2008 Fuel Flexibility Conference

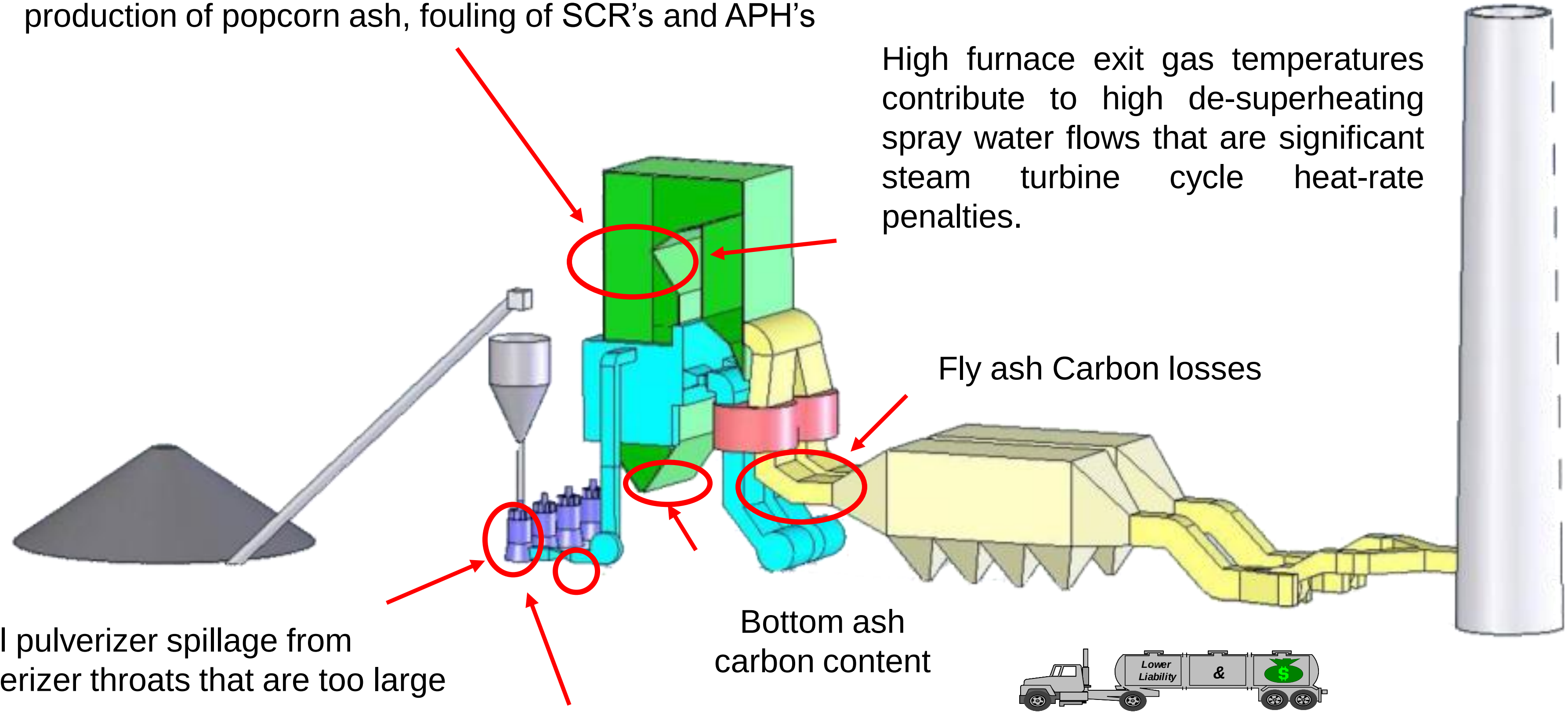
"Strategies & Tactics for Coal Consumers"

Maximizing Plant Performance

Presented by, Stephen Storm
Storm Technologies, Inc

Sheraton Inner Harbor Hotel
Baltimore, Maryland
July 29th, 2008

Overall Plant Performance Opportunities



High furnace exit gas temperatures contribute to overheated metals, slagging, excessive soot blower operation, production of popcorn ash, fouling of SCR's and APH's

High furnace exit gas temperatures contribute to high de-superheating spray water flows that are significant steam turbine cycle heat-rate penalties.

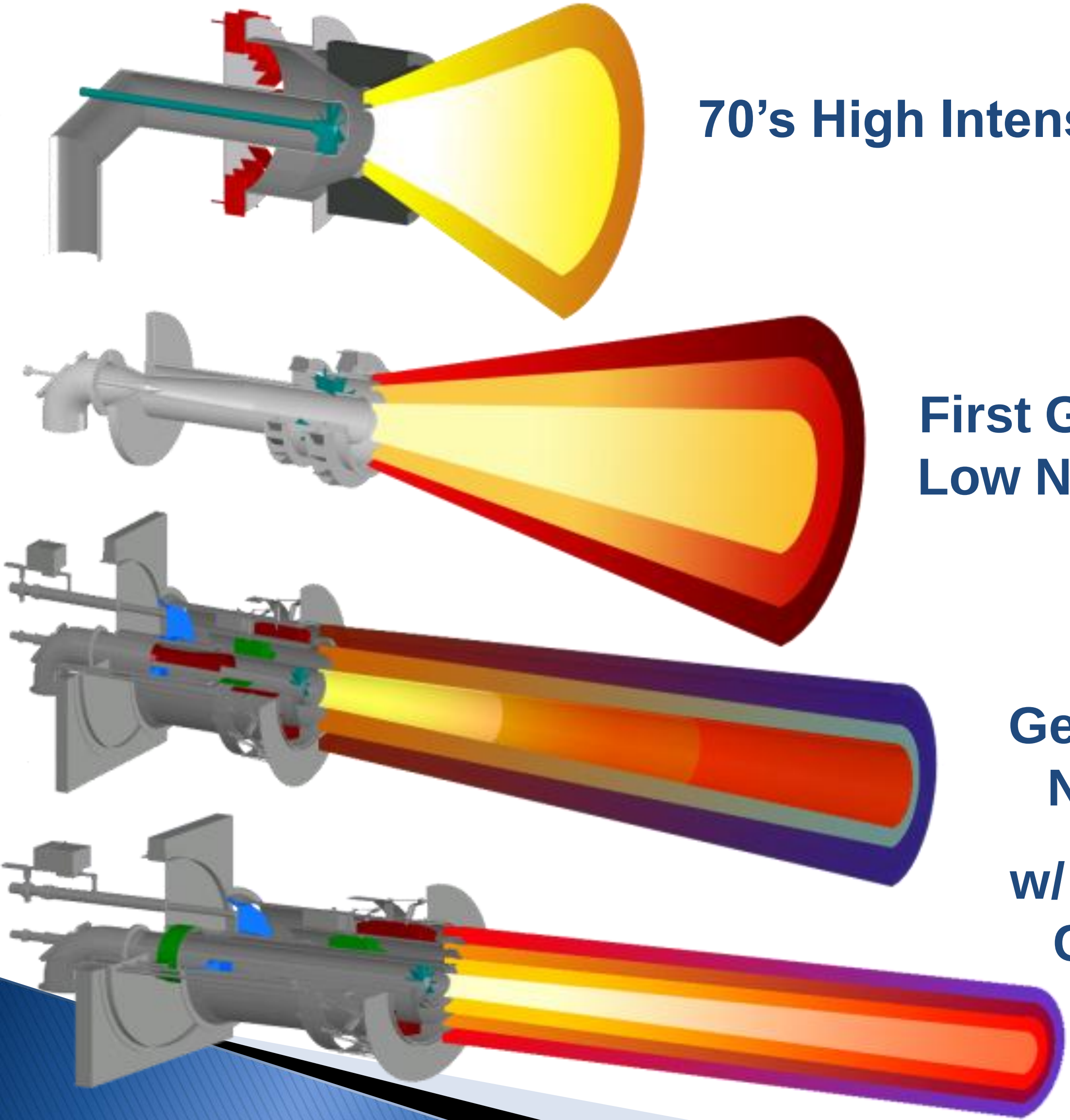
Fly ash Carbon losses

Coal pulverizer spillage from pulverizer throats that are too large

Bottom ash carbon content

High primary airflows contribute to unnecessarily high dry gas losses. Also poor fuel distribution , poor coal fineness, load Control & Excessive NOX

Low NO_X Firing Evolution Challenges



70's High Intensity Burner

First Generation Low NO_X Burner

2^{nd} & 3^{rd} Generation Low NO_X Burners

w/ OFA / Staged Combustion

Forgiving

Sensitive

Unforgiving

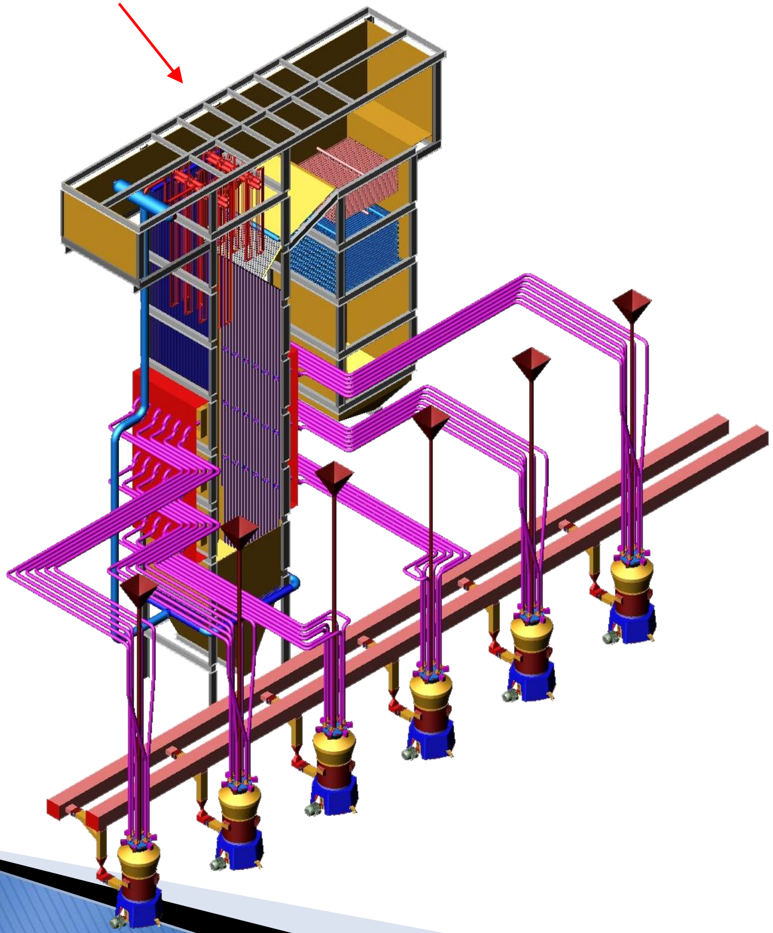
Challenging !

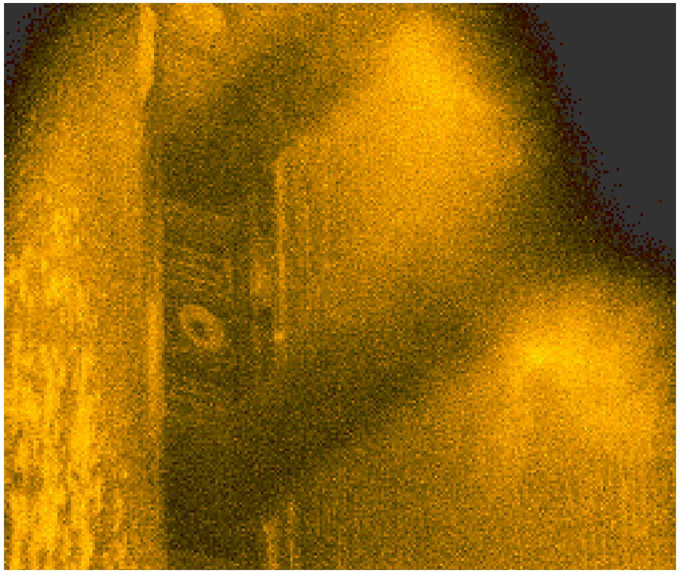
All are 175 – 185MMBTU

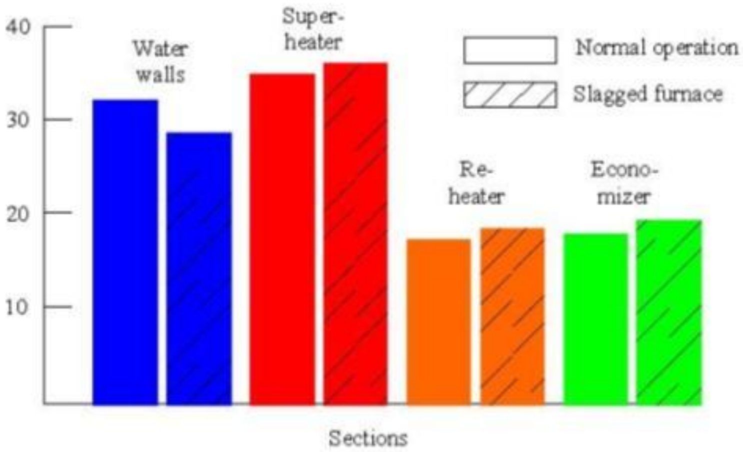
Secondary Combustion (video)

Excessive de-superheating spray flows & heat rate

Too much heat absorption in the upper furnace will contribute to high de-superheating water spray flows

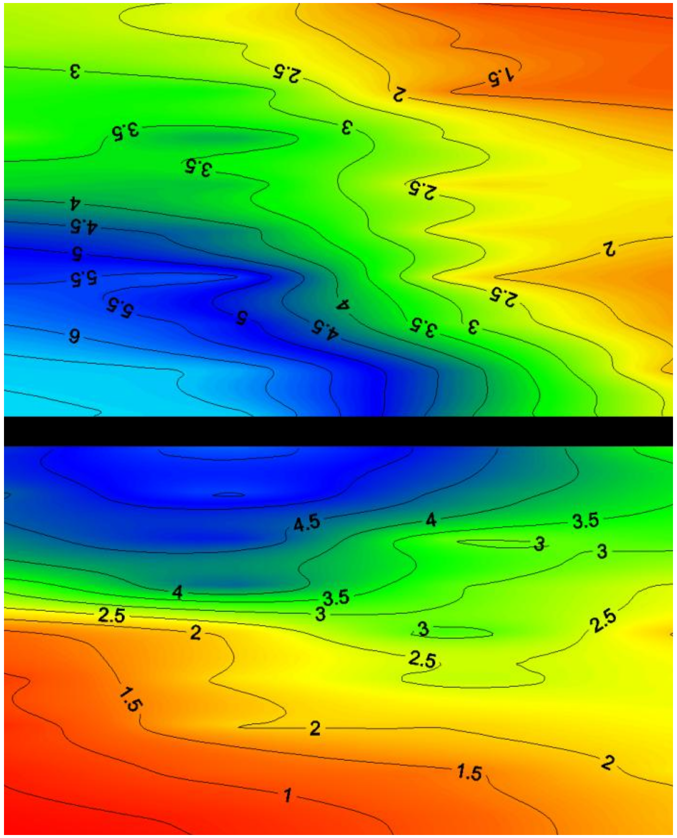


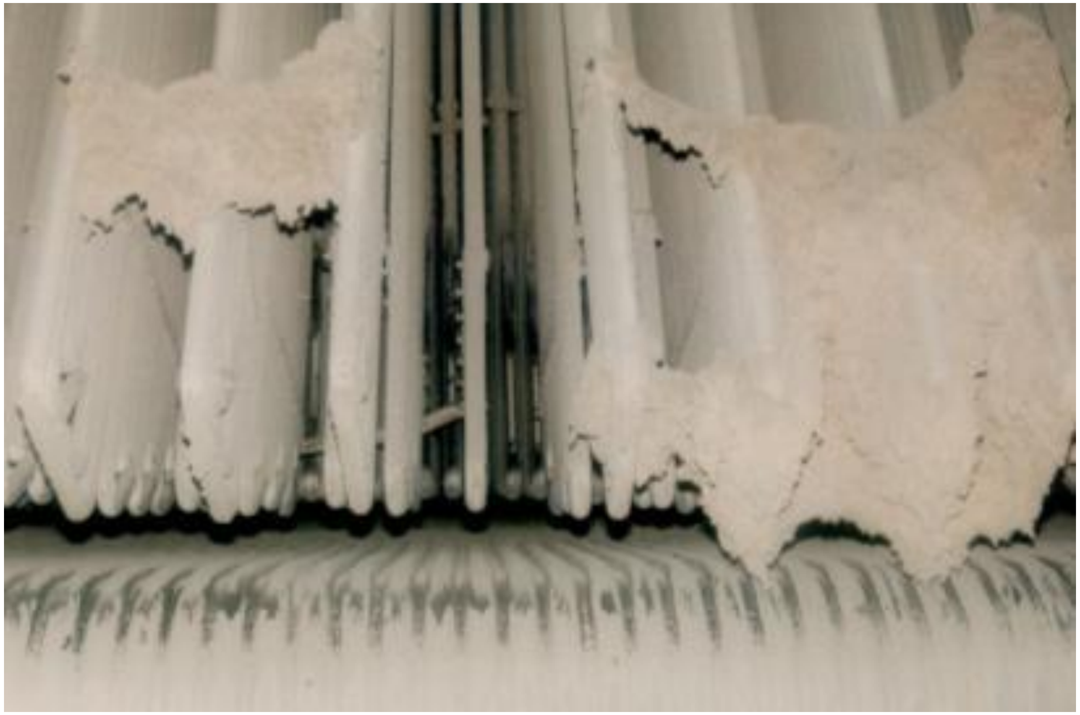




Active Secondary Combustion (video)

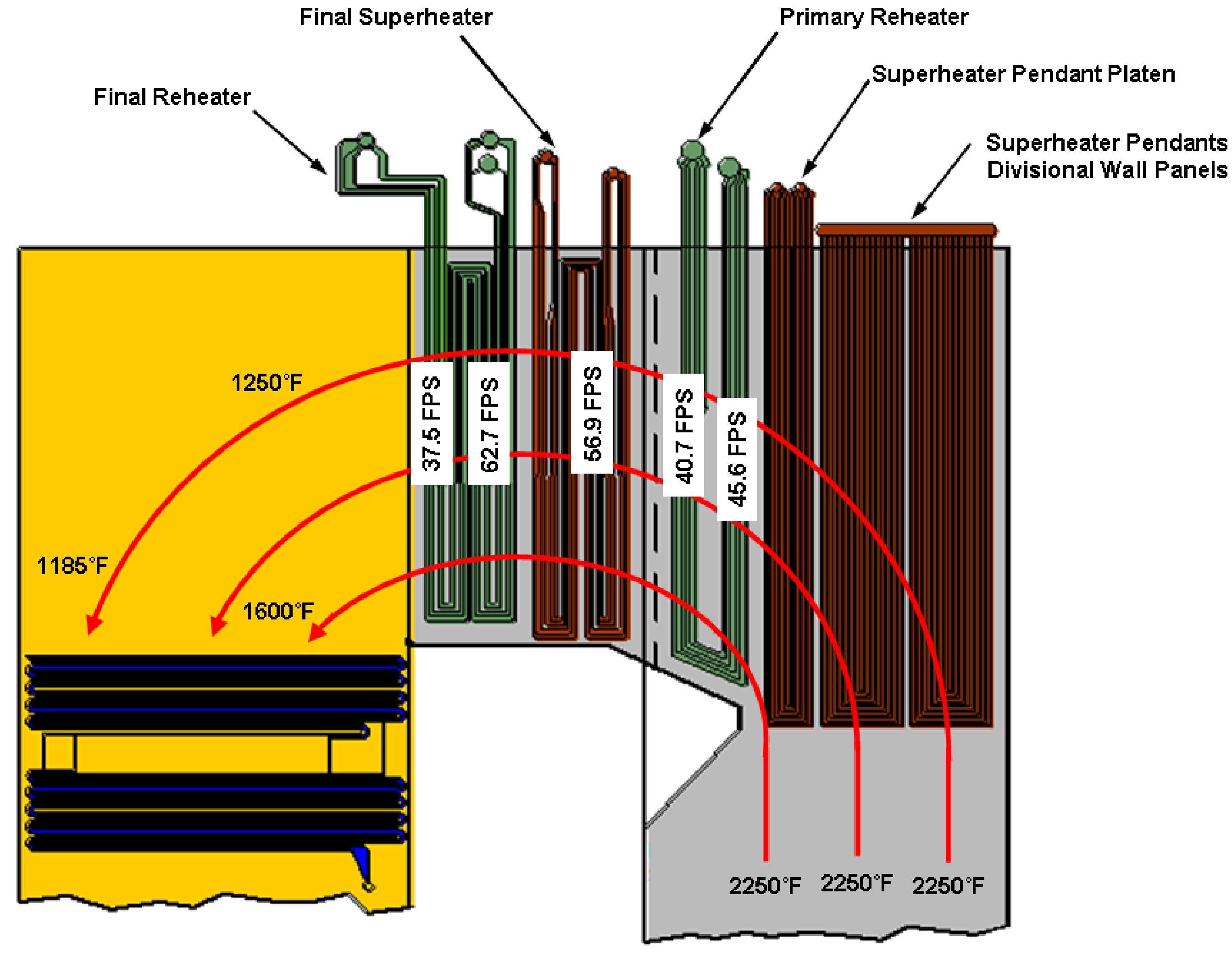
Furnace Exit Gas Profiles





Minimization of Reducing atmospheres at the furnace exit is the Key to optimizing flue gas temperatures and reducing slag bridging, heavy levels of secondary combustion and hot tube circuits.

