WILLIAMSON ENERGY, LLC

2nd Annual Illinois Basin Coal Symposium

SERVICE QUALITY RESULTS STORM

# Combustion Optimization by Application of the Fundamentals as it Relates to Illinois Basin Coal

Presentation by, Richard F. "Dick" Storm
CEO, Storm Technologies, Inc

2nd ANNUAL ILLINOIS BASIN COAL SYMPOSIUM
Sunday, November 9th – Tuesday, November 11th 2008
PGA National Resort & Spa – Palm Beach Gardens, Florida

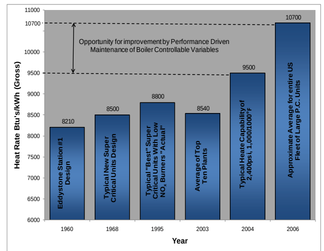
# Goals of this Talk:

1. Discuss How and Why Furnace Combustion Optimization is important.
2. Present the Storm "13 Essentials of Combustion Optimization in PC Units.
3. Provide a review of the consequences of "Not Optimizing Furnace Inputs"
4. Describe How Storm Recommends Optimizing the Furnace Inputs. **(Both Air & Fuel)**
5. Review Large Utility Boiler Furnace Combustion.
6. Briefly Cover Why Some boilers are more "Forgiving" than others.

# FYI, **Storm Technologies, Inc. Business is Improving Overall Coal Plant Performance**

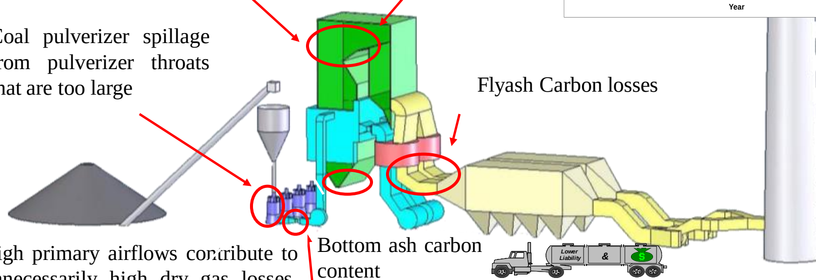
High furnace exit gas temperatures contribute to overheated metals, slagging, excessive sootblower operation, production of popcorn ash, fouling of SCR's and APH's

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




Coal pulverizer spillage from pulverizer throats that are too large

Flyash Carbon losses



High primary airflows contribute to unnecessarily high dry gas losses. Also poor fuel distribution and poor coal fineness.

Bottom ash carbon content

Non optimum primary airflow measurement and control ; Excessive $NO_X$ levels

# Typical Opportunities for Improvement

## Capacity, Reliability, Heat Rate, Environmental and Fuels Flexibility

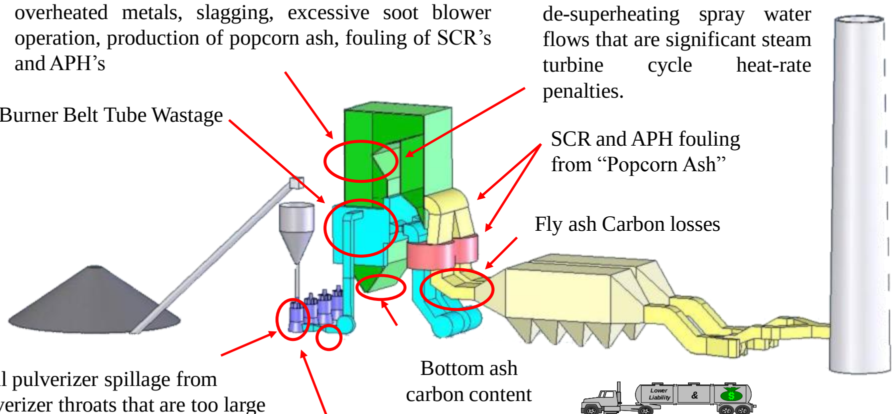
High furnace exit gas temperatures contribute to overheated metals, slagging, excessive soot blower operation, production of popcorn ash, fouling of SCR's and APH's

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

Burner Belt Tube Wastage

SCR and APH fouling from "Popcorn Ash"

