
- Variability of Fuel; Moisture Content, Ash Constituents, N, Cl, etc.
- Boiler Performance
- AQCS Performance
- Ash Quality / Saleability of Ash

Co-Firing with Biomass (cont'd): Boiler Performance

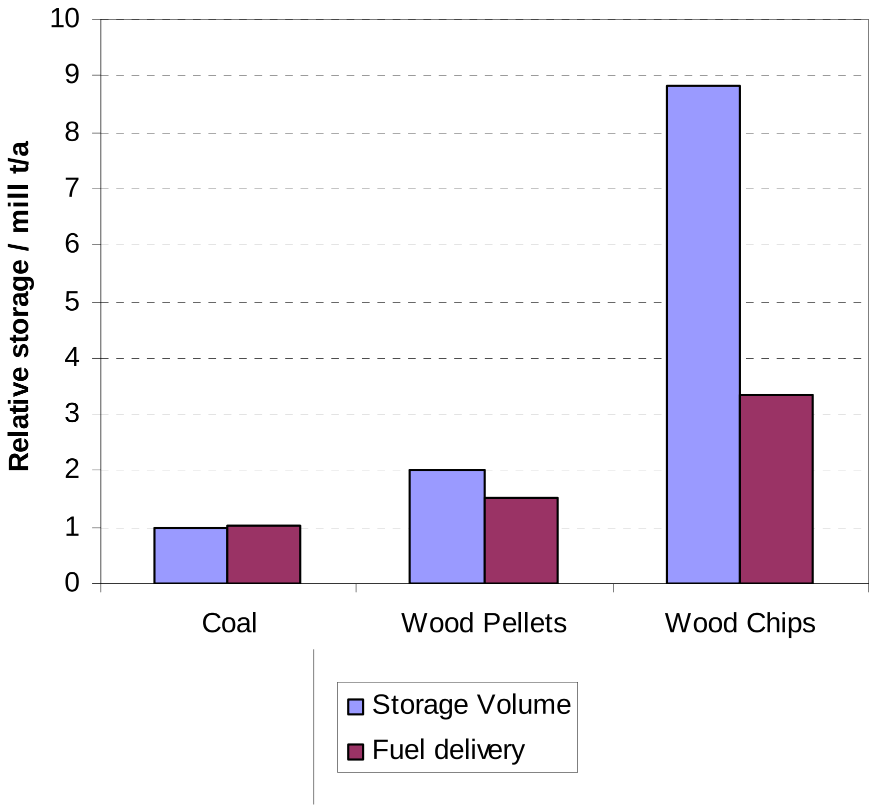
- Boiler Load
  - Fuel Input
  - De-rating
- Boiler Efficiency
- Steam Temperatures
- Gas Weights / Velocities
- Flue Gas Outlet Temperature
- Slagging / Fouling
- Corrosion / Erosion
- Air Heaters
- Auxiliary Equipment – ESP, FD, ID Fans, etc

Co-Firing with Biomass (cont'd): Boiler Performance

- Impact on Boiler Load, Efficiency and Steam Temperatures
- Impact on Flue Gas Velocities (Erosion) and Flue Gas Outlet Temperatures
- Impact on Sub-cooling Delta Temperature & Circulation
- Impact on Furnace Slagging and Fouling
- Impact on Corrosion / Erosion of Various Boiler Components / Sections
- Location of Biomass Burner
- Impact on Emissions (I.e. NOx, SOx, CO, etc.)
- Impact on Backend Equipment (i.e., ESP, Baghouse, SCR, etc.)
- Impact on Auxiliary Equipment (i.e., FD Fans, ID Fans, Air Heaters, etc.)
- Selection of Equipment Suitable for Grinding Type of Biomass Materials
- Design / Location of Milling Plant and Pneumatic Transport system
- Dust Control and Explosion Prevention

Storage Considerations

- Bulk Storage
  - Acts as a buffer between delivery and utilization
- Considerations
  - Fuel type and physical properties
  - Low energy density compared to coal
  - Bulk density
  - Moisture content
  - Storage time, weekend or longer
  - Delivery schedule
  - Climatic conditions



Fiddler's Ferry Co-firing Experience

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Fiddlers Ferry

- 4 x 500 MWe T-Fired Boilers - Units 2 and 4
- First dedicated Biomass co-firing plant in the UK
- Previously tried co-milling, decision made to go to dedicated co-firing system
- 20% MCR Biomass by heat input basis
- Wide range of biomass fuels; wood pellets, palm kernels, olive stones, olive cake <15% moisture