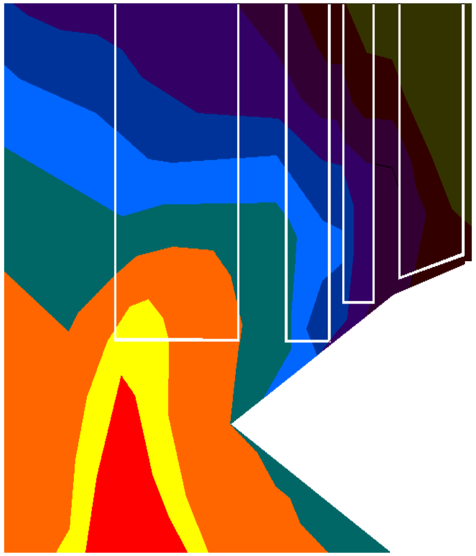
Typical Flue Gas Stratifications & Flue Gas Temperatures - Velocities

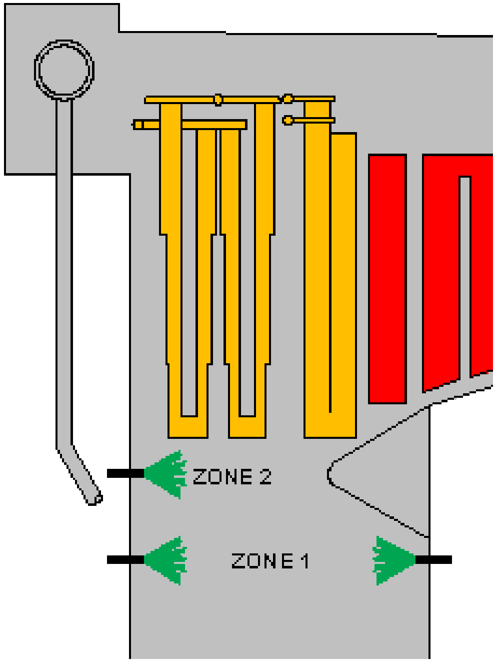


Post Combustion Techniques To Reduce NO_X

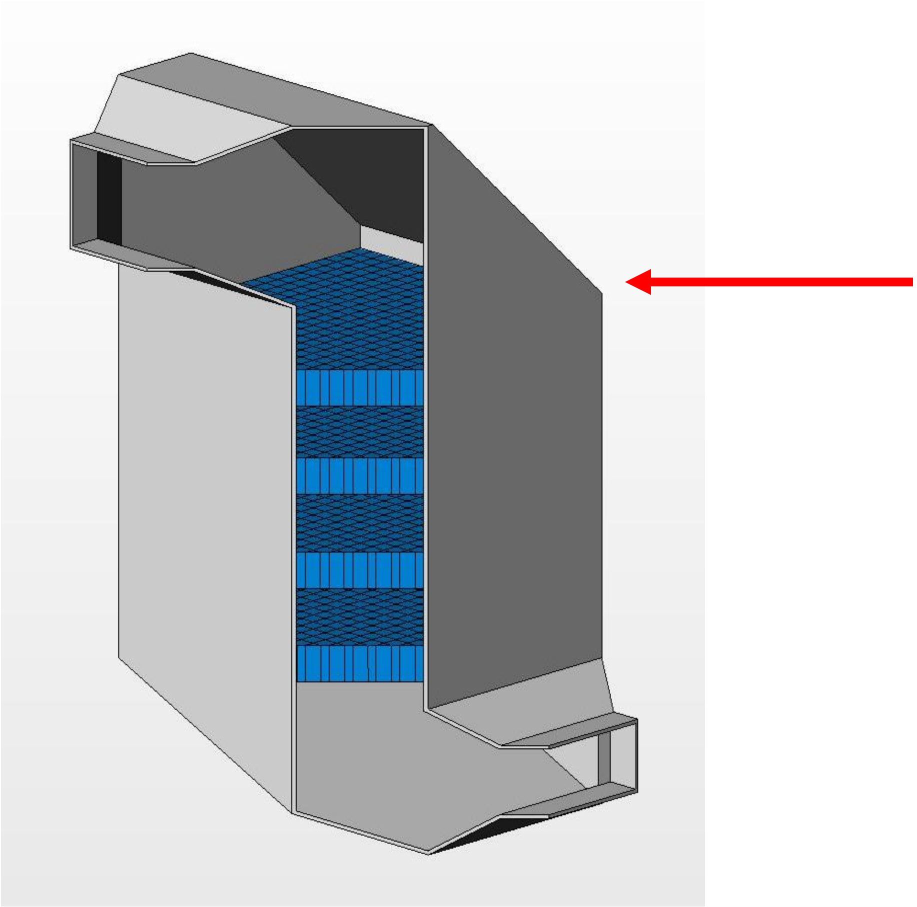
- SNCR (Selective non-catalytic reduction) injects a reducing agent into NO_X laden flue gas within a specific temperature zone or window.

- The chemical agent and the flue gas need to properly mix for optimum NO_X reduction. The mixture must have adequate residence time for the reduction process to take place. For urea the temperature window is approximately 1,800ºF-2,100ºF. For Ammonia the temperature window is 1,600ºF-1,800ºF.





Issues with “Pop Corn Ash”

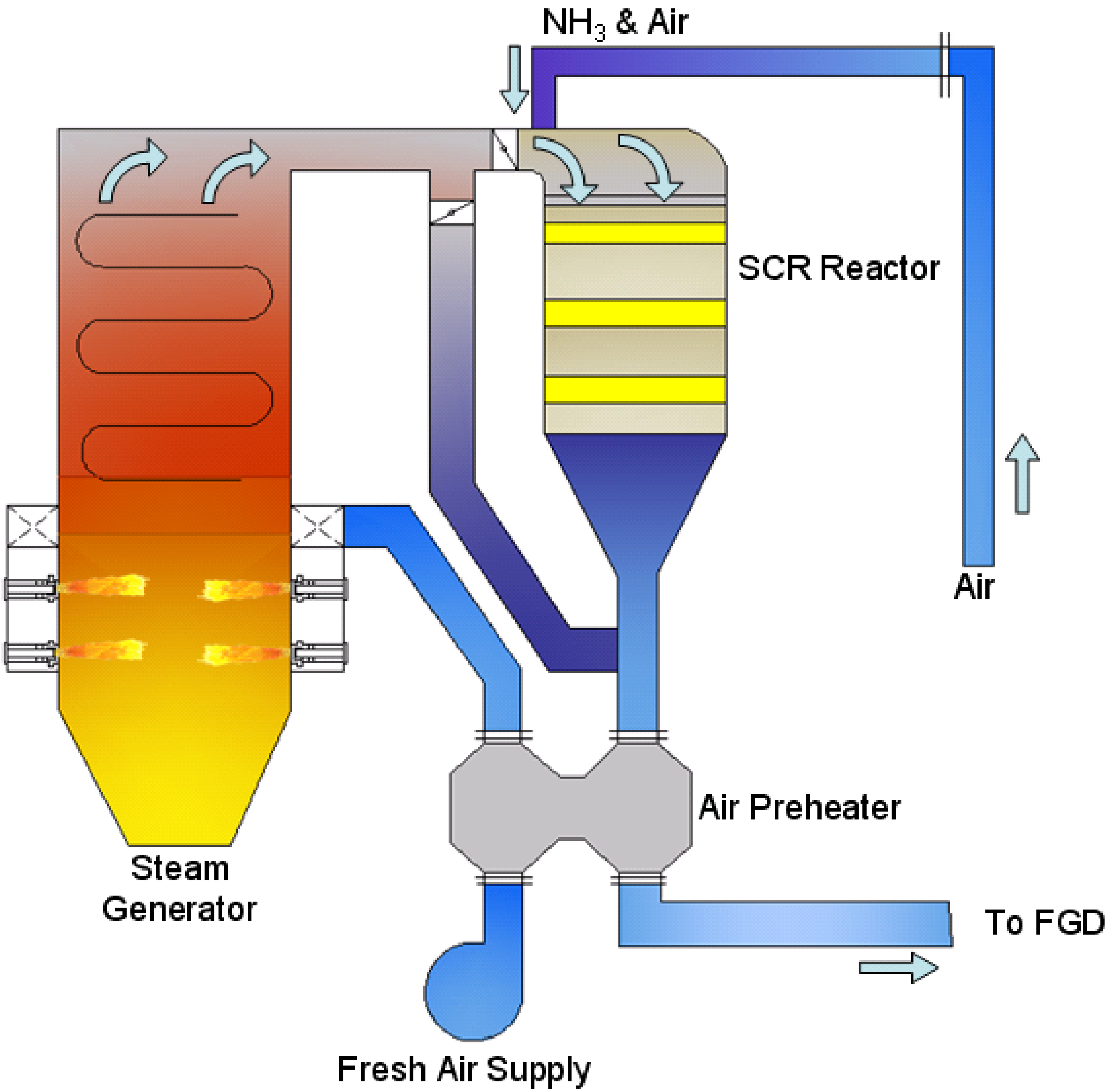


SCR (Typical Layout)

Popcorn Ash

Ash build-up – plugging half of a catalyst due to popcorn ash

SCR Performance Optimization



Coal Variations

Ultimate Analysis	High Slagging Coal	Low Slagging Coal	
Moisture	6.09	2.2	% by wt.
Carbon	63.25	72.7	% by wt.
Hydrogen	4.32	4.7	% by wt.
Nitrogen	1.37	1.27	% by wt.
Sulfur	3.81	0.76	% by wt.
Ash	15.63	13.4	% by wt.
Oxygen	5.53	4.97	% by wt.

Ash Fusion Temperatures			
Reducing			
Initial Deformation	1,955	2750+	° F
Softening	2,180	2750+	° F
Hemispherical	2,290	2750+	° F
Fluid	2,400	2750+	° F
Oxidizing			
Initial Deformation	2,440	2750+	° F
Softening	2,515	2750+	° F
Hemispherical	2,585	2750+	° F
Fluid	2,660	2750+	° F

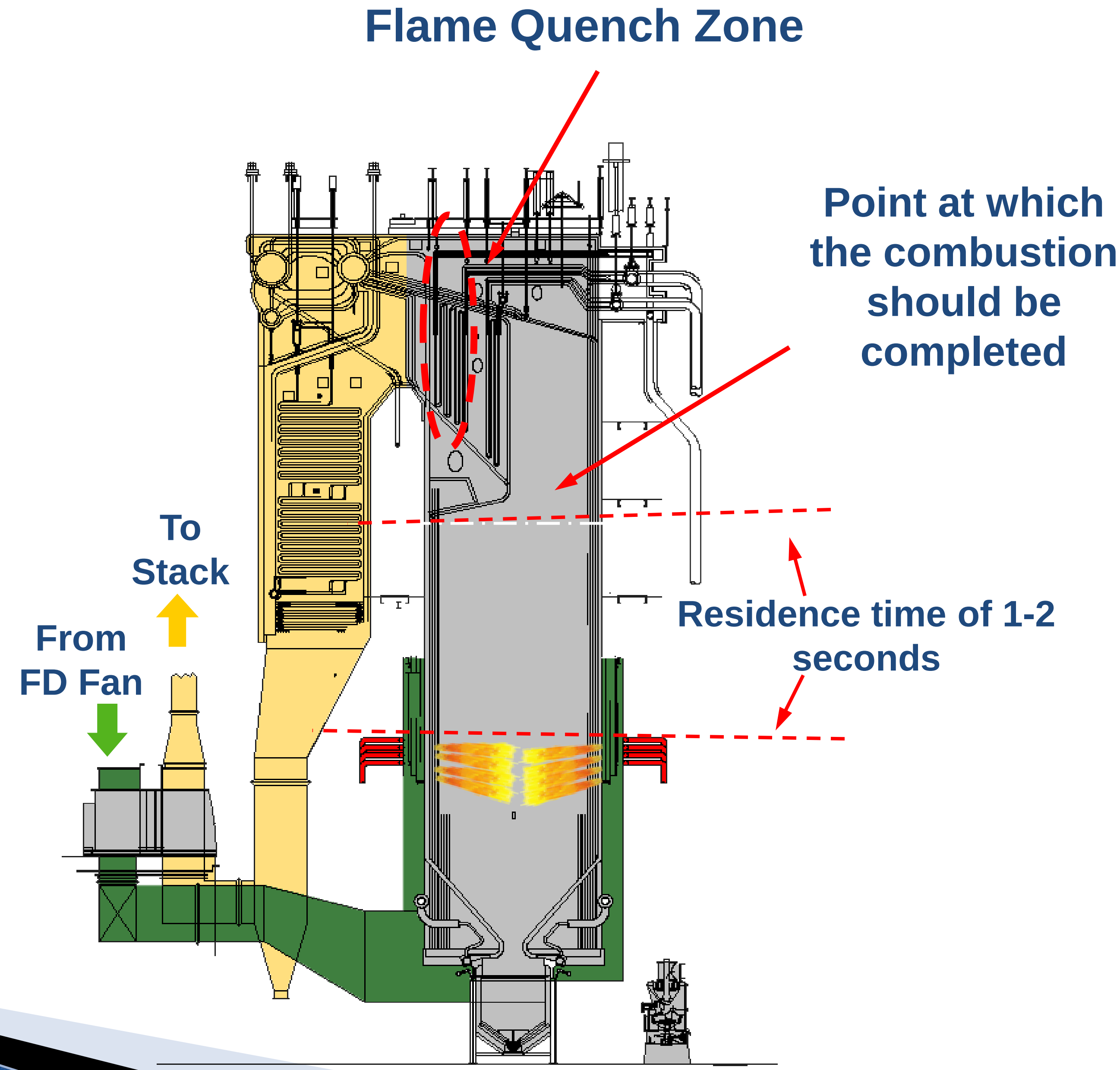
Mineral Ash Analysis			
Silicon Dioxide	45.9	59.6	% by wt.
Aluminum Oxide	20.5	27.42	% by wt.
Titanium Oxide	0.96	1.34	% by wt.
Iron Oxide	26.94	4.67	% by wt.
Calcium Oxide	1.36	0.62	% by wt.
Magnesium Oxide	0.73	0.75	% by wt.
Potassium Oxide	2.13	2.47	% by wt.
Sodium Oxide	0.21	0.42	% by wt.
Sulfur Trioxide	0.91	0.99	% by wt.
Phosphorous Pentoxide	0.3	0.42	% by wt.

Relationship of Poor Fineness w/ Water Wall Wastage

Microscopic Investigation of Deposits
Source: Rod Hatt, CCI

Poor Fineness will not only result in poor distribution, but also heavier Iron Concentration in the Ash; **High Iron + Reducing Atmosphere = Trouble**

Furnace Residence Time



Flame Quench Zone

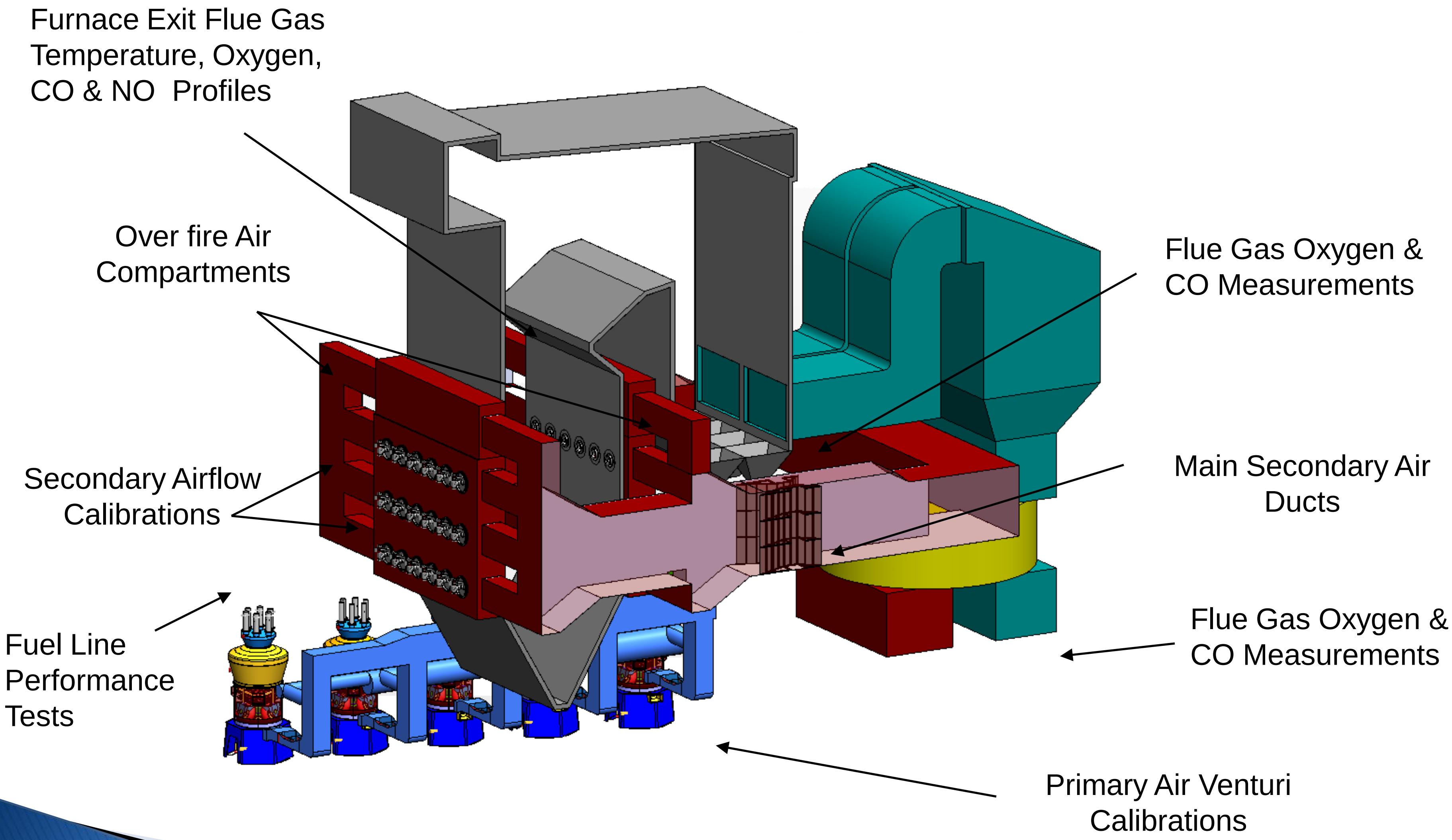
Point at which the combustion should be completed

Residence time of 1-2 seconds

To Stack

From FD Fan

Performance Driven Maintenance Techniques


Furnace Exit Flue Gas Temperature, Oxygen, CO & NO Profiles

Over fire Air Compartments

Secondary Airflow Calibrations

Fuel Line Performance Tests

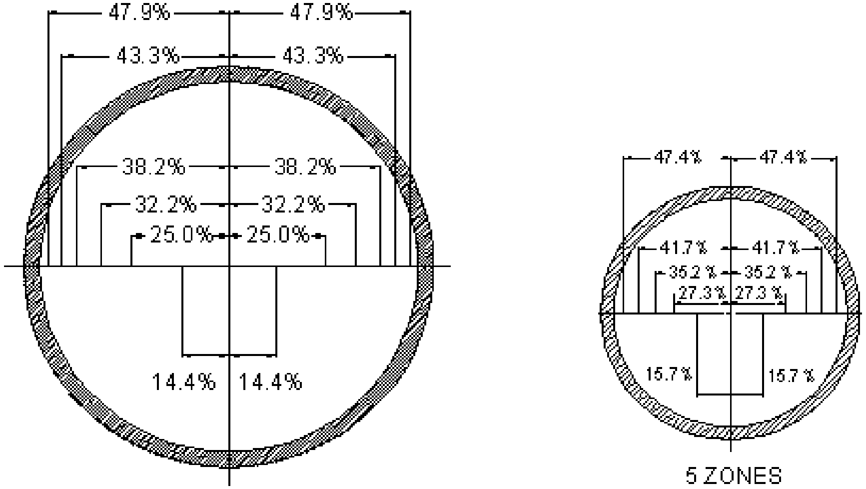
Flue Gas Oxygen & CO Measurements

Main Secondary Air Ducts

Flue Gas Oxygen & CO Measurements

Primary Air Venturi Calibrations

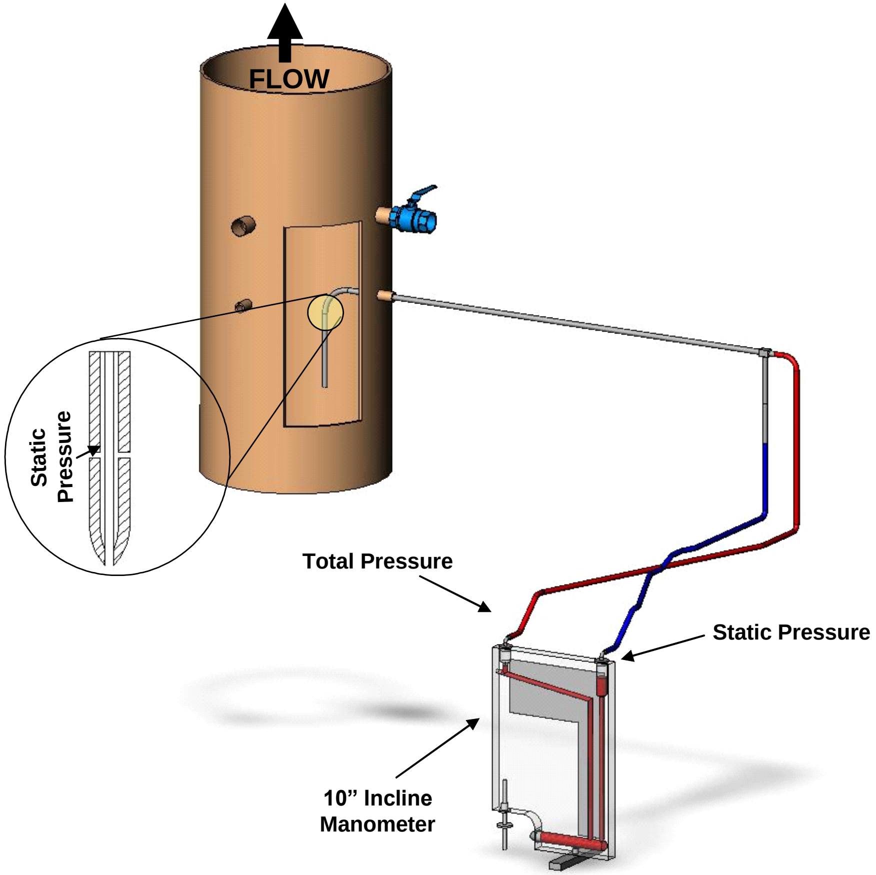
The Clean Air Test



6 ZONES
12" OR LARGER

5 ZONES
10"-11" PIPE

EQUAL AREA TRAVERSE GRID FOR CICULAR DUCTS AND PIPE
Dimensions are "Percent of Pipe Diameters"

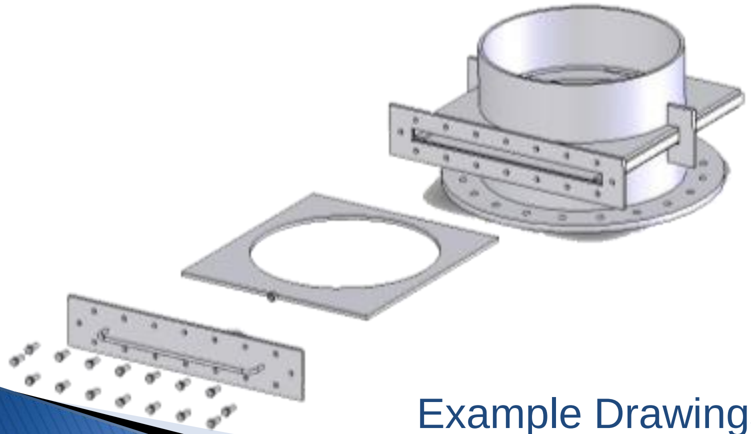


Fuel lines should be balanced to each burner by "Clean Air" test ±2% or better to establish equal system resistance between each of the burners

Fuel Line Balancing
"Clean Airflow"

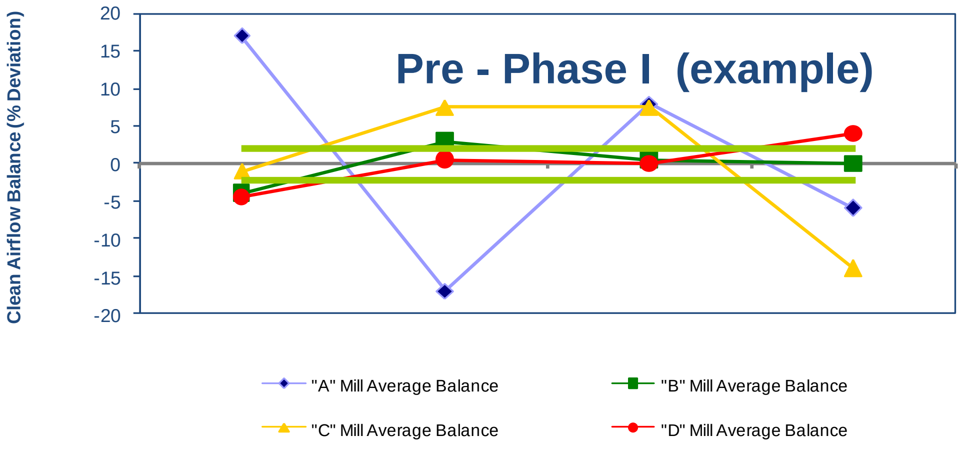
Balance the fuel line system resistances by clean air testing. Using the STORM Two Team, Dual Traverse Method, to achieve resistance within 2% for all pipes.