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 $NO_X$

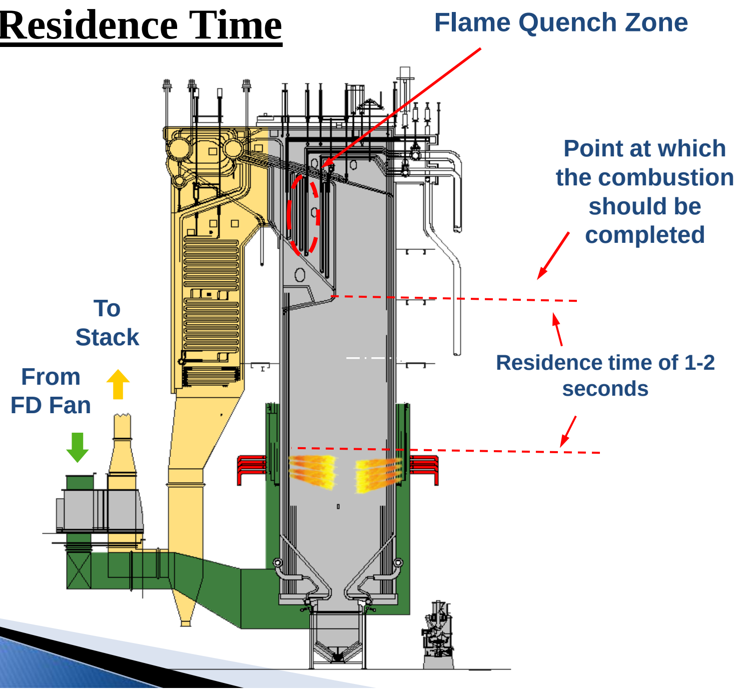
## STORM®

*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.

## Furnace Residence Time

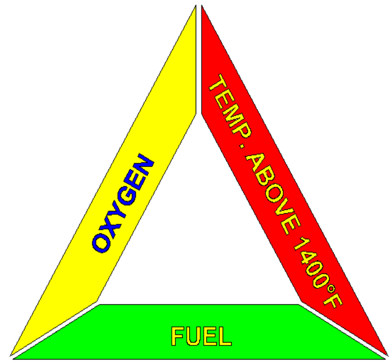


# The Combustion of Solid Carbon

- The combustion of solid carbon or "char" must be completed in a very short time.

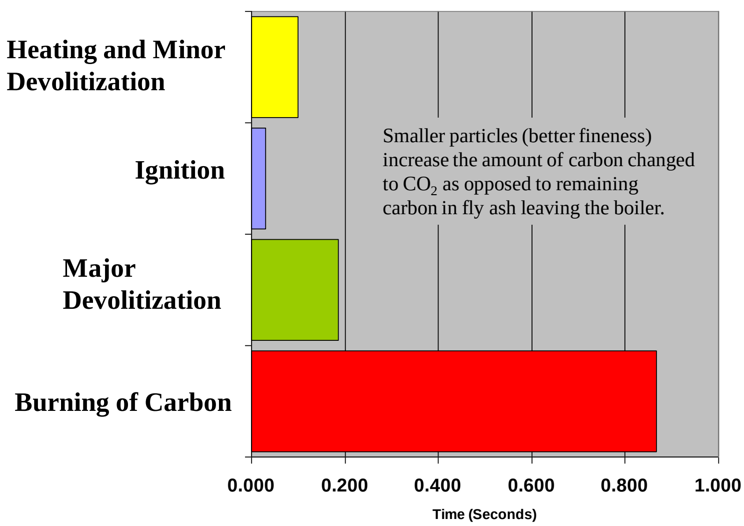
- If air and carbon are not well mixed, combustion requires even more time. From the time a coal particle enters the furnace, it spends approximately 1 to 1.5 seconds above it's ignition temperature of 1,400 degrees F.

- Most of this time is used for burning of the carbon.



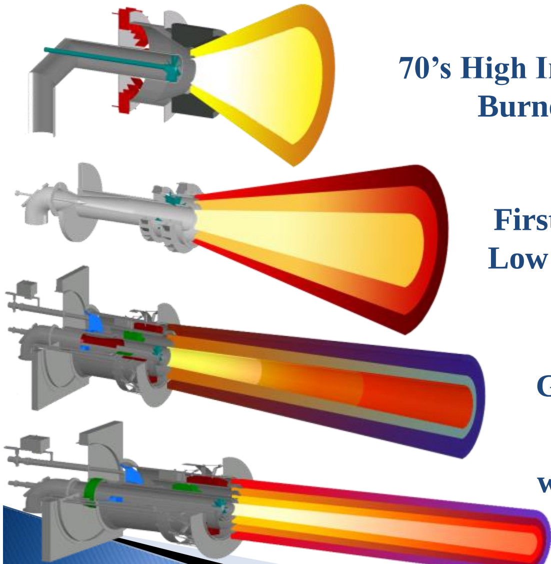

**Carbon Char Burn-Out Requires 3 Essential Elements**

**This graph illustrates typical time requirements for combustion of coal. These times will vary with different coals & firing conditions but the combustion of carbon always requires the most time.**