Design of dedicated biomass co-firing system

Boiler Performance

<u>Operational findings</u>

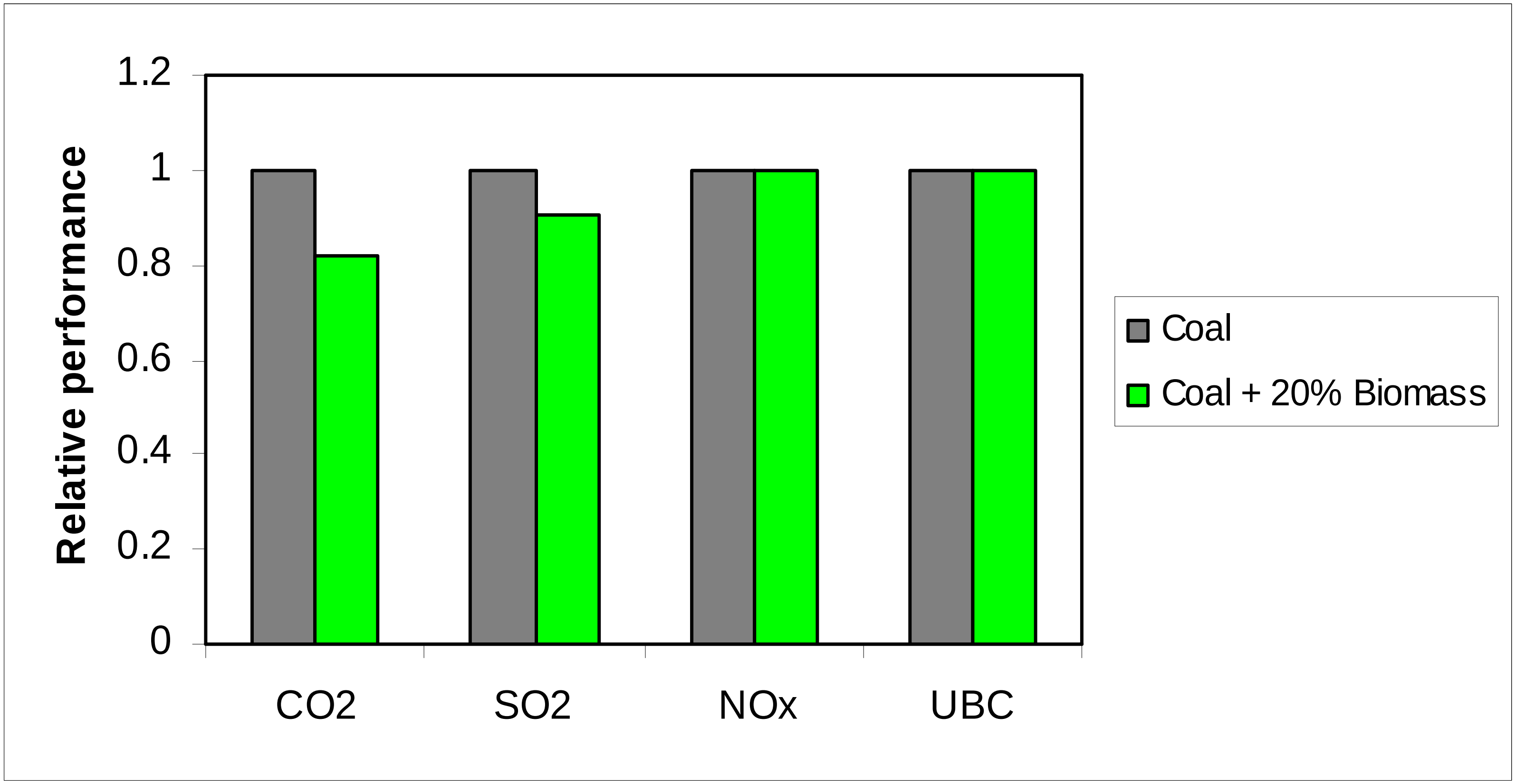
- Plant fully commissioned and operational since mid 2006
- Plant availability ~95%
- CO_2 savings per year = > 1million tons/yr (based on 100% capacity)
- Plant consistently delivers rated output of 100 MWe per unit
- Each stream capable of processing up to 1440 t/day
- Multi fuel capability – limited moisture <15%

Boiler Performance

- Gas volumes increase slightly due to higher proportion of moisture within the gas stream and increased gas temp.
- No major impact on steam temp
- Slagging and fouling not observed
- 20% MCR Biomass has minimal impact on efficiency <0.4% diff.
- Performance of ID fan and ESP not affected

Performance

Emissions - CO_2, NOx, SO_2 and UBC (Palm Kernels)