The most expeditious way to achieve 2% balance is to install orifice housings as shown in Figure.

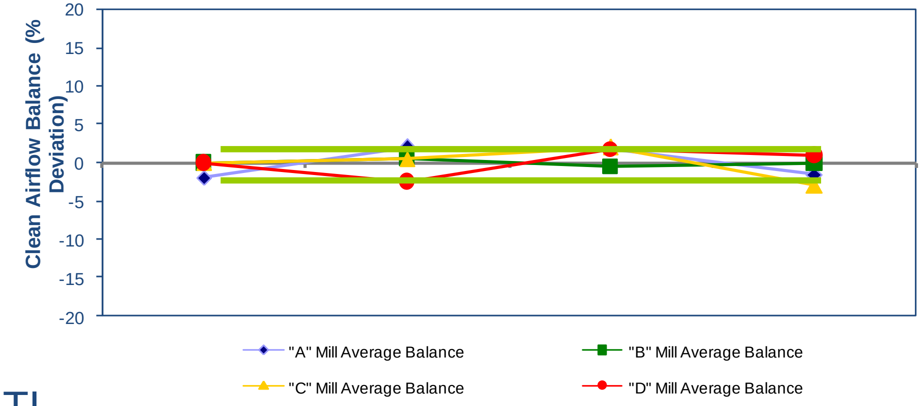


Example Drawings of STI orifice housing assemblies

As Found

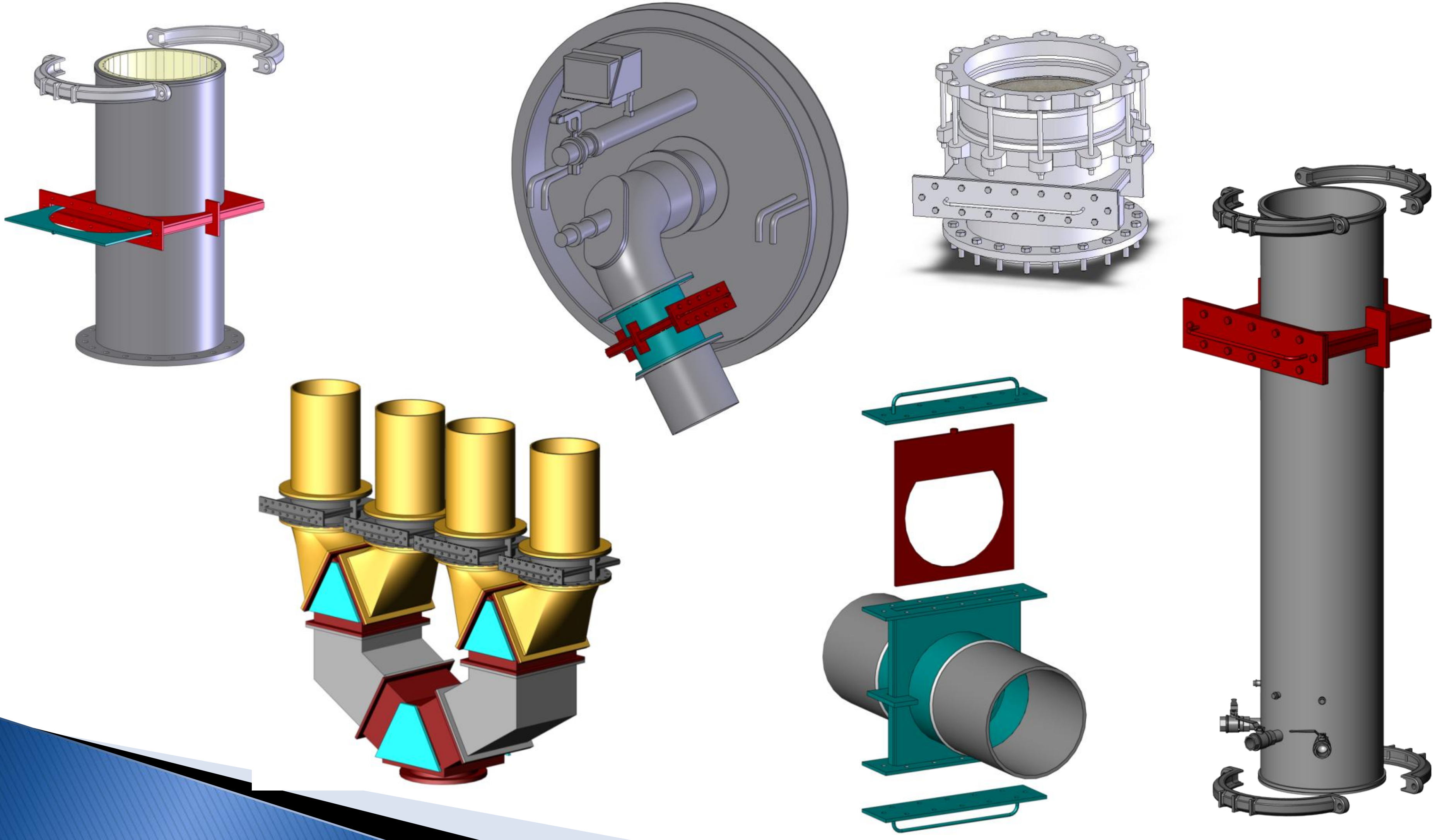


After Left



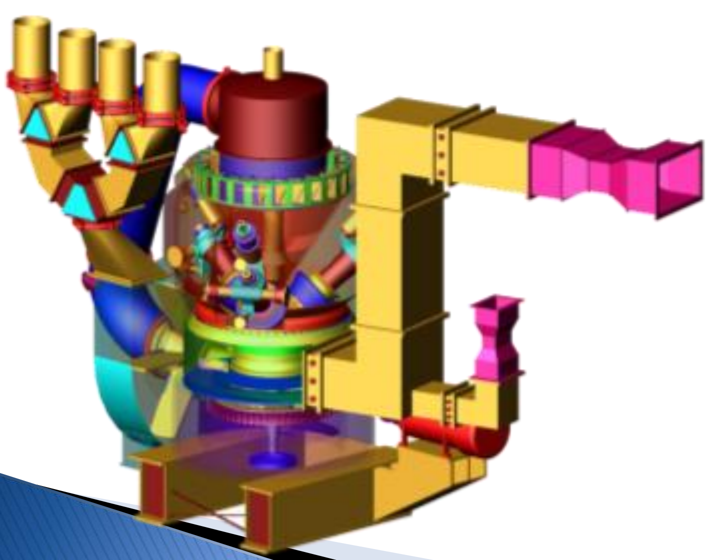
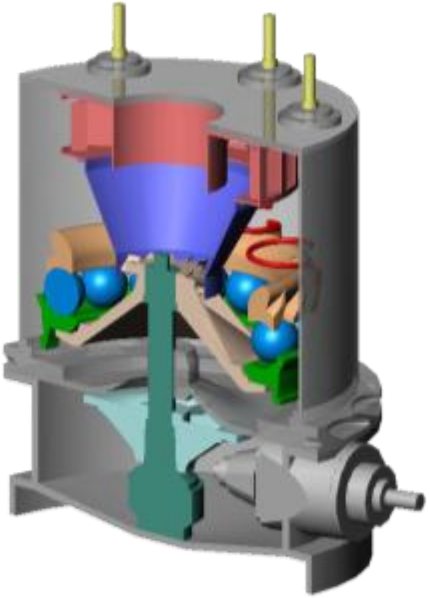
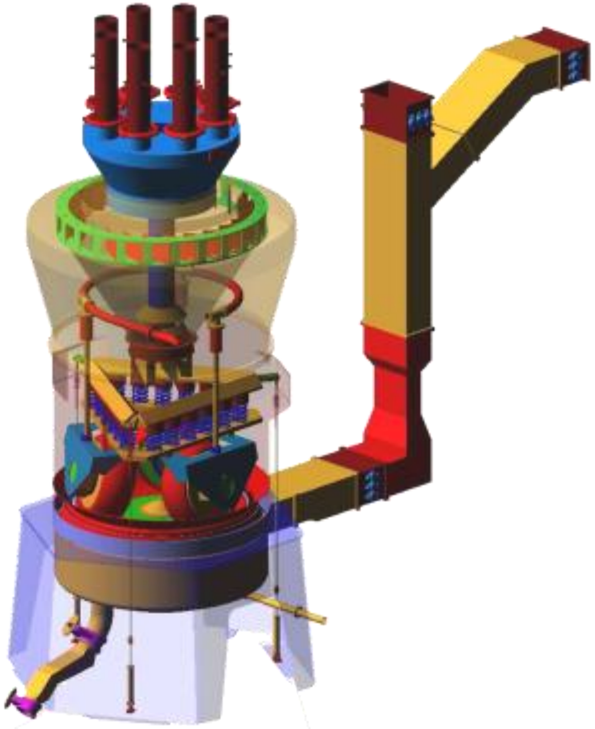
Balancing the fuel lines by Clean air

Balance the fuel line system resistances by clean air testing. Using the STORM Two Team, Dual Traverse Method, to achieve resistance within 2% for all pipes.

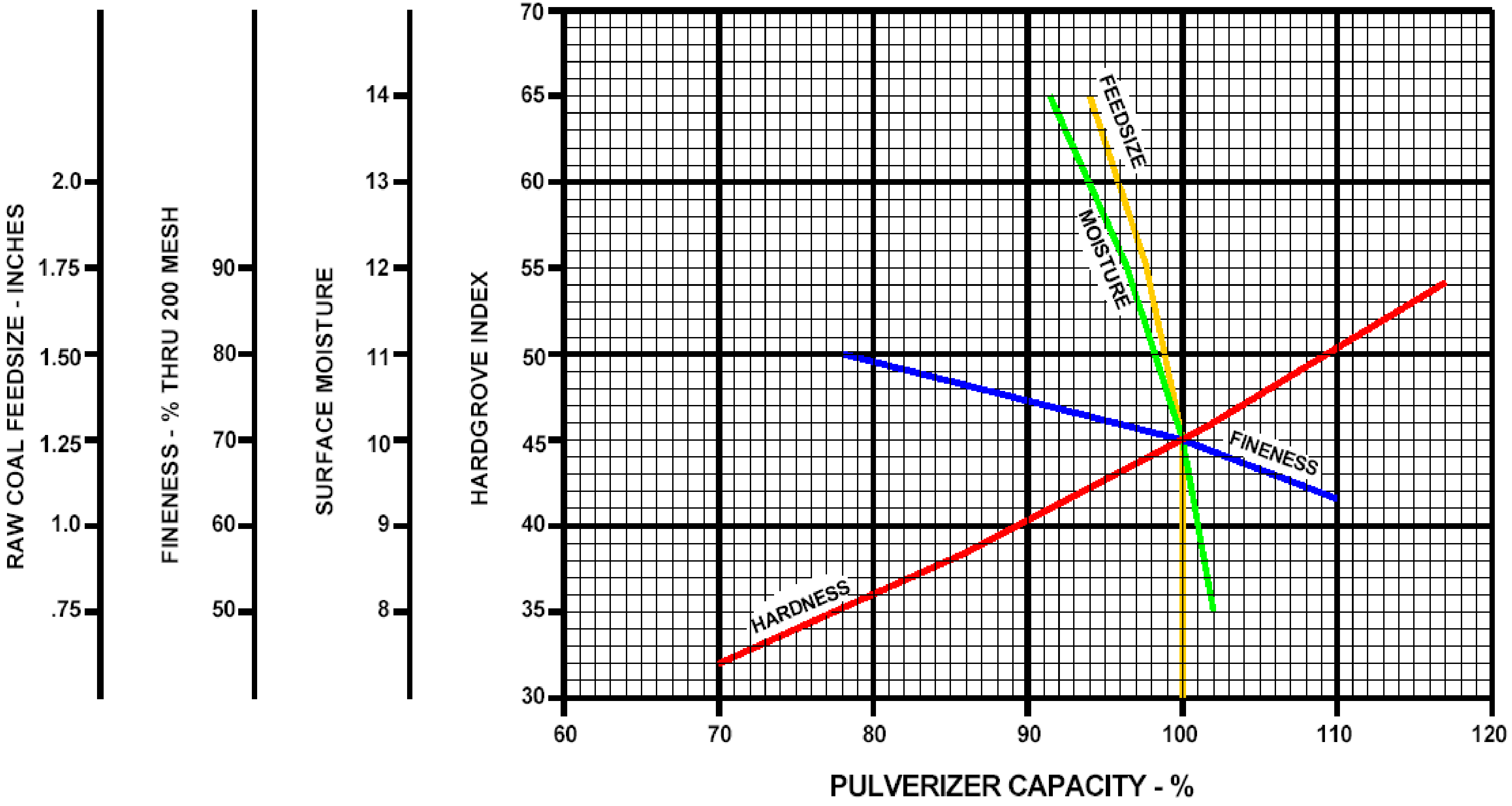


Key Parameters for Characterizing Mill Performance & Capacity

- Coal HGI & Moisture
- Coal Fineness
- Primary air flow Accuracy
- Air & Fuel Control Across the load range
- Input Power requirements
- Mill Outlet Temperature
- Pyrite/Coal Rejects

Coal Quality Variables that Impact Mill Performance

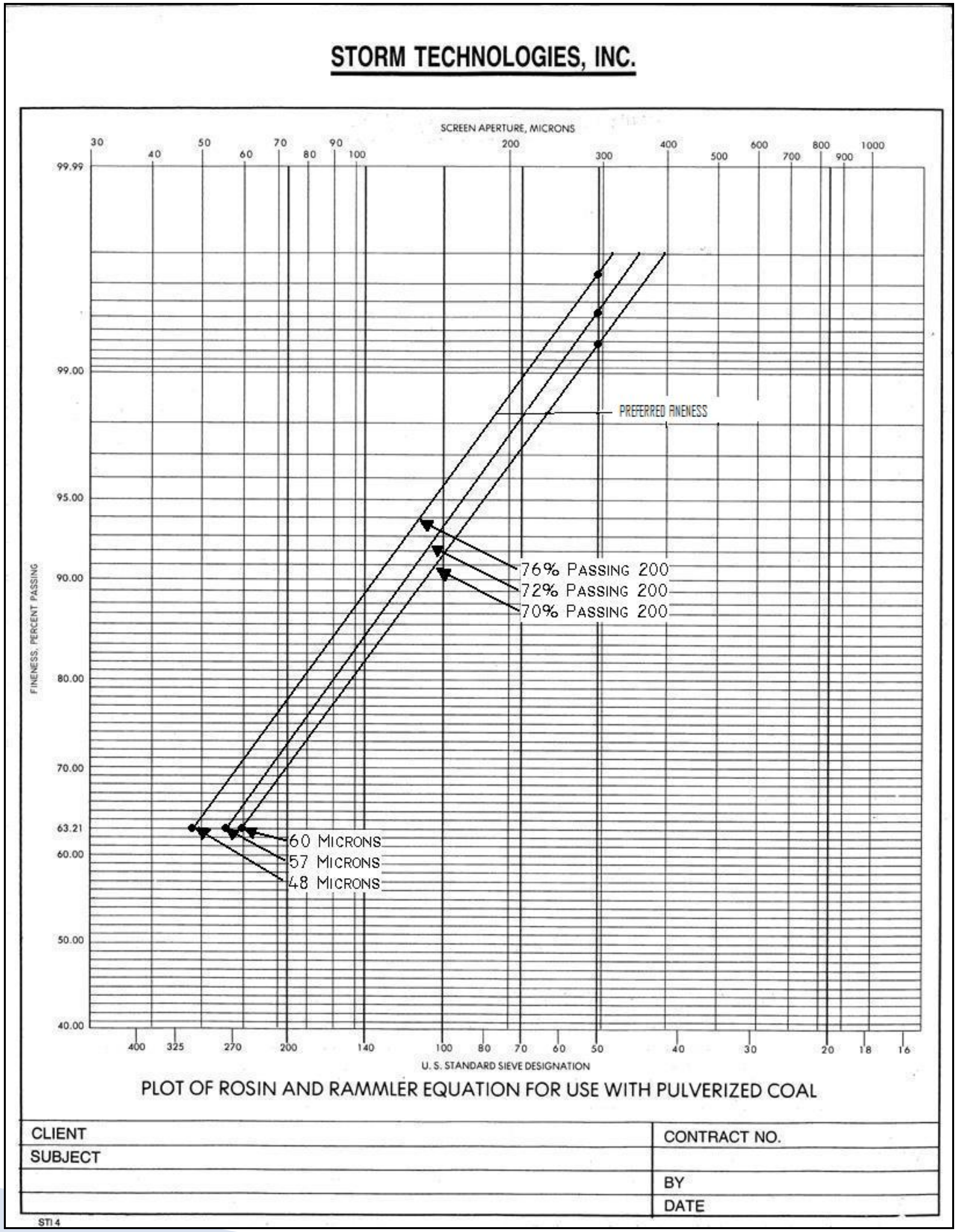


Dirty Airflow Testing & Isokinetic Coal Sampling

- Ascertain relative pipe to pipe fuel balance.
- Quantify individual fuel line air to fuel ratios
- Quantify pulverizer air to fuel ratio
- Quantify individual fuel line velocity and airflow
- Ascertain pipe to pipe airflow balance
- Quantify fuel line temperature and static pressure
- Obtain representative fuel samples for coal fineness analysis

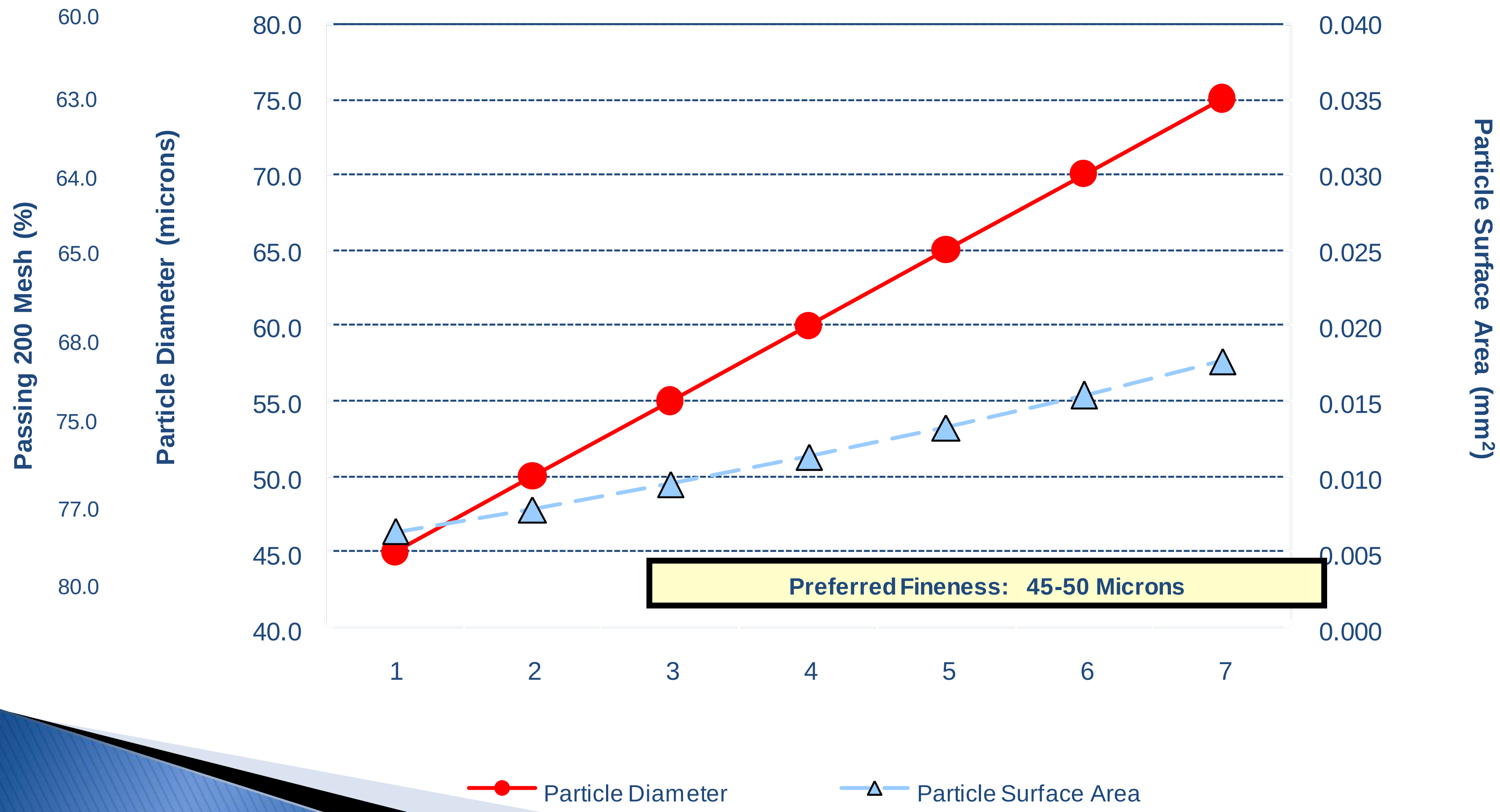
Coal Fineness Analyses

Fuel line fineness shall be 75% or more passing a 200 mesh screen. 50 mesh particles shall be less than 0.1%.



Average Collected Particle Size
(from Isokinetic Coal Sampling)

60% thru 200 mesh vs. 80% thru 200 mesh,
yields a 85.7% difference in the particle surface area (mm^2)



Preferred Fineness: 45-50 Microns

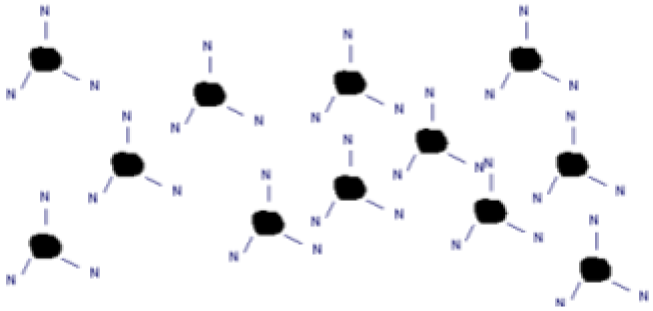
Pulverizer Optimization is Not Optional
First Affect of Fuel Fineness on NO_X

“Release of Fuel Bound Nitrogen in the De-Volatilization Zone”

Good Fineness

Fuel

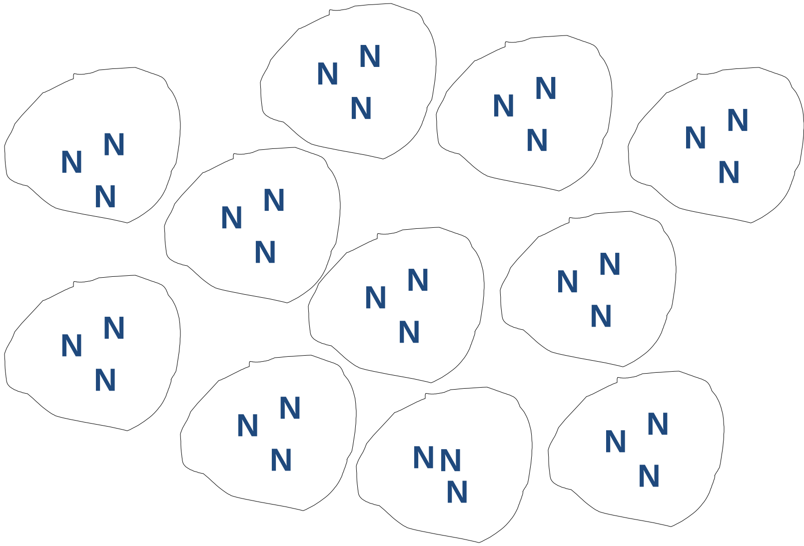
Nozzle



Poor Fineness

Fuel

Nozzle



Performance Testing Data

(Before & After Performance Improvements via Isokinetic Coal Sampling)

Note: Coal is 1,000 times more dense than air. The finer the product the better the distribution *(as finer coal acts more like a fluid or gas).*

Improved Coal Fineness Reduces:

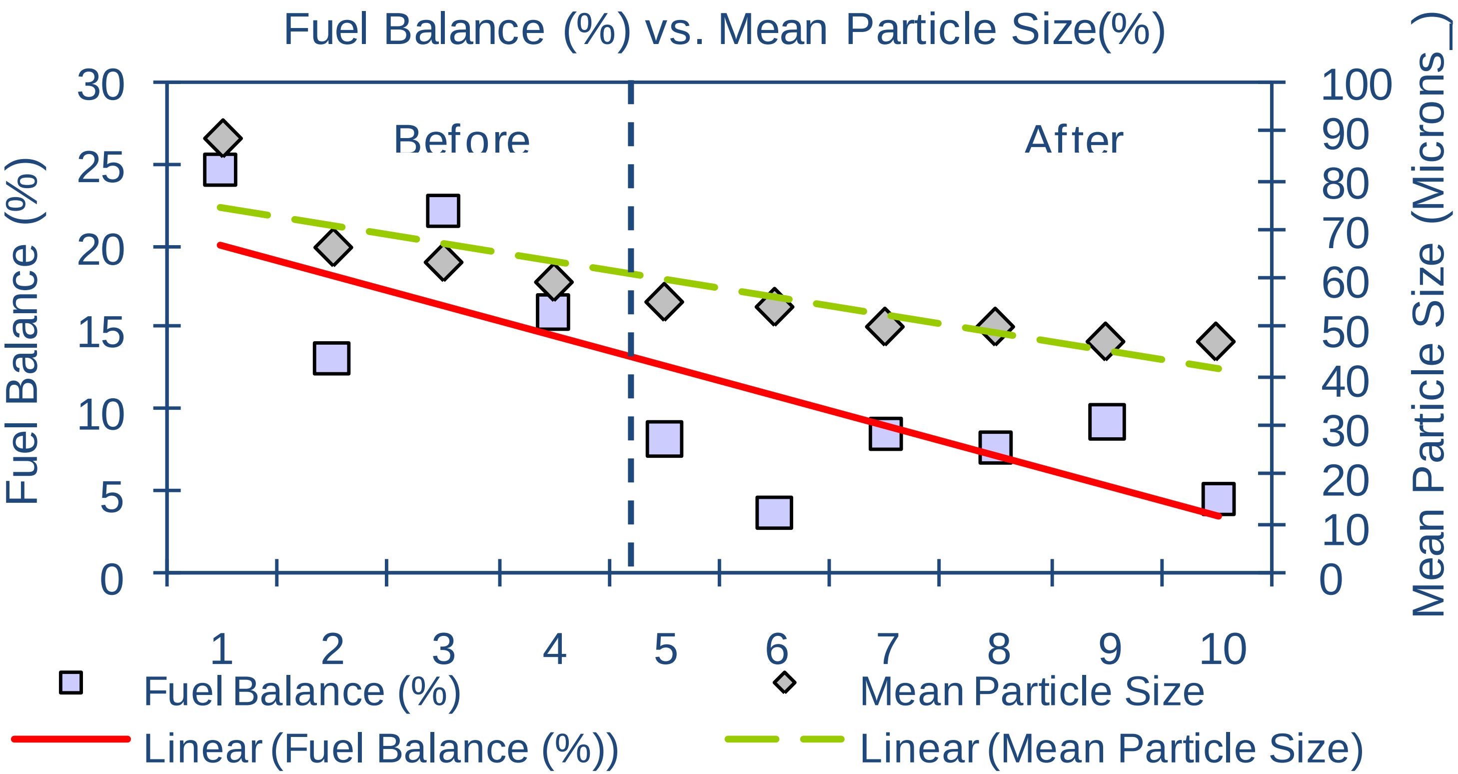
Slagging propensity

Upper furnace slagging & fouling

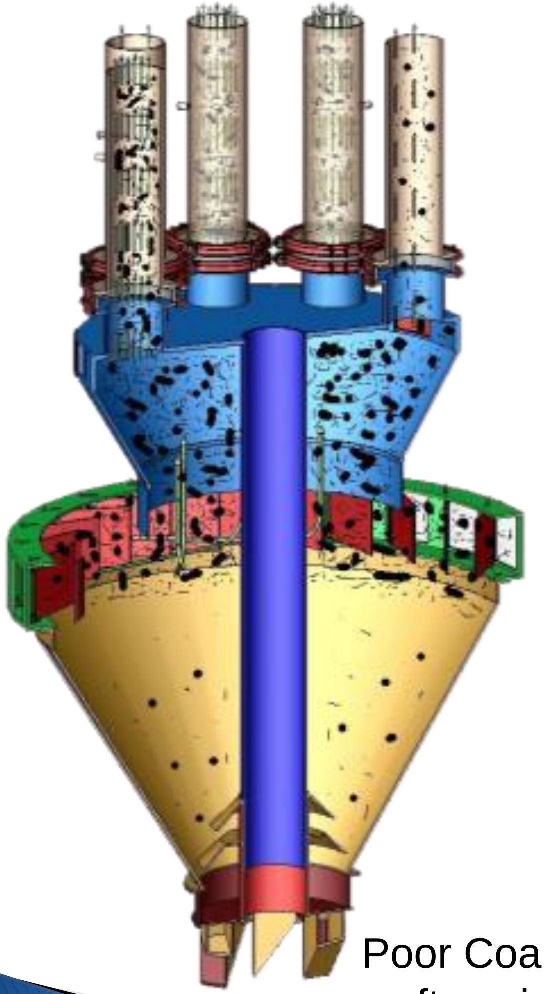
Fuel Imbalances

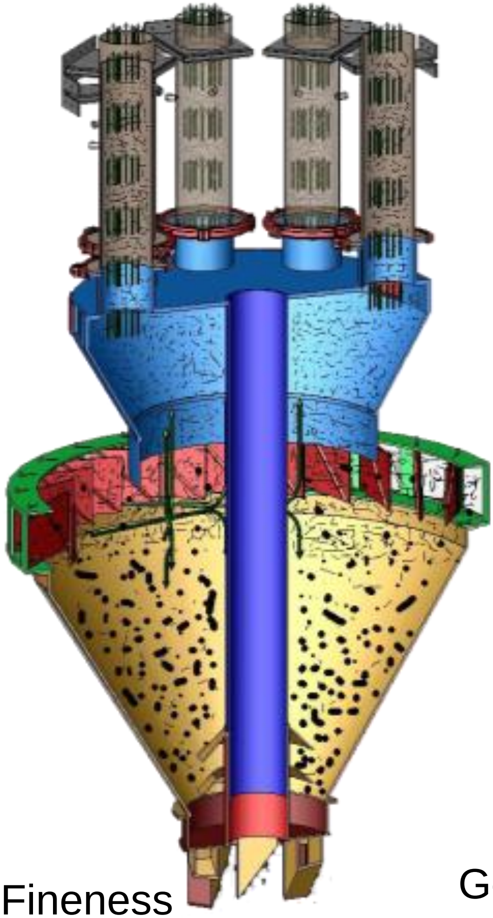
Water wall Wastage

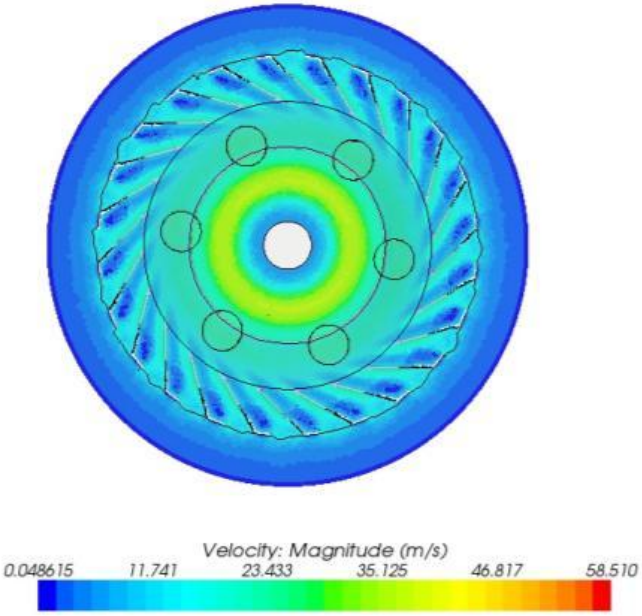
NO_X



Effects of poor coal fineness vs. Good coal fineness Mechanical Synchronization With Velocity Vectors



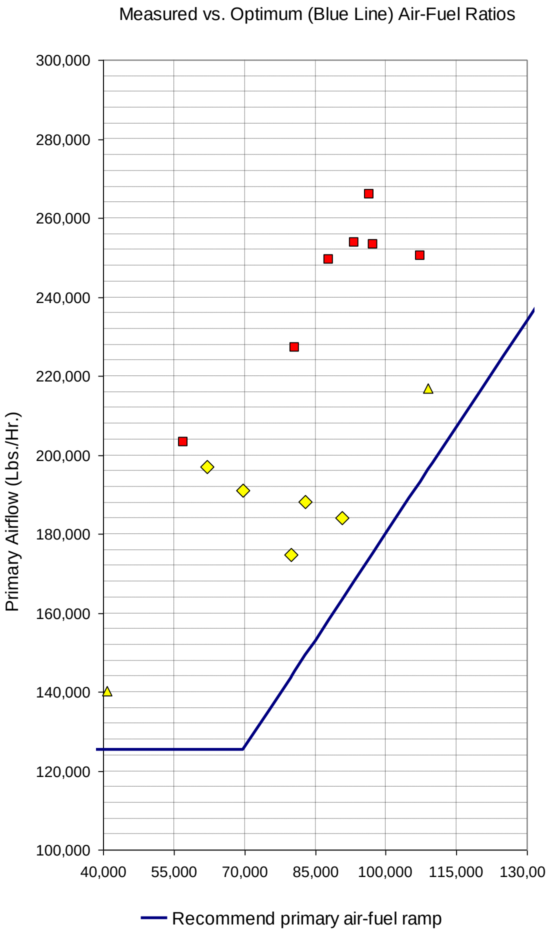




Poor Coal Fineness often yields poor distribution

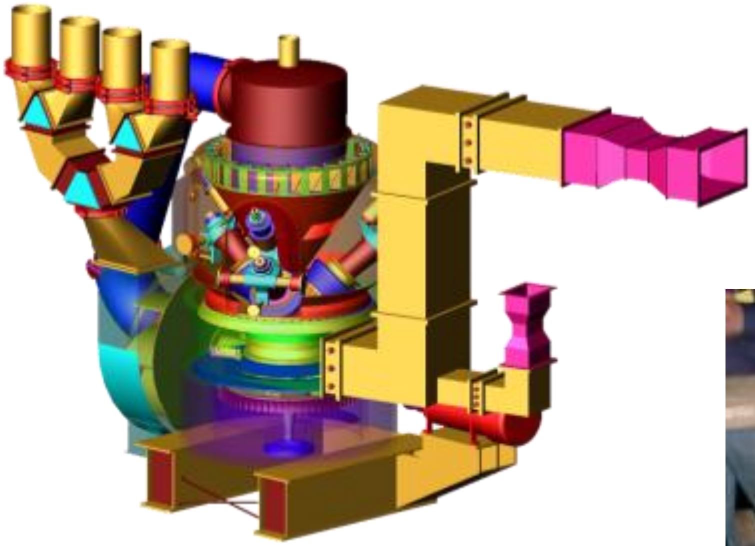
Good Fineness Creates a homogenous & balanced mixture & will produce a more homogenous mixture if mechanical synchronization is optimum

Primary air/fuel ratio shall be accurately measured & controlled when above minimum



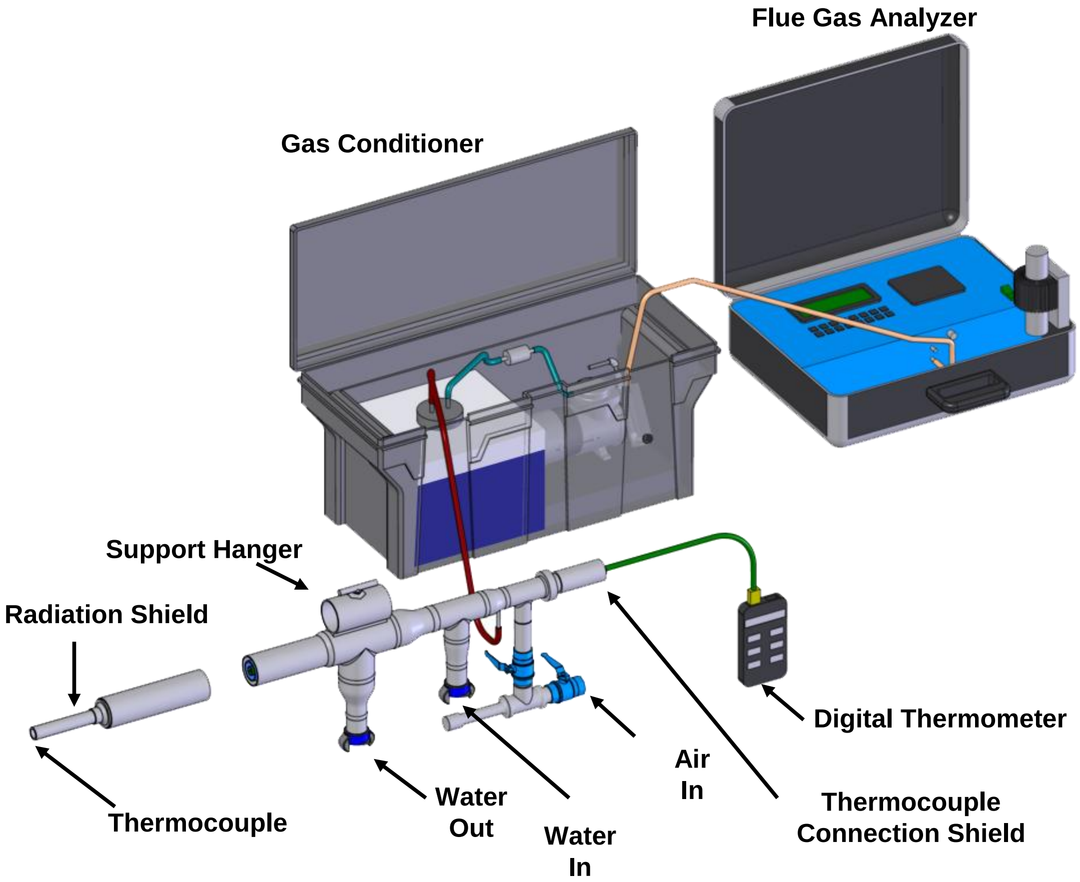
Typical "As Found" Performance

Optimum Primary Airflow Contributes to Best Heat Rate Operation

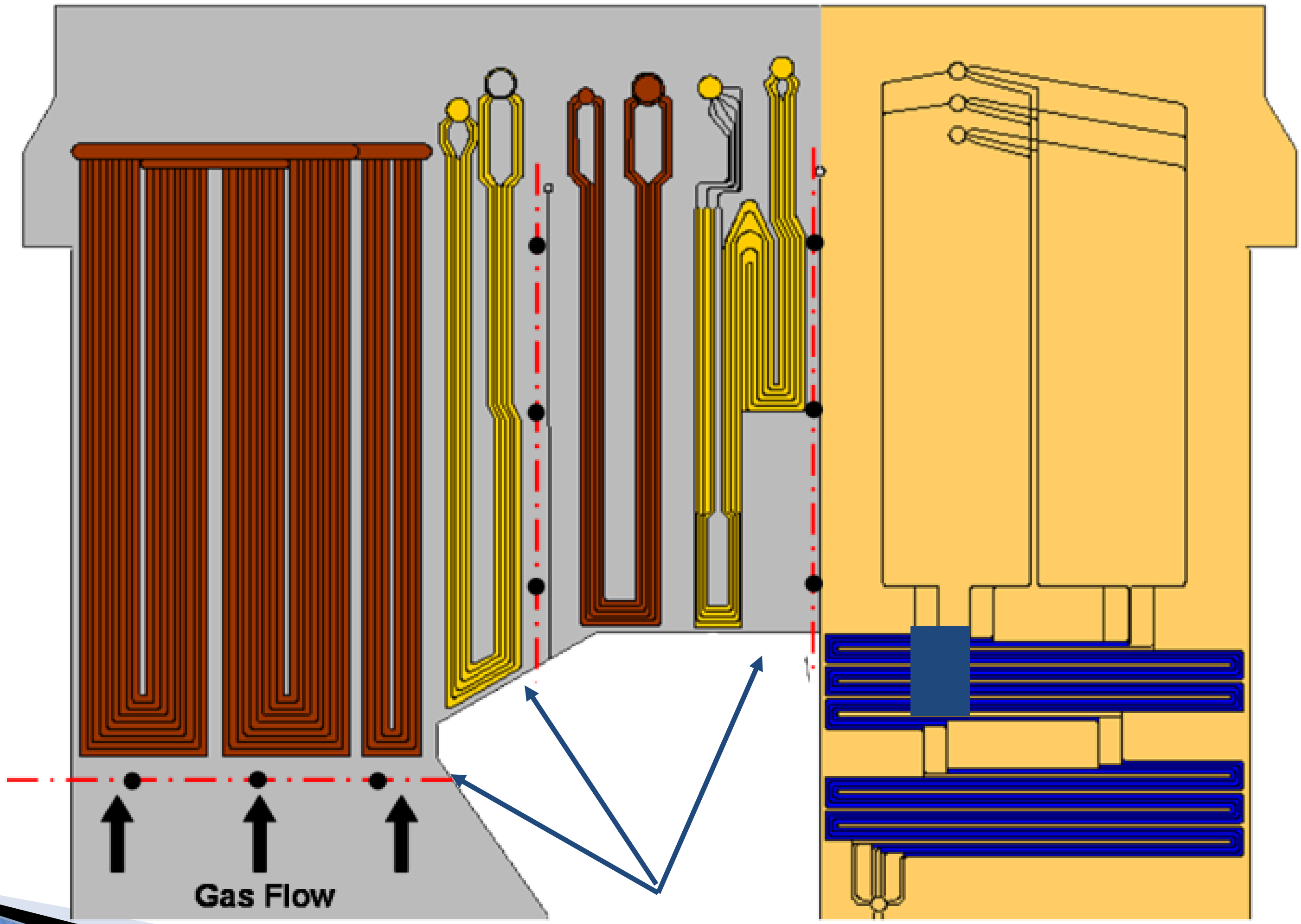


High Tempering Airflow Bypasses the Air Heater and contributes to a less desirable "X" Ratio. Therefore, the mills must be optimized to insure that optimum performance is compatible with a desirable air-fuel ramp