Co-firing Biomass in a Coal Fired Boiler

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Economics

- More Cost Effective to Co-fire Biomass at Existing Plant than to Build a New Facility
- Potential Low Cost “Opportunity” Fuel Supply
- Potential State & Federal Funding Incentives
- Potential “Green Power” Pricing Premiums

Agenda

Biomass Background

Biomass Fundamentals and Technical Considerations

Natural Gas Background

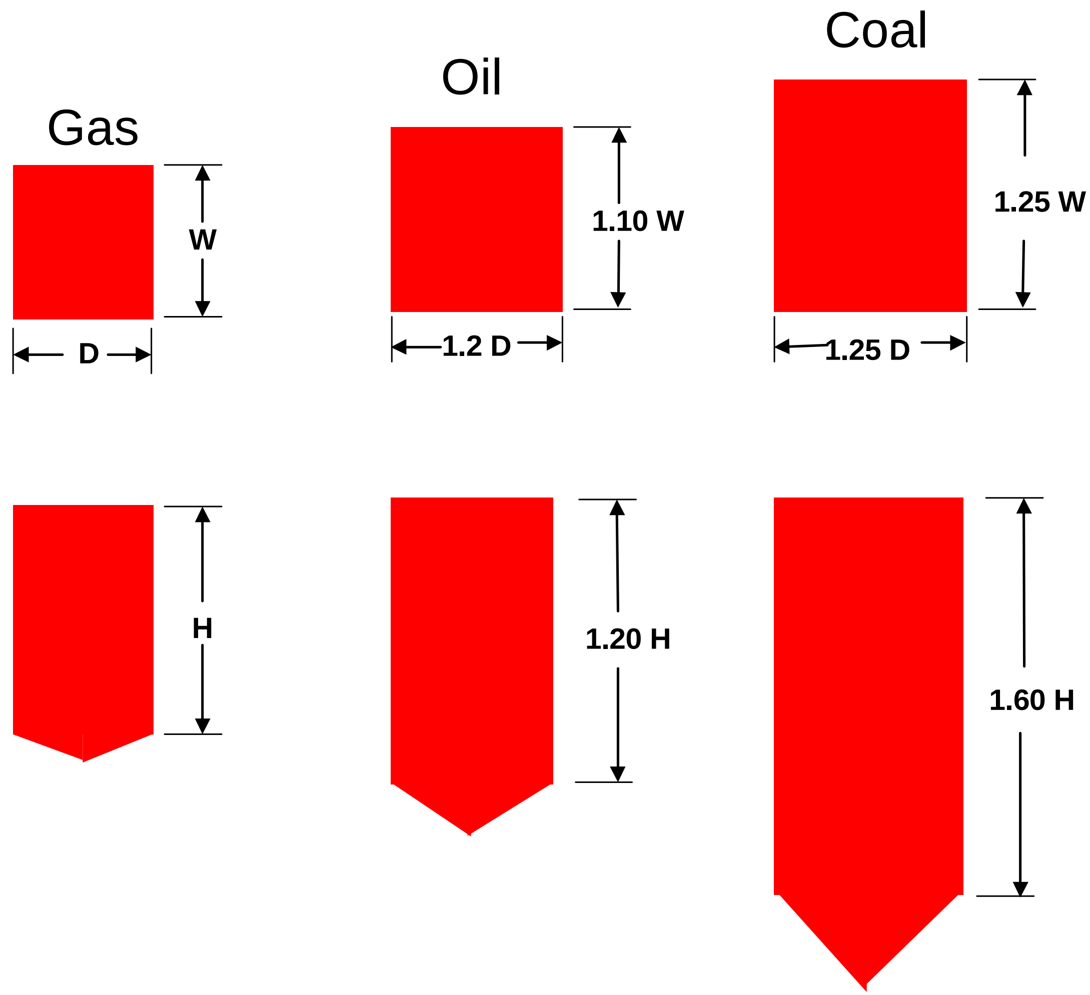
Natural Gas Fundamentals and Technical Considerations