Furnace Exit HVT Testing

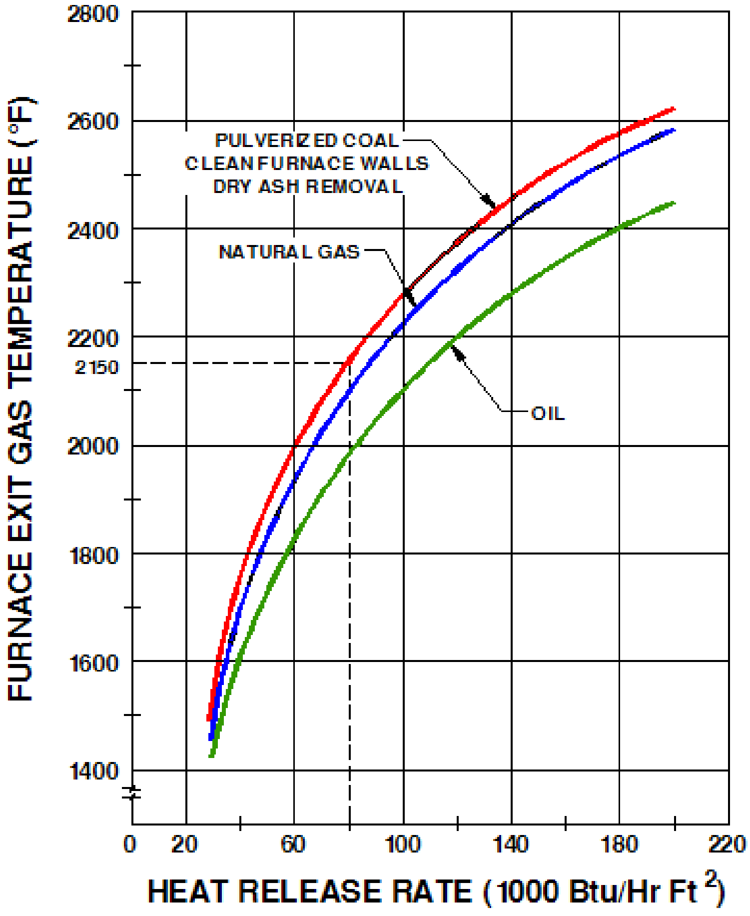


Typical HVT Testing Locations



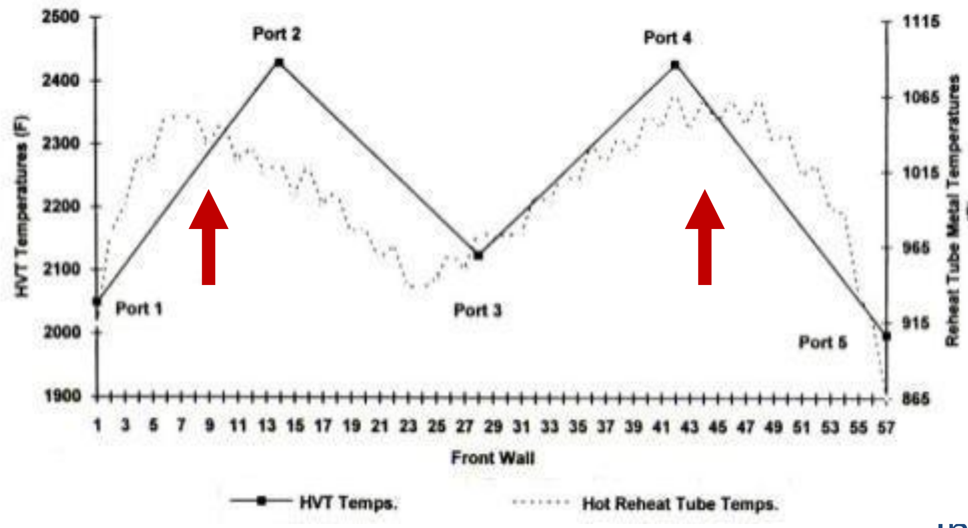
Typical HVT Traverse Planes

The Furnace Exit Gas Temperature (FEGT)



High furnace exit gas temperatures can contribute to overheated metals, such as these superheater alignment castings that only lasted 1 year due to greater than 2,500°F. furnace exit gas temperatures.

Tube Metal Thermocouples



The flue gas Bulk temperatures typically coincide with "Hot" tube circuits

Installation of PSH Tube Metal Thermocouples

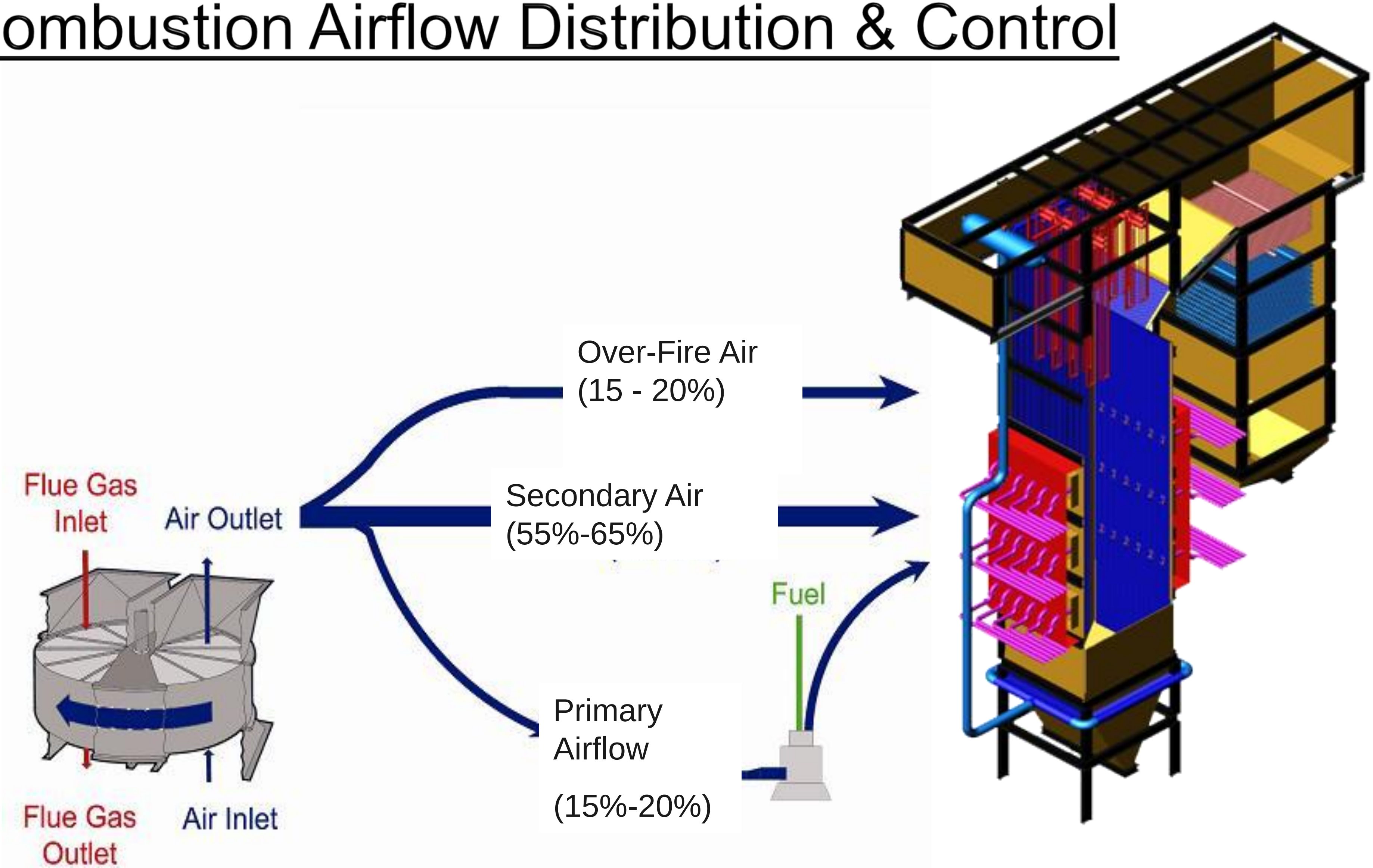
Primary Super-Heat (PSH) Element Tube Metal Thermocouple Installation Progress

Online FEGT Monitors

FEGT Monitor

HVT Probe Test Port

Combustion Airflow Distribution & Control



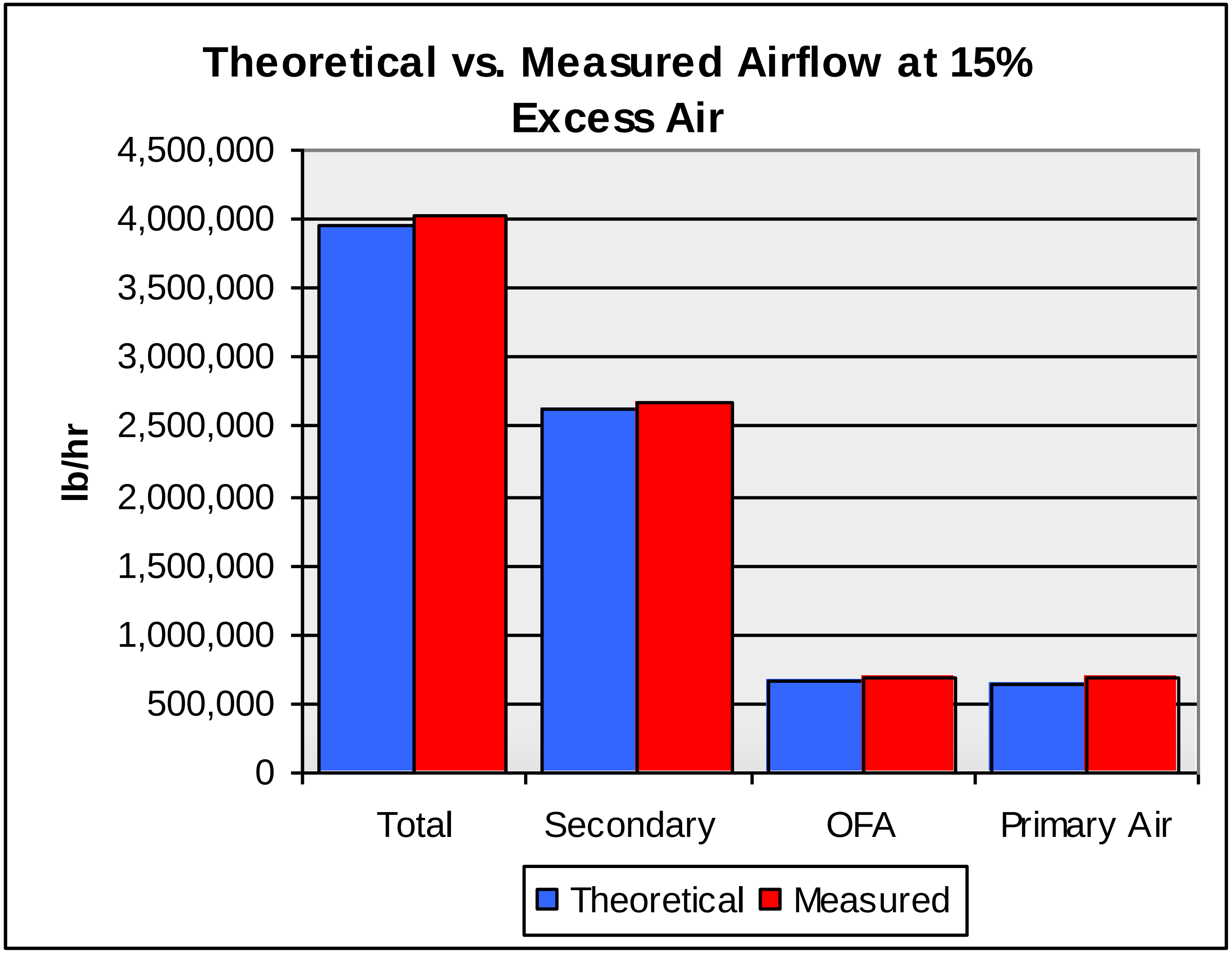
Over-Fire Air
(15 - 20%)

Secondary Air
(55%-65%)

Primary Airflow

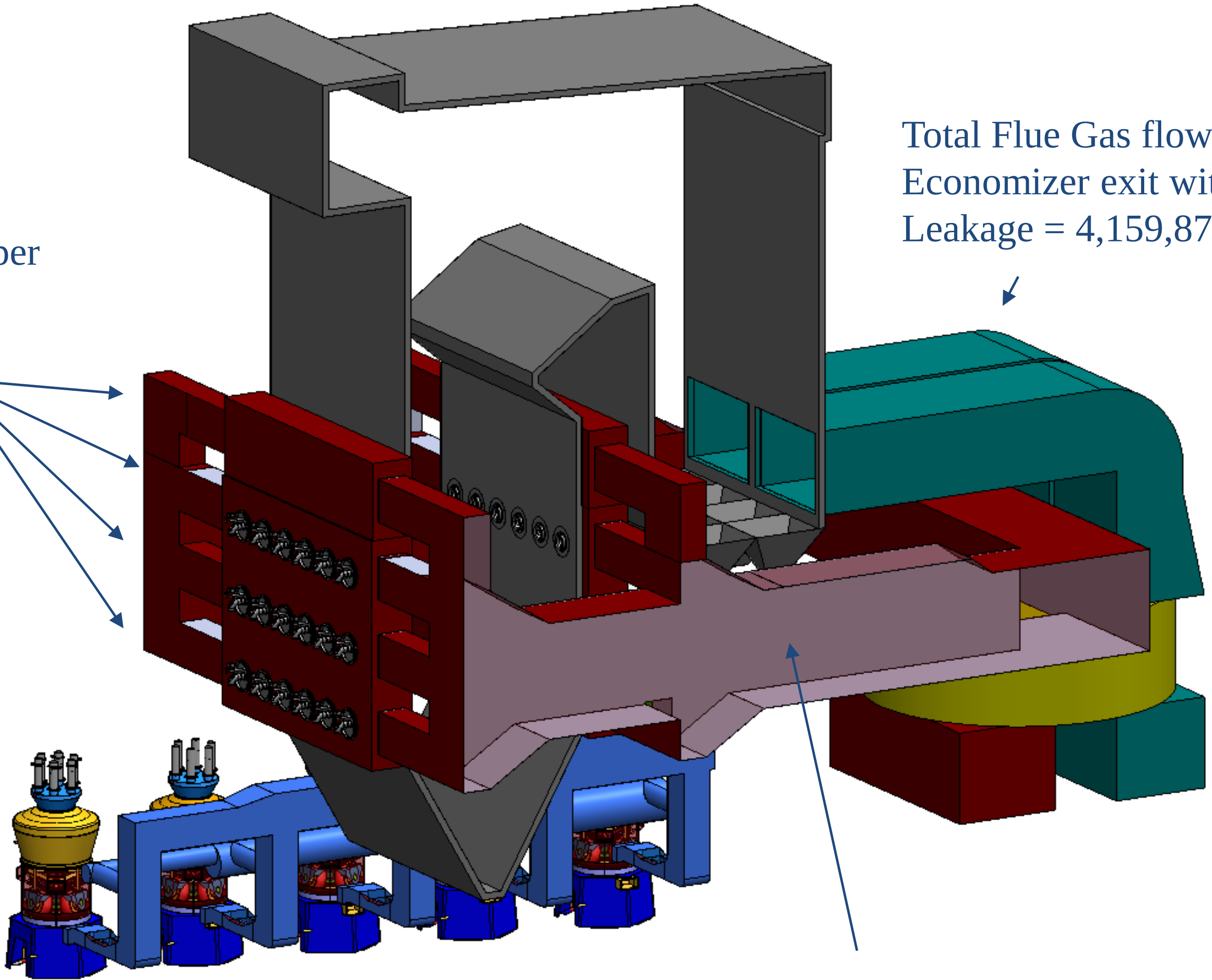
(15%-20%)

Theoretical Excess Air vs. Measured Combustion Air



Example of Theoretical vs. Measured Test Results

Total Airflow Measurement Example



Total Flue Gas flow at Economizer exit with 10% Leakage = 4,159,875 lb/hr

Secondary Air per compartment = 329,256 lb/hr

Total Primary Air per Mill = 161,702 lb/hr (at venturi)

Total Secondary and Over-Fire Air North/South = 1,653,016 lb/hr

500 MW Operation (100% MCR)

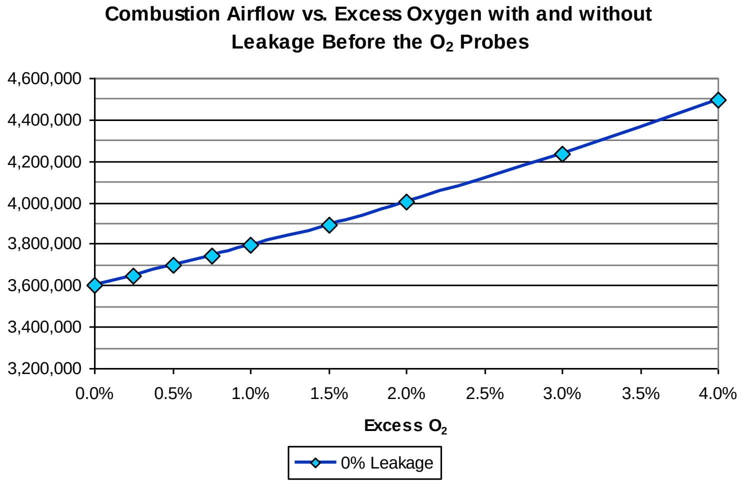
10,000Btu/KwHr Heat Rate, 11,500Btu/Lb. Coal, 15% Excess Air & with 0% air in-leakage from the furnace to the Excess O_2 probes

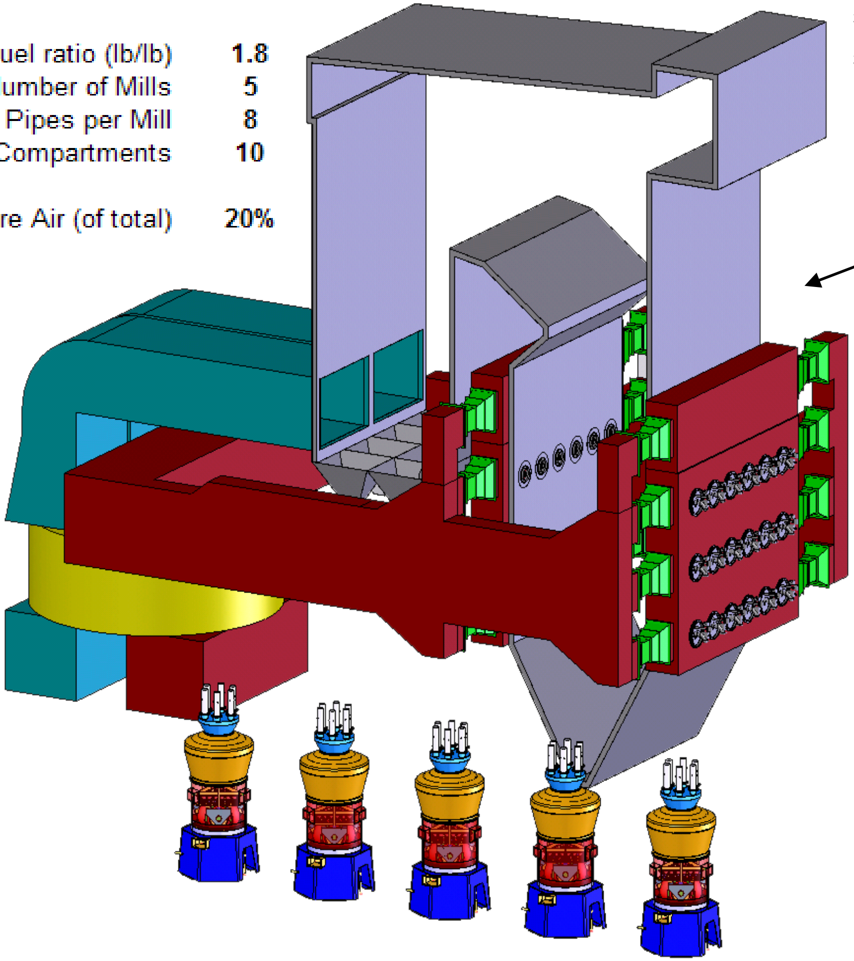
Unit Load MCR (Gross MW)	**500**
Heat Rate (BTU/kWhr)	**10,000**
Fuel HHV (BTU/lb)	**11,500**
Excess Air	**15.0%**
% Carbon	**63.25%**
% Hydrogen	**4.32%**
% Oxygen	**10.00%**
Theoretical Air Req. (lb/lb of fuel)	8.29
Theoretical Air Req. (lb/mmBTU)	720.8
Total Air Req (w/ excess; lb/lb of fuel)	9.53
Total Air Req (w/ excess; lb/mmBTU)	828.9
Excess O_2	2.63%
Mill Air to Fuel ratio (lb/lb)	**1.8**
Number of Mills	**5**
Pipes per Mill	**8**
Number of Compartments	**10**
% Over-Fire Air (of total)	**20%**

Total Airflow: 4,144,710lbs/Hr.

Secondary Air: 2,533,160lbs/Hr.

OFA: 828,942lbs/Hr.


Combustion Airflow vs. Excess Oxygen with and without Leakage Before the O_2 Probes



When assuming zero leakage, the Stoichiometry is 1.15 or 15.0% Excess Air at this point.

When assuming zero leakage, the burner belt stoichiometry is .92 (average) or -8% Excess Air.

500 MW Operation (100% MCR)

10,000Btu/KwHr Heat Rate, 11,500Btu/Lb. Coal, 15% Excess Air

& with 7% air in-leakage from the furnace to the Excess O_2 probes

Unit Load MCR (Gross MW)	**500**
Heat Rate (BTU/kWhr)	**10,000**
Fuel HHV (BTU/lb)	**11,500**
Excess Air	**15.0%**
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Total Air Req (w/ excess; lb/lb of fuel)	9.53
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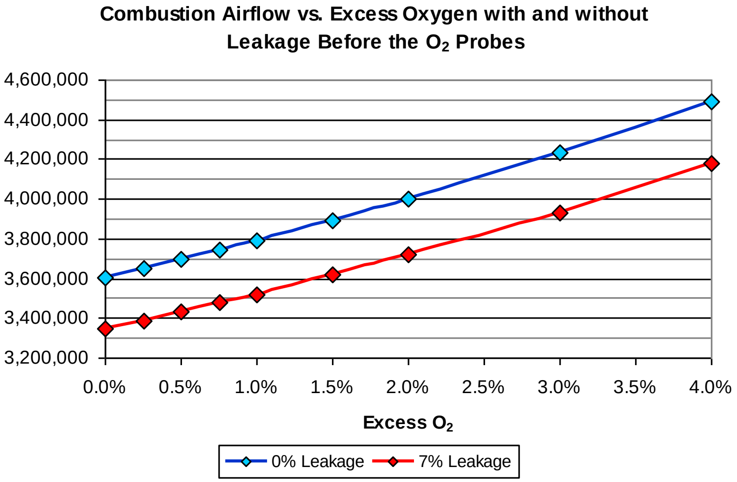
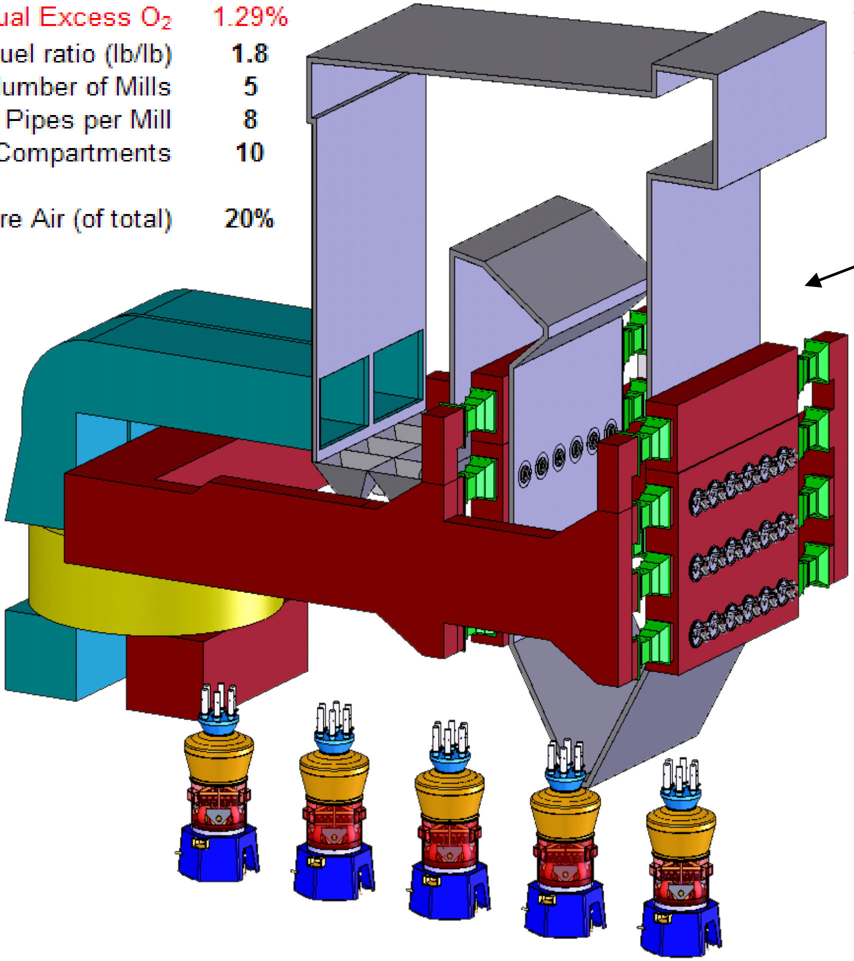
Excess O_2	2.63%
Actual Excess O_2	1.29%
Mill Air to Fuel ratio (lb/lb)	**1.8**
Number of Mills	**5**
Pipes per Mill	**8**
Number of Compartments	**10**
% Over-Fire Air (of total)	**20%**

Total Airflow: 4,144,710lbs/Hr.
Actual Airflow: 3,851,497lbs/Hr.

Secondary Air: 2,533,160lbs/Hr.
Actual Secondary Air: 2,298,589lbs/Hr.

OFA: 828,942lbs/Hr.
Actual OFA: 770,299lbs/Hr.





When assuming zero leakage, the Stoichiometry is 1.15 or 15.0% Excess Air at this point. With 7% leakage stoichiometry drops to 1.07 or 6.86% Excess Air. Actual Excess O2% Drops to 1.29%

When assuming zero leakage, the burner belt stoichiometry is .92 (average) or -8% Excess Air. With leakage burner stoichiometry drops to 0.855 (average) or -14.5% Excess Air.

Burner Stoichiometry

From the Example:

Burner Stoichiometry: no Leakage: 0.92

Burner Stoichiometry: 7% Leakage: 0.855

Averages

With Burner Imbalances of:

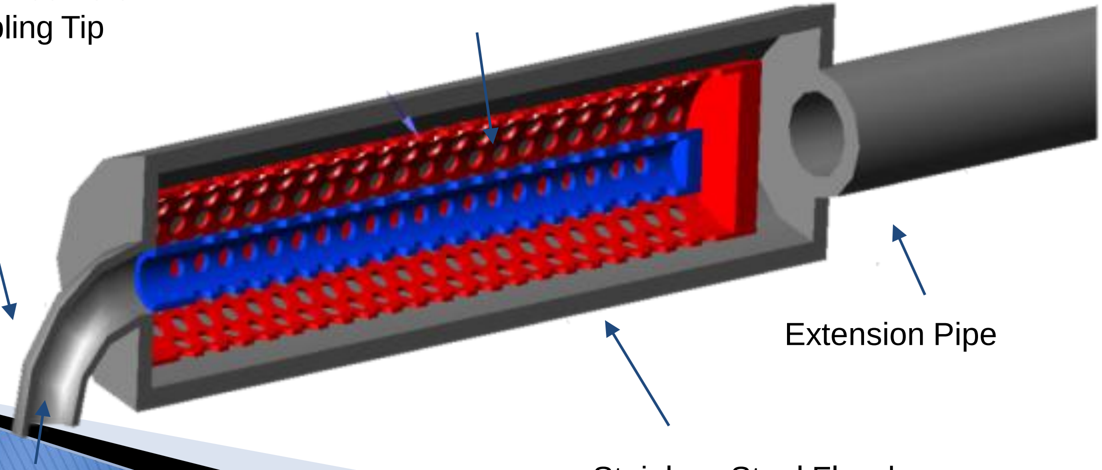
- 5% Primary Air
- 5% Secondary Air
- 10% Fuel Flow

These imbalances are the maximum allowable. Most units have imbalances much higher!

Maximum and minimum burner stoichiometry based on above burner imbalances

	Lowest Possible	**Average**	**Highest Possible**
Stoichiometry	**0.738**	**0.855**	**0.997**
Excess Air	**-26.2%**	**-14.5%**	**-0.3%**

STORM® Fly ash Samplers (Traditional)



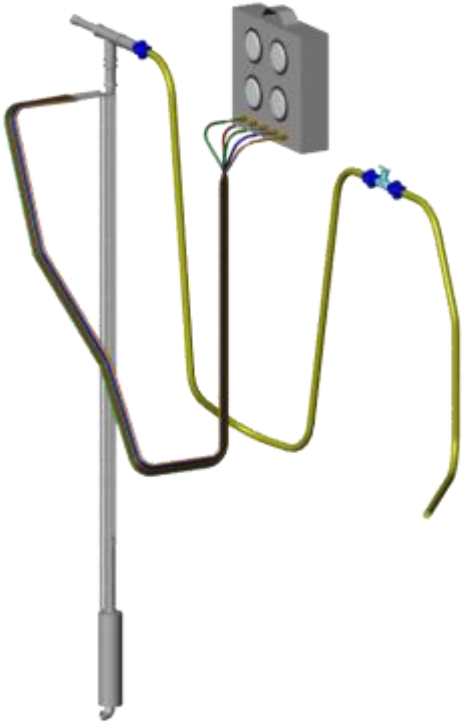
Stainless Steel Flyash Canister Sampling Tip

Stainless Steel Perforated Cylinder for Filter Paper to Collect Flyash Sample

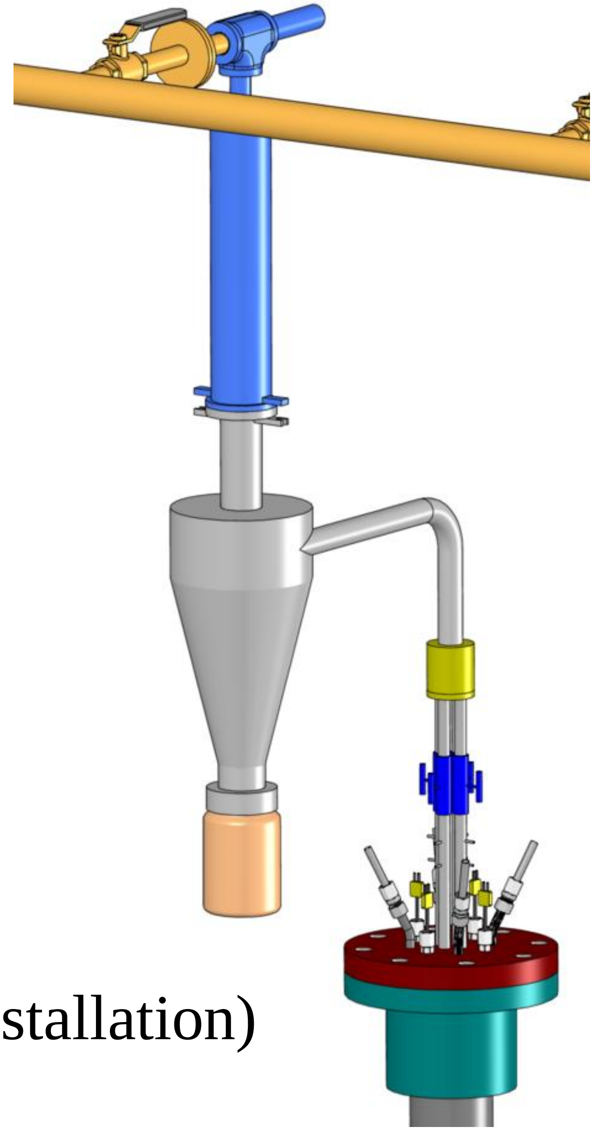
Extension Pipe

Stainless Steel Flyash Filter Canister

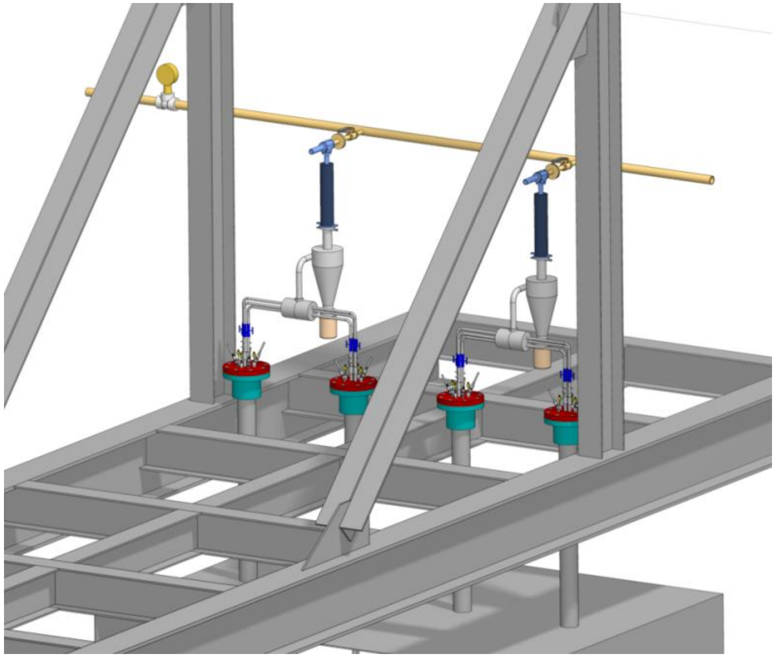
Gas Flow



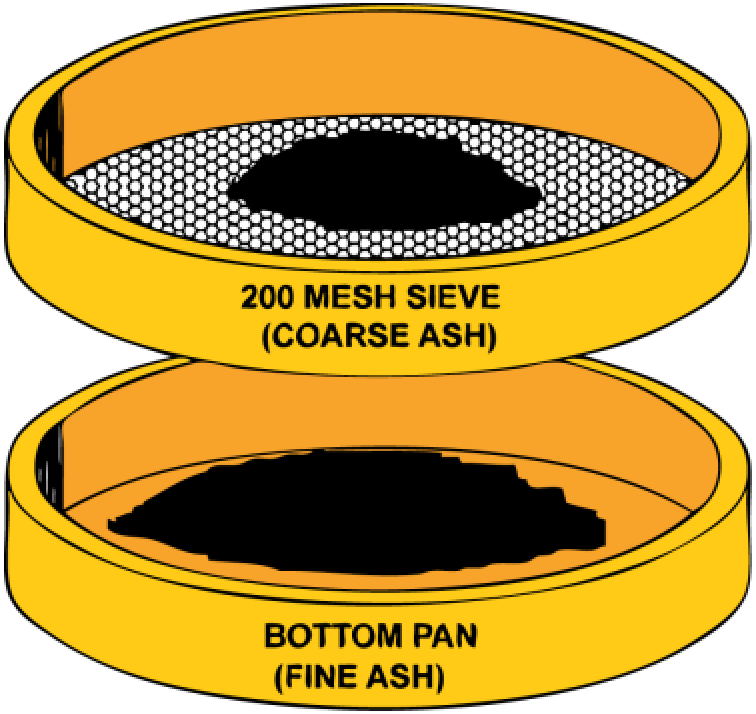
STORM® Multi-Point Flue Gas & Ash Sampler



(Permanent Installation)



Fly ash Analysis



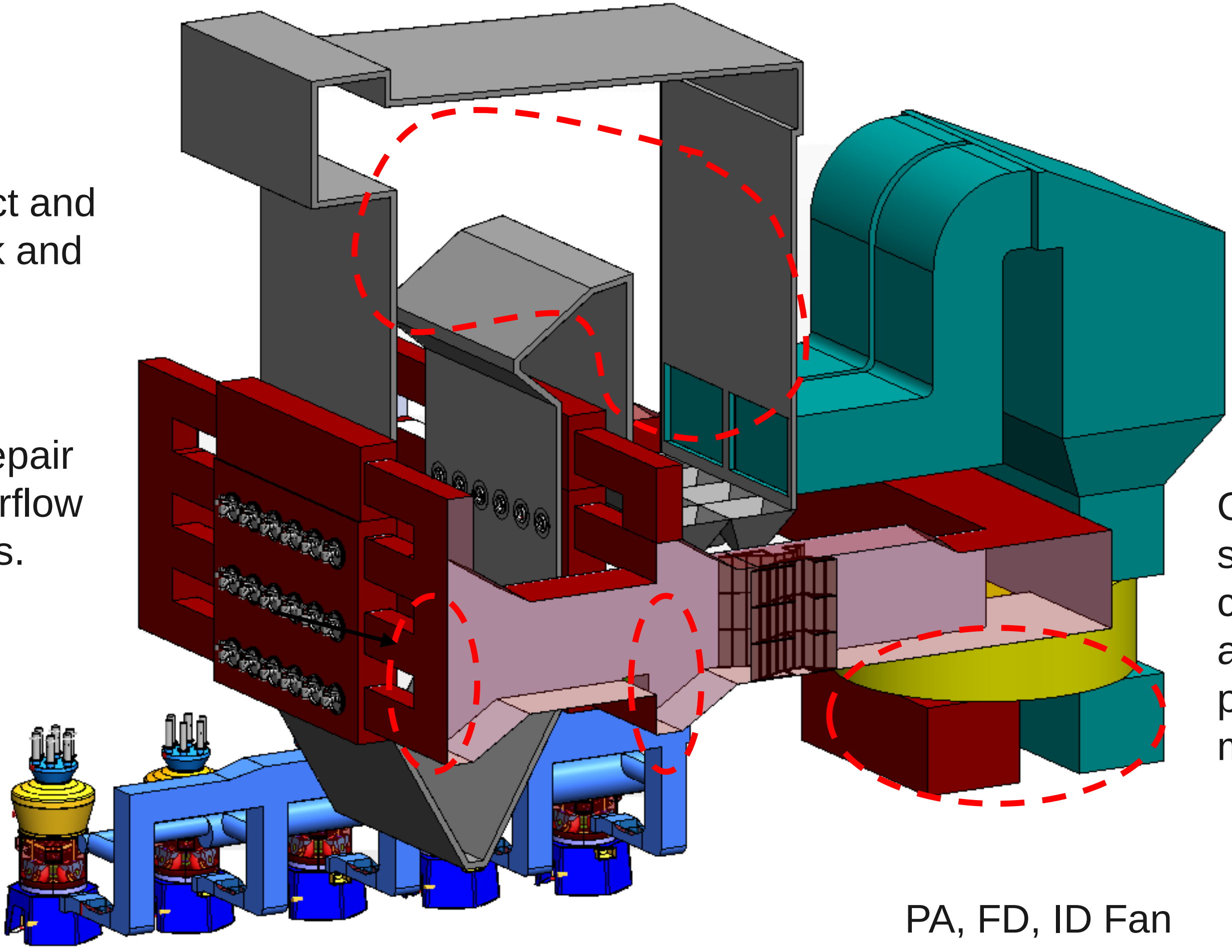
Place Sample of Ash on the Stacked 200Mesh Sieve/Pan and Shake for 20 minutes.

Determine LOI of residue on 200M Screen and for what's on the pan.

200 Mesh Fly ash is typically High in LOI (often 30% – 60% LOI)

The (-) 200 Mesh ash should be very low in LOI. (typically <1-2 % w/ eastern coals)

Typical Outage Activities



Inspect tubes for corrosion or wear, check for any problems with alignment bars and tube shields.

Air-in leakage inspections and repairs.

Verify damper strokes (all dampers to be verified from inside ducts).

Thoroughly inspect and repair all ductwork and expansion joints.

Leak check and repair sensing lines to airflow measuring devices.

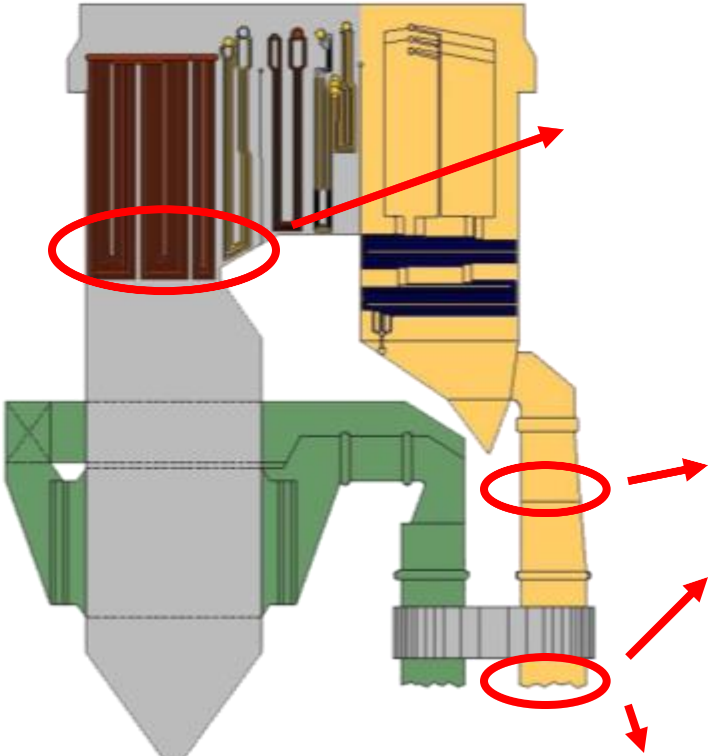
Optimize air heater seals, basket cleanliness, check and repair sector plates and all moving parts.