Items to be covered

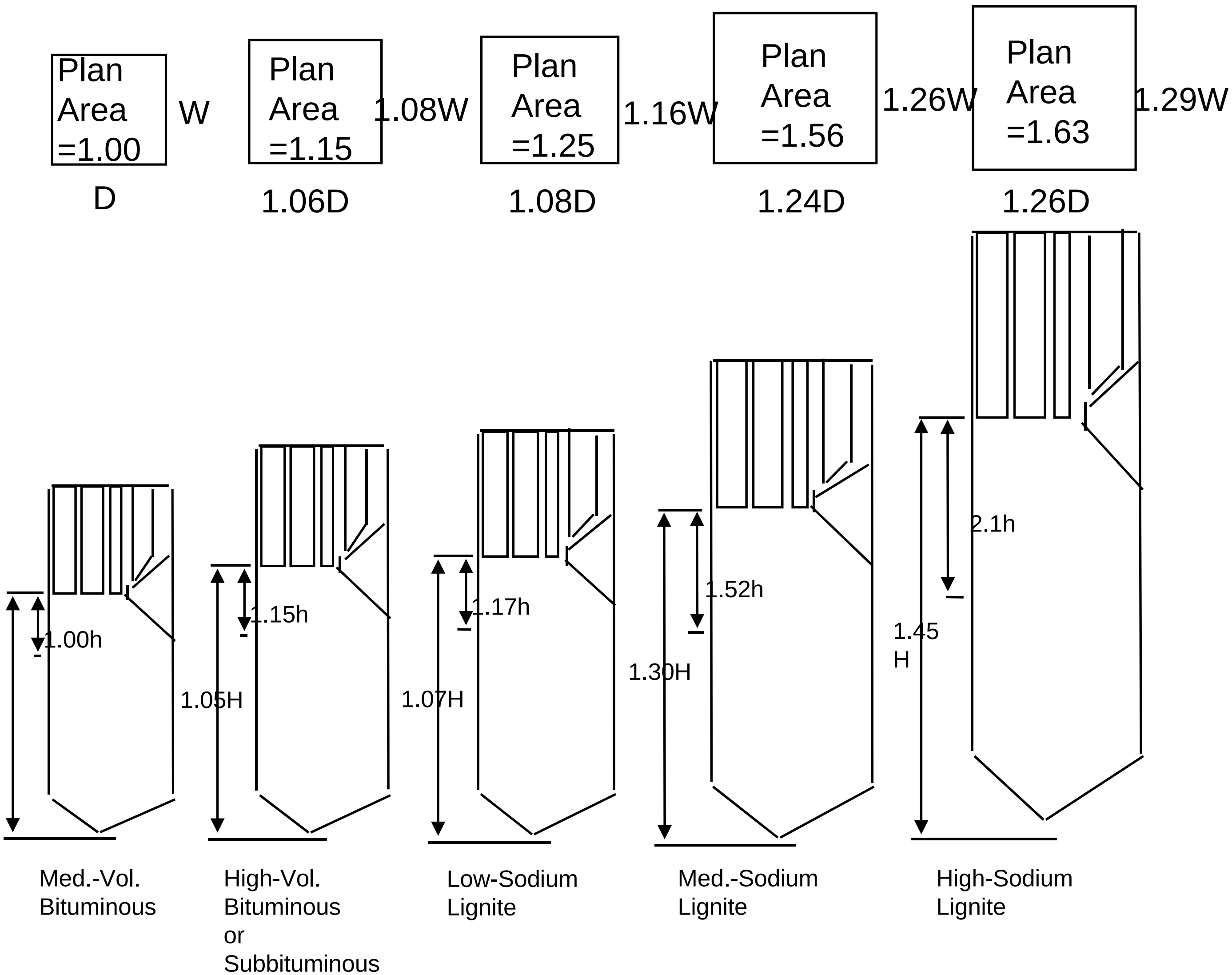
- Boiler Sizing
- Gas Firing – Emissions
- Converting Bituminous Coal Fired Boiler to Gas Firing
- Converting PRB Coal Fired Boiler to Gas Firing
- Pulverizer and Fan Systems
- Summary

Normal Boiler Sizing

- Boilers are normally designed for a specific fuel.
- Anytime a boiler has a change in fuel, there will be performance compromises.