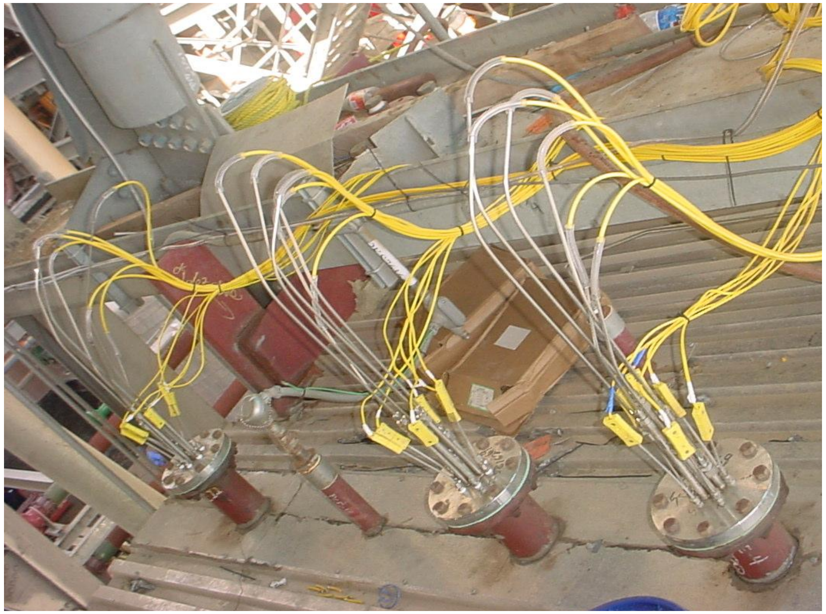
Refurbish burners.

Rebuild pulverizer grinding elements.

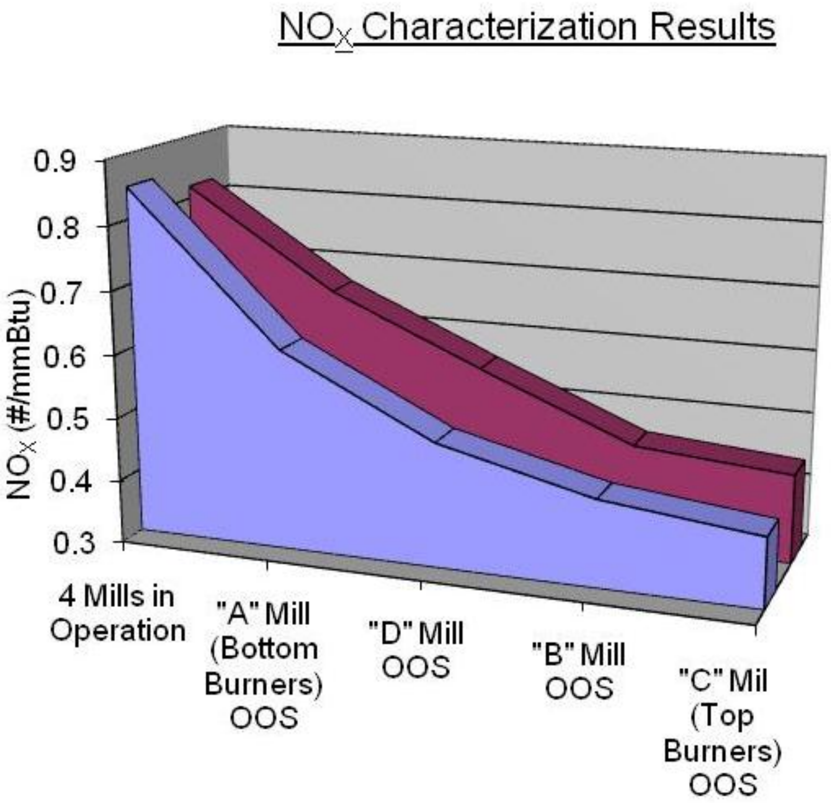
PA, FD, ID Fan clearances and damper/inlet vane checks.

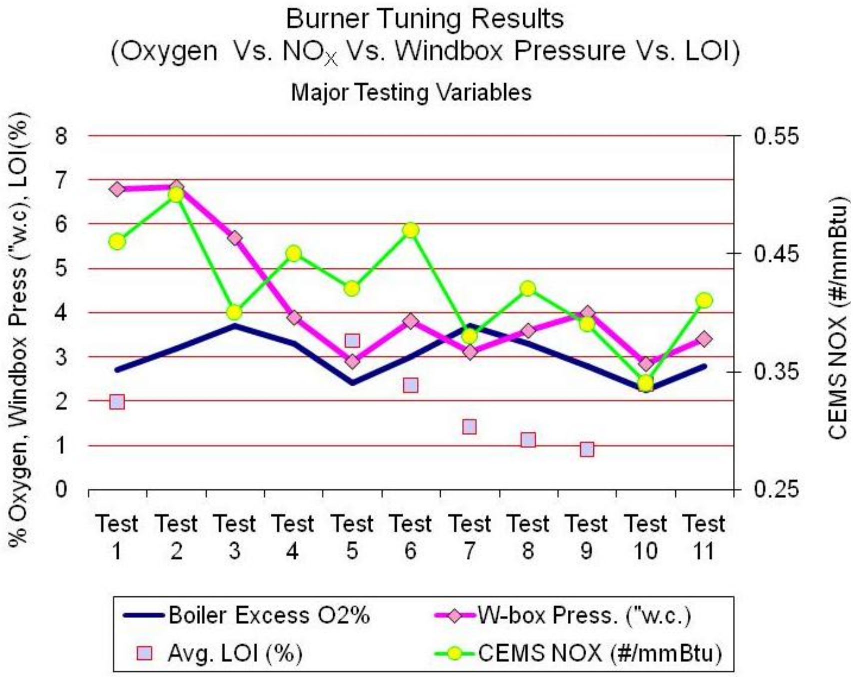
Boiler Testing & Tuning

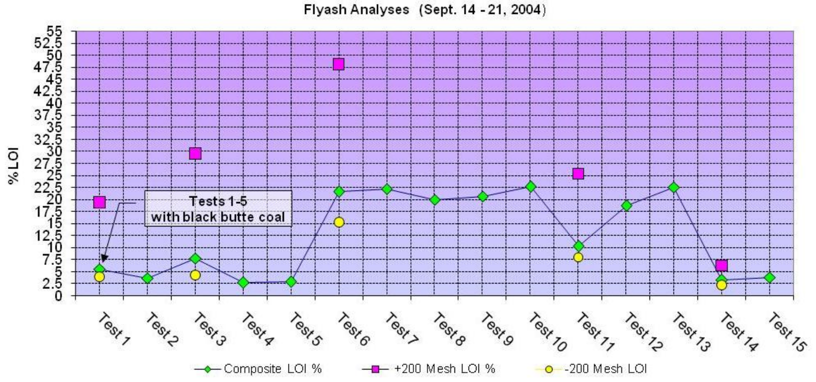




The “Inputs” Measurements & Adjustments should be used to guide burner tuning efforts (Not Just an Economizer Outlet Flue Gas Measurement Grid)





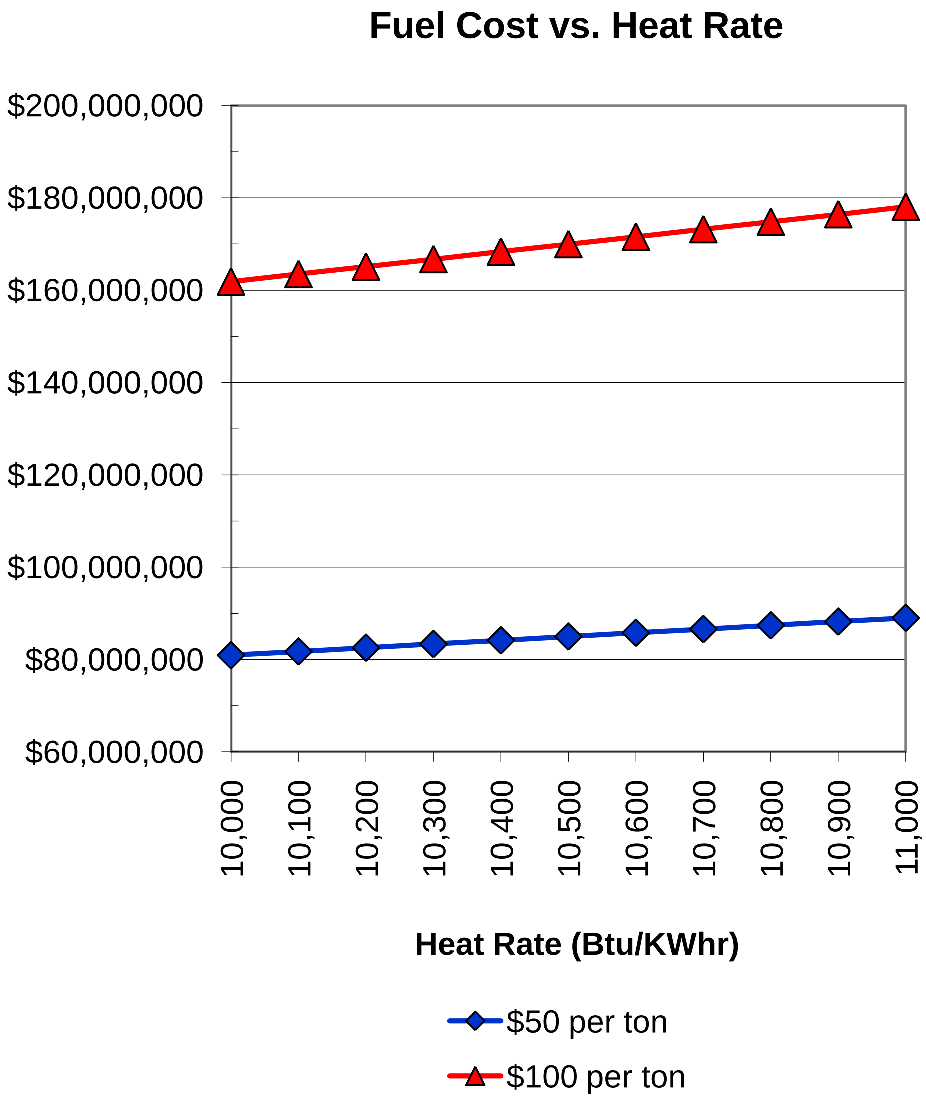


Economic Case Study

Description	Variable
Load	500MW(Gross)
Operation	7,446Hrs.
Fuel HHV	11,500 Btu‘s/Lb.
Coal Cost	$50.00/Ton
Coal Cost	$100.00/Ton
Ash Content	10%

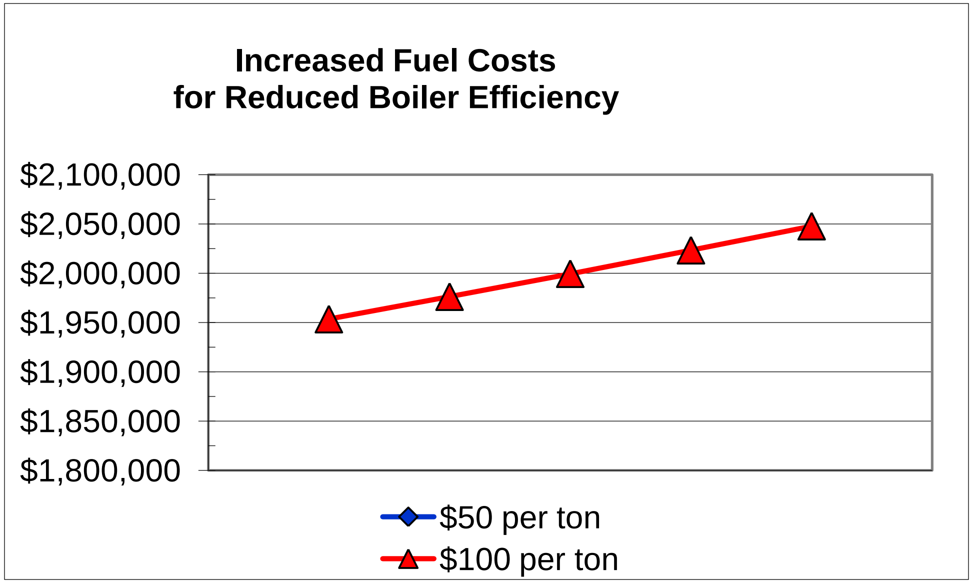
Annual Fuel Cost Vs. Heat Rate

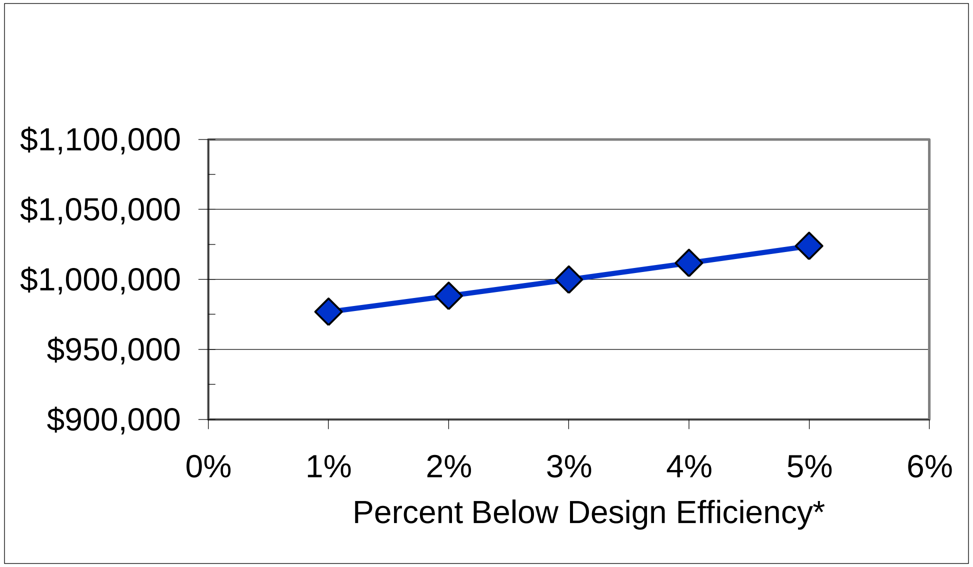
Btu/kw hr	$/yr	$/yr
10000	80,934,783	161,869,565
10100	81,744,130	163,488,261
10200	82,553,478	165,106,957
10300	83,362,826	166,725,652
10400	84,172,174	168,344,348
10500	84,981,522	169,963,043
10600	85,790,870	171,581,739
10700	86,600,217	173,200,435
10800	87,409,565	174,819,130
10900	88,218,913	176,437,826
11000	89,028,261	178,056,522



Fuel Cost vs. Boiler Efficiency Change

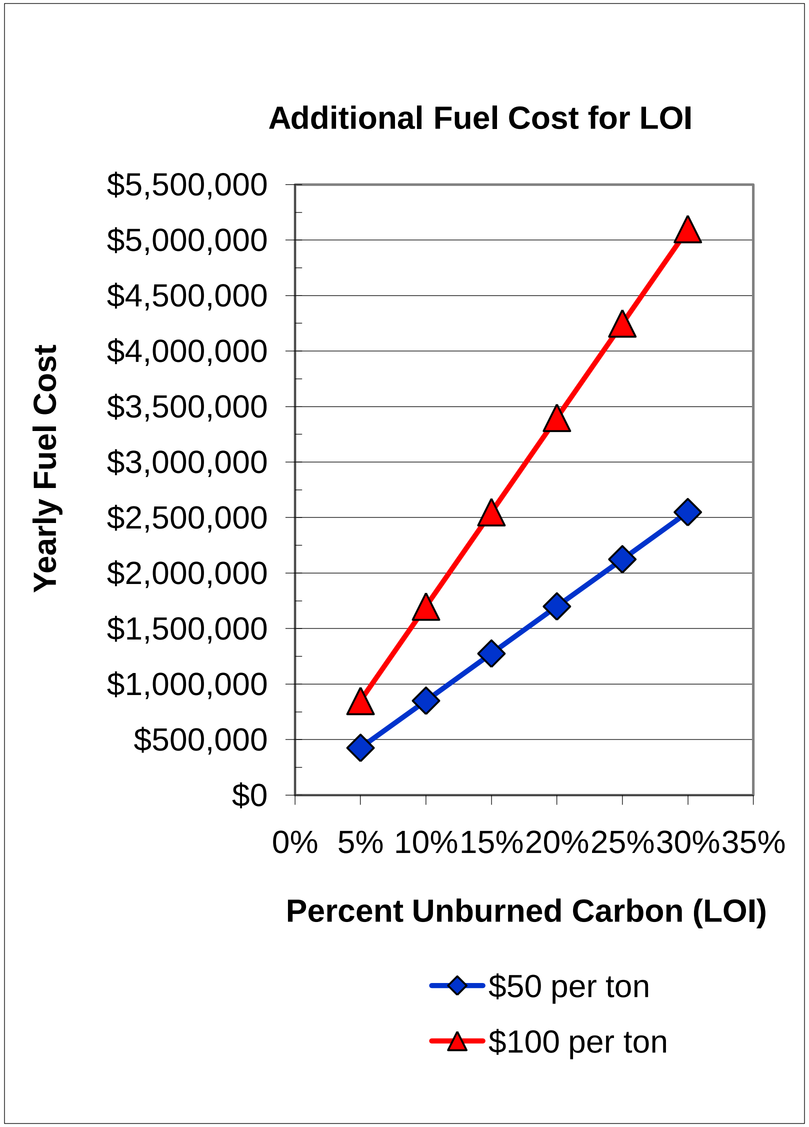
% Under Design Eff.	$50/ton Coal Cost	$100/ton Coal Cost
1%	976,799	1,953,598
2%	988,157	1,976,314
3%	999,783	1,999,565
4%	1,011,685	2,023,370
5%	1,023,874	2,047,748



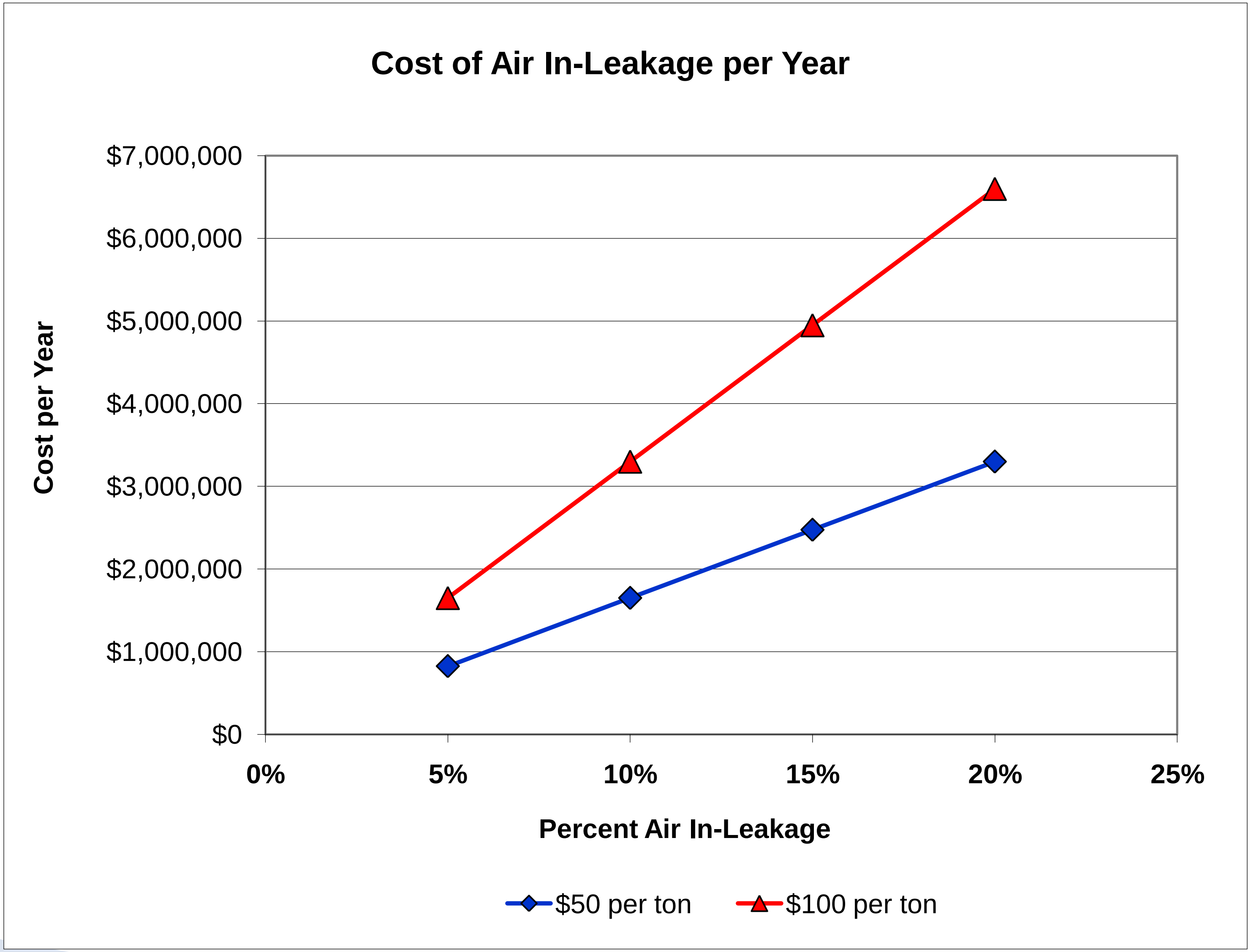


Cost of High LOI vs. Fuel Consumption($)