Coal Fired Boilers



Basic Fuel Effects on Performance

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FUEL		Coal (Bit)	Coal (Subbit)	Coal (Lignite)	Natural Gas	Oil
Excess Air		**(20% XA)**	**(20% XA)**	**(20% XA)**	**(12.5% XA)**	**(20% XA)**
Fuel Analysis						
Carbon	%	66.6	50.64	41.69	71.77	86
Hydrogen	%	4.7	3.45	2.8	23.9	10.1
Nitrogen	%	1.2	0.7	0.8	4.32	0.7
Oxygen	%	6.8	11.72	12.71		0
Sulfur	%	3.7	0.4	0.43		2.55
Ash	%	8.5	5.2	10.74		0.35
Moisture	%	8.5	27.9	30.83		0.3
		100.0	100.0	100.0	100.0	100.0
VM	%	38.0	31.0	27.8		-
HHV	Btu/lb	12,000	8,692	7,154	22,808	18,096
Typical XA	%	18	20	20	10	6
Wet Air	lb/MBtu	758.5	767.7	757.3	732	742.6
Dry Gas Weight	lb/MBtu	929.9	945.1	942.7	763.0	893.4
% Change in Fuel Flow (lb/MBtu vs. Bit)	%	**100%**	**143%**	**164%**	**58%**	**72%**
% Change in Air Flow (lb/MBtu vs. Bit)	%	**100%**	**102%**	**100%**	**91%**	**98%**
% Change in Total Products (lb/MBtu vs. Bit)	%	**100%**	**105%**	**105%**	**88%**	**96%**
Boiler Efficiency	%	88.0	85.5	84.1	84.5	88.9
Weighted Total Fuel (Based on B.E. or Q_F)	lb/MBtu	86	127	148	52	62
Weighted Total Air (Based on B.E. or Q_F)	lb/MBtu	1031	1084	1080	975	1002
Weighted Total P (Based on B.E. or Q_F)	lb/MBtu	1118	1212	1228	1026	1064
% Change in Fuel Flow (vs. Bit)	%	**100%**	**147%**	**171%**	**60%**	**72%**
% Change in Air Flow (vs. Bit)	%	**100%**	**105%**	**105%**	**95%**	**97%**
% Change in Flue Gas Flow (vs. Bit)	%	**100%**	**108%**	**110%**	**92%**	**95%**

Gas Firing - Emissions

NOx Formation

NOx is formed by two primary mechanisms:

- Thermal fixation of atmospheric nitrogen-- "thermal NOx"
- Fixation of nitrogen contained in the fuel-- "fuel NOx" (no fuel NOx in gas)

Parameters Influencing NOx Formation

Boiler Operation

- Unit Load
- Tilt Position
- Excess Air
- WB Air Distribution
- Fuel/Air Staging

Parameters Influencing NOx Formation

Boiler Design

- Heat Release Rates
- Air Inleakage
- Firing Systems Design

Fuel Properties

- Fuel Nitrogen - Not applicable

NOx Technology Questions

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- Current NOx Emissions Levels
- Required (or desired) NOx Emissions Levels
- Available Options
- Current Performance
- Performance Requirements

NOx Reduction Methods

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Reduce Burner Zone Stoichiometry

- Low NOx Burners
- Lower Excess Air
- Overfire Air (OFA)
- Flue Gas Recirculation

Lower Flame Temperature

- Reduce Secondary Air Temperature
- Reduce Load
- Steam/H_20 Injection
- Flue Gas Recirculation
- Spread Out the Heat Release

Flue Gas Recirculation (can also be used to maintain outlet steam temperatures)

- Forced
- Induced
- Premixed

Reburn

SNCR

Agenda

Biomass Background

Biomass Fundamentals and Technical Considerations

Natural Gas Background

Natural Gas Fundamentals and Technical Considerations

Bituminous Coal with Natural Gas Co-Firing

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Possible Issues Include:

- An increase in SH desuperheater spray water flow
- An increase in RH desuperheater spray water flow
- An increase in forced draft fan volumetric flow
- SHO & RHO steam temperatures may not be achieved in some cases
- These issues may or may not require capacity increases in their respective equipment

Bituminous Coal with Natural Gas Co-Firing

Solution:

- Increase the SH desuperheater spray water capacity
- "Tip" the forced draft fans to increase their volumetric flow capacity
- May require re-surfacing for steam temperature

PRB/Lignite Coal with Natural Gas Co-Firing ALSTOM

Possible Issues Include:

- Inability to attain design SH steam outlet temperature
- Inability to attain design RH steam outlet temperature
- Insufficient forced draft fan volumetric capacity
- Insufficient forced draft fan motor size
- Primary air system not useful
- Exceeding steam turbine steam inlet temperature lower limits
- Exceeding steam turbine SH/RH steam inlet differential temperature limits

Co-Firing Natural Gas in a Coal Fired Boiler

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- Up to 15% NG, there should be little change to boiler performance.
- From 15% to 50% NG, a cursory study may be need but in most cases the boiler will maintain performance.
- From 50% to 100% NG, a detail study is needed to determine how much the boiler performance is effective. Determine boiler modifications that are needed to restore performance.

Co-Firing Natural Gas in a Coal Fired Boiler (con't)

- Boilers from 100 MWs to 600 MWs can co-firing NG.
- Boilers that are 600 MWs or larger normally co-firing NG for start-up fuel or low load operation only.
  - Pipeline may be limiting factor.

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