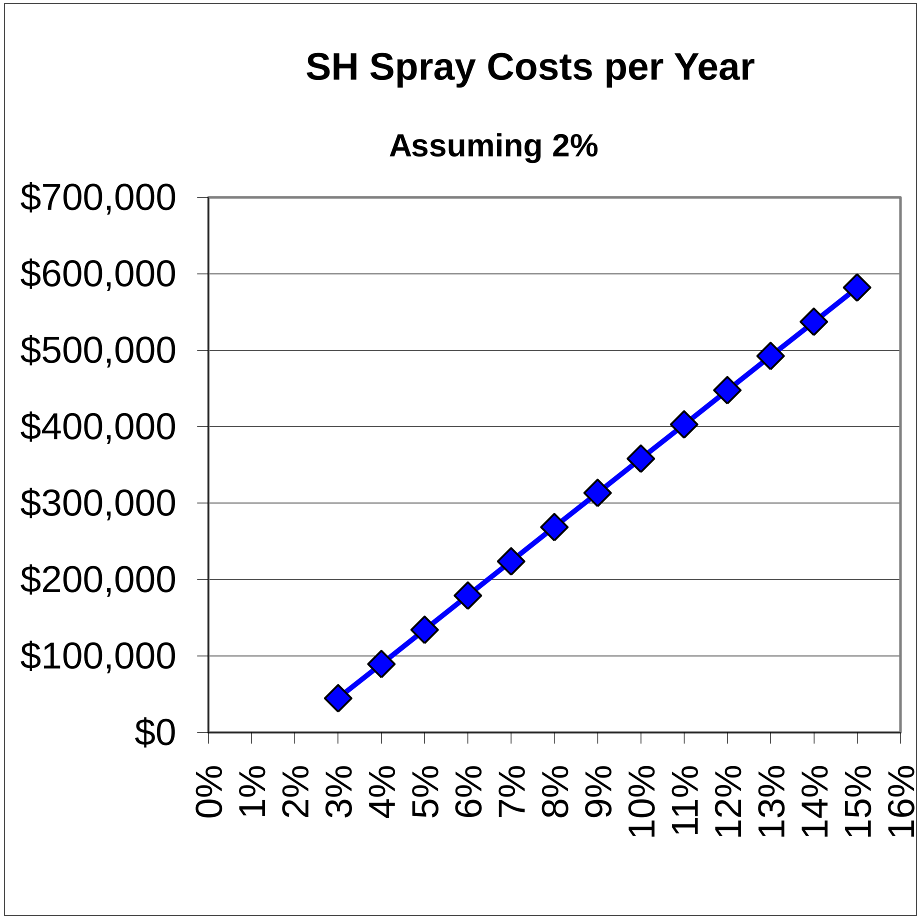
Fly ash	Fuel cost	Fuel cost
UBC	**$50/ton**	**$100/ton**
5%	424,908	849,815
10%	849,815	1,699,630
15%	1,274,723	2,549,446
20%	1,699,630	3,399,261
25%	2,124,538	4,249,076
30%	2,549,446	5,098,891

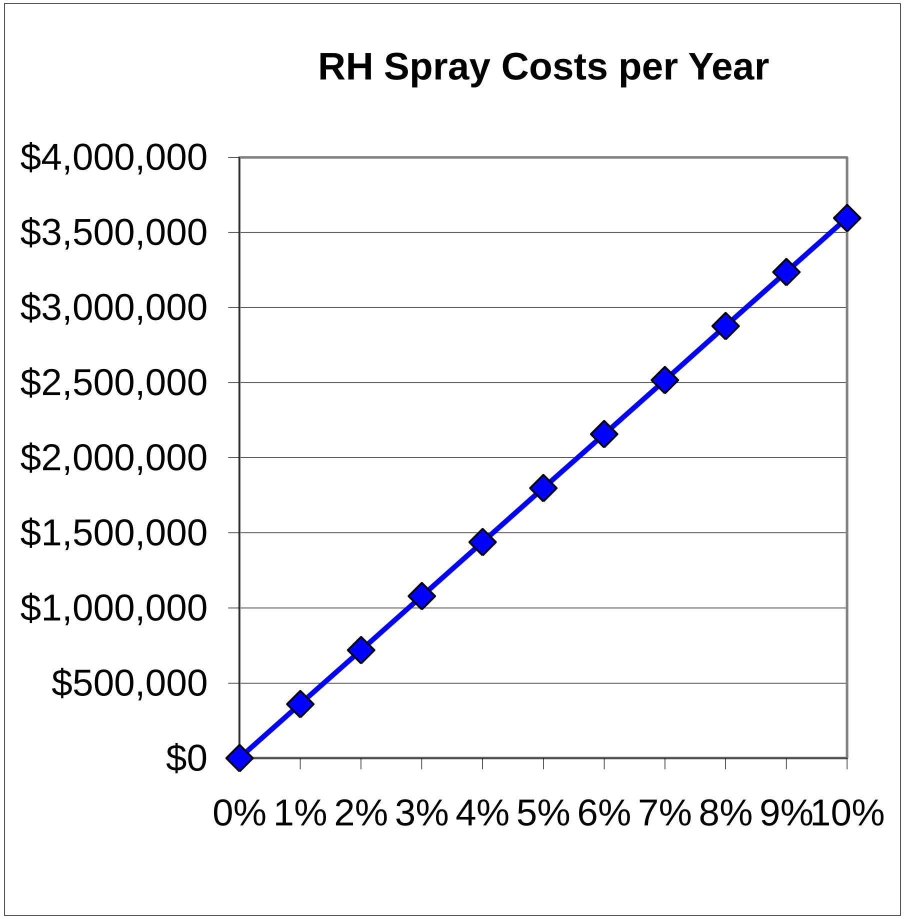


Cost of Air In-Leakage

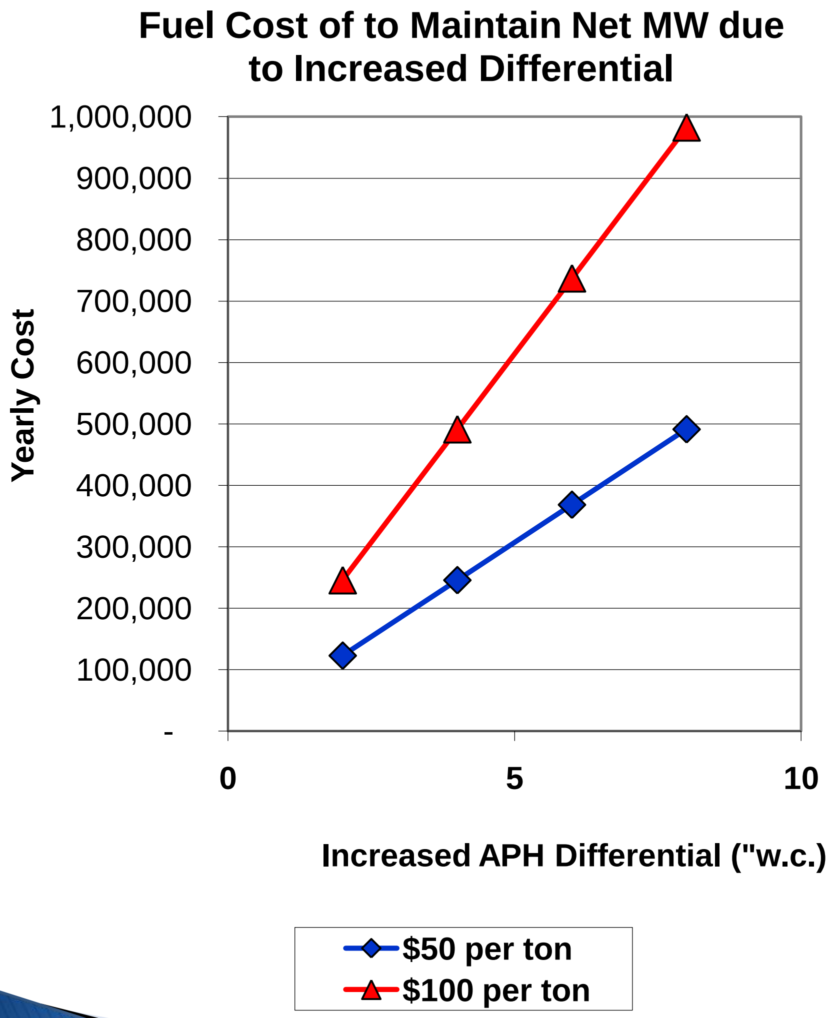


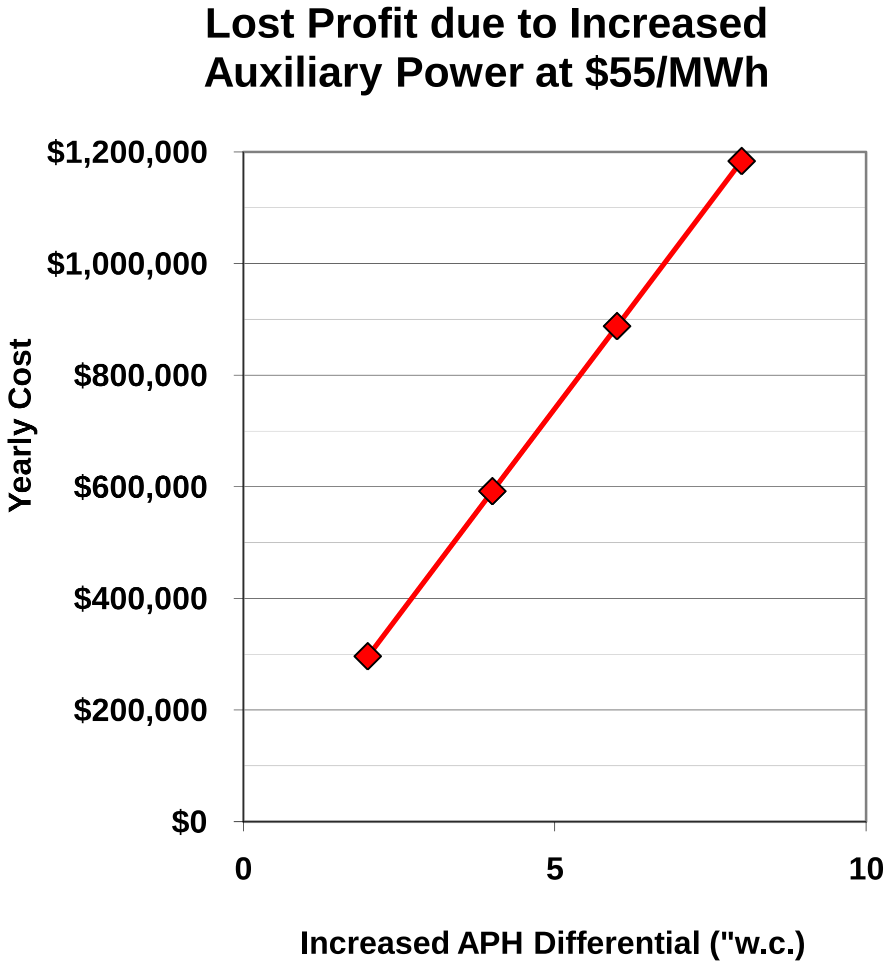
SH & RH Spray Flow Cost





Cost of Increased Auxiliary Power Consumption


Fuel Cost of to Maintain Net MW due to Increased Differential


Lost Profit due to Increased Auxiliary Power at $55/MWh

Replacement Power Cost (RPC)

500MW Unit - Case Study

More uniform FEGT and improved combustion yields fewer tube failures & improve reliability & reduce replacement coal power costs. For example, let's say we have 4 forced outages due to tube failures, slagging outages

- 72 Hr outages for a 500Mw Unit.
- Lost Generation due to forced outage =(72hours)(4)(500Mw)=144,000Mw's
- Assumed Cost of generation w/ Coal @ $20/Mw, Assumed Cost of generation w/ gas @ $60/Mw; Δ = $40/Mw
- Therefore, the estimated lost of only 288 Hours of downtime to replace with high cost gas turbine power

Lost Generation Capability Cost for Replacement Generation = (144,000Mw's)($40/Mw extra) = $5,760,000

Automotive Industry (Past)

Mechanical Fuel Injection
(Historic Solution)

Air/Fuel Mixtures Mechanically Controlled by Carburetors

Mechanical Fuel Pumps Governed by Flexible Internal Diaphrams

Static Parameters

Less Efficient Operations Leads to Greater Emissions

Automotive Industry (Present)

Electronic Fuel Injection
(Modern Standard)

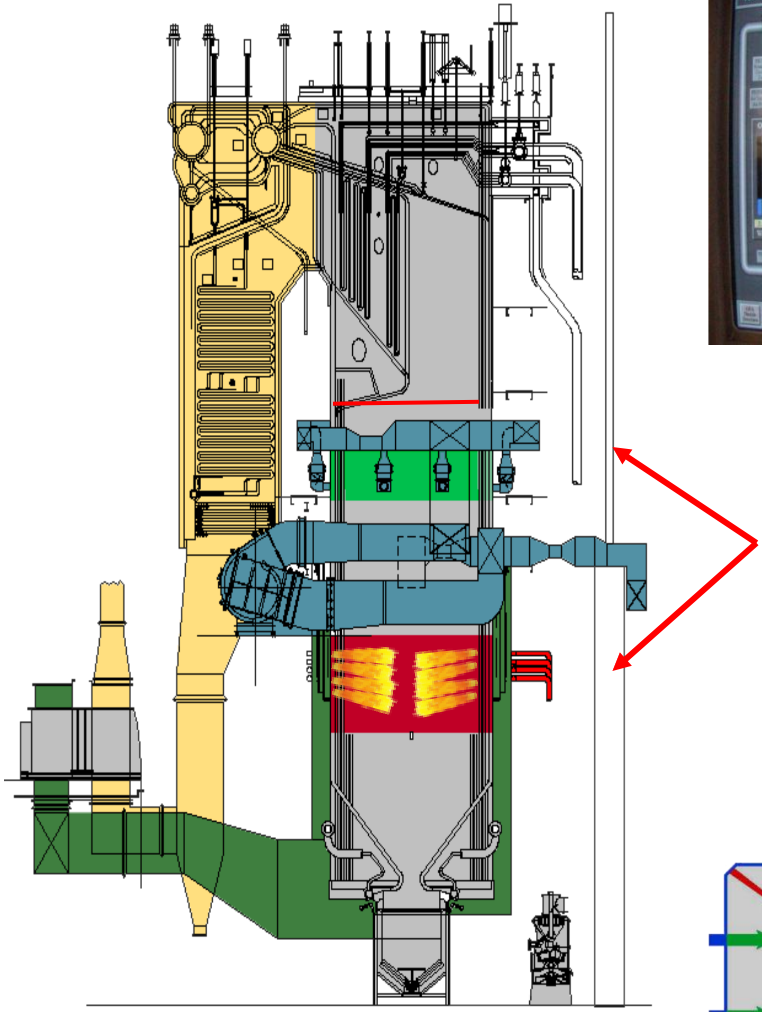
Air/Fuel Mixtures Electronically Controlled by an onboard computer relying on Feedback from Oxygen and other Sensors

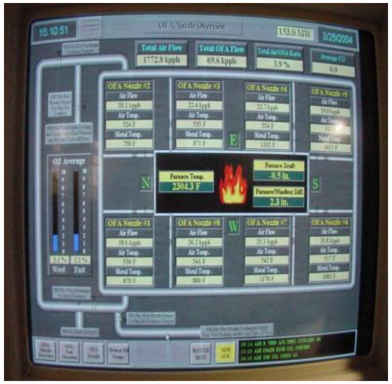
Electric Fuel Pumps React to Changing Fuel Needs as Required

Dynamic Parameters

Precise air/Fuel Distribution Between Cylinders Results in Greater Efficiency and Reduced Emissions

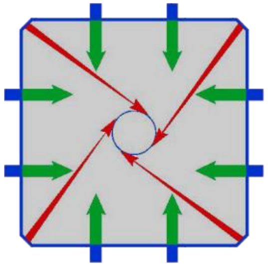
Precise Combustion Air Staging

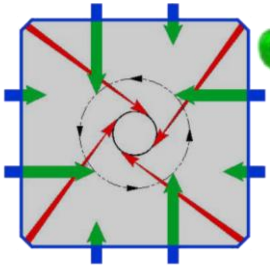


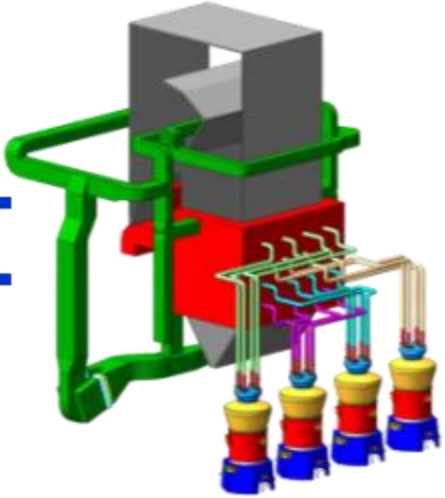


Controlled Burner Belt & Furnace Stoichiometry

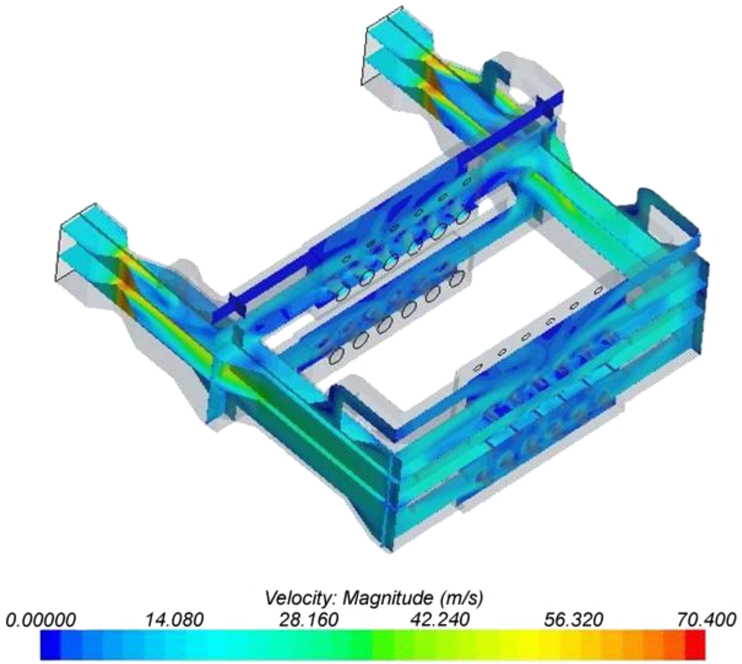
Airflow Control Stations should be designed such that all airflow paths are measured, controllable & most importantly ACCURATE. These flow rates should be periodically be measured for verification of accuracy.

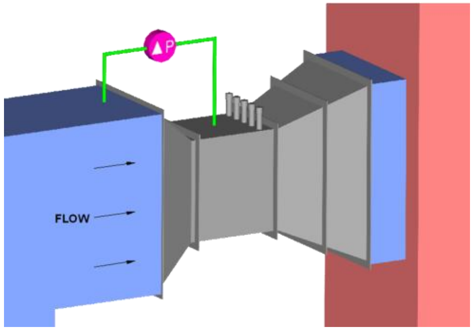


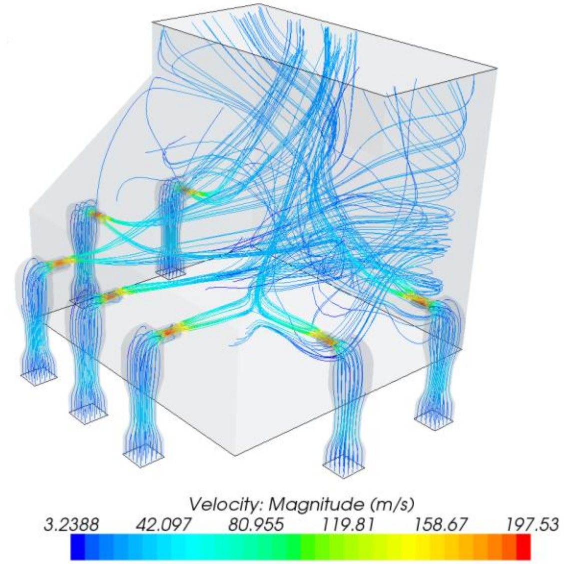


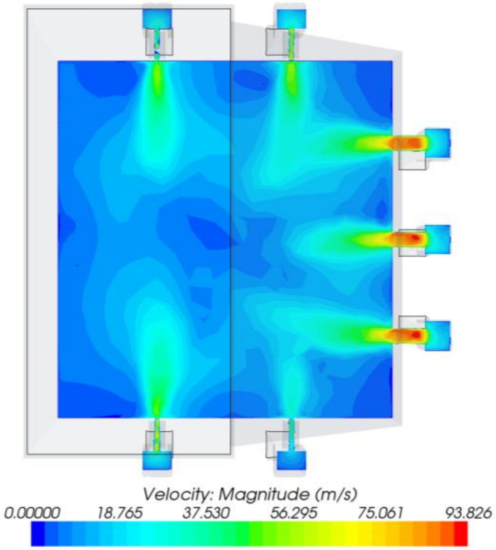


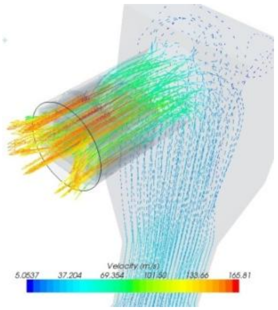
CFD, Based on Actual Measured Results with Varying OFA Nozzle Sizes

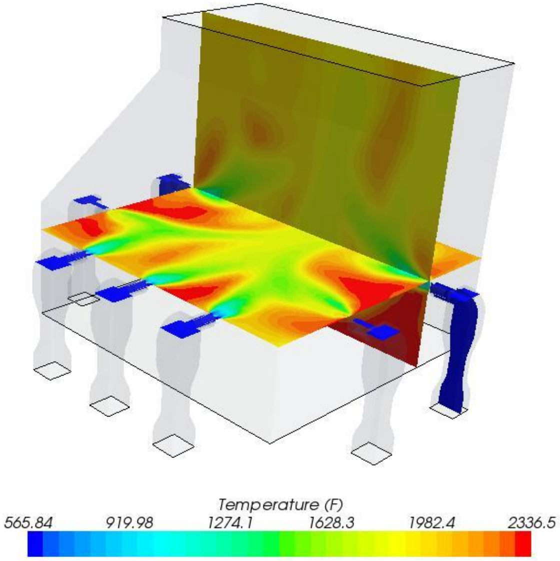












STORM®

Specialists in Combustion and Power

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.