**Note: This is why small particle sizing is important.**

## 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

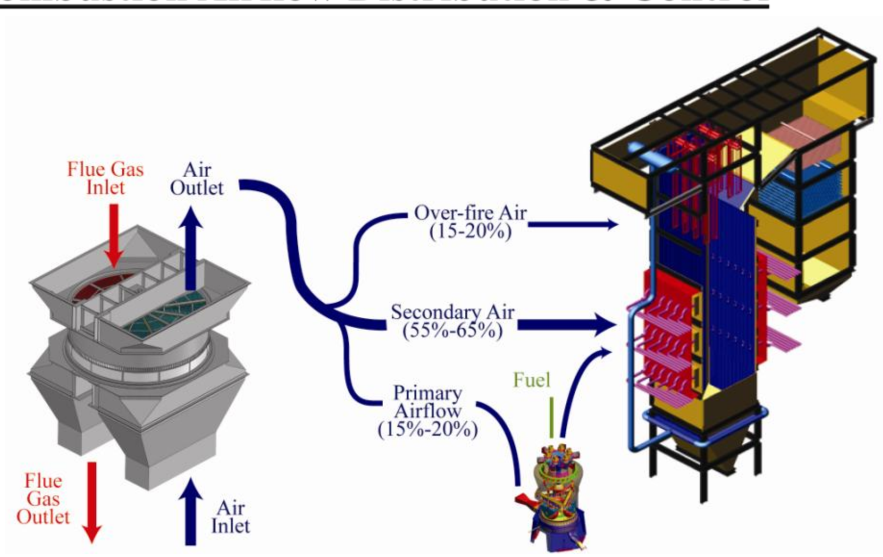
Sensitive

Unforgiving

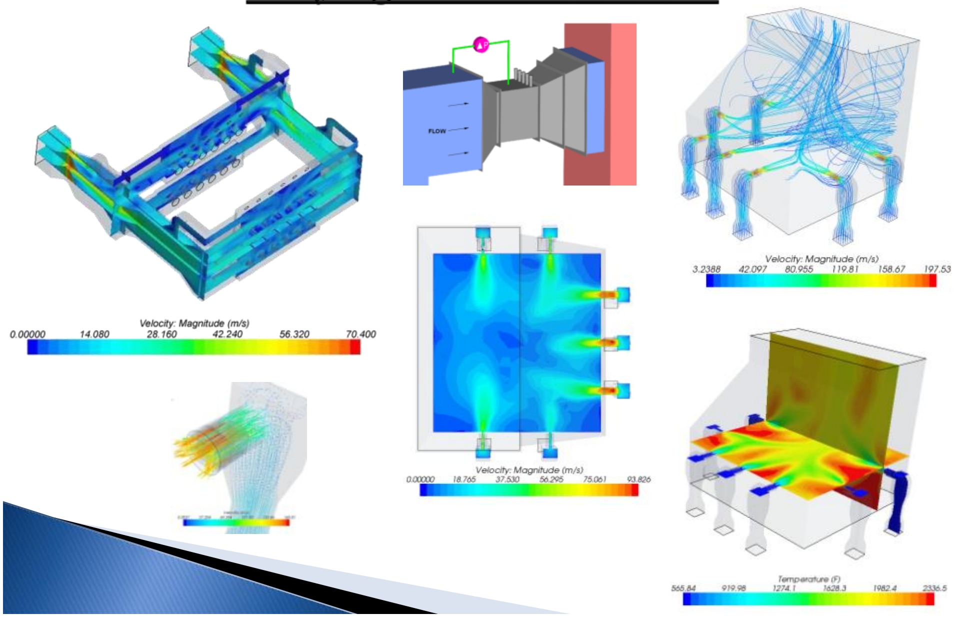
Challenging !

*All are 175 – 185MMBTU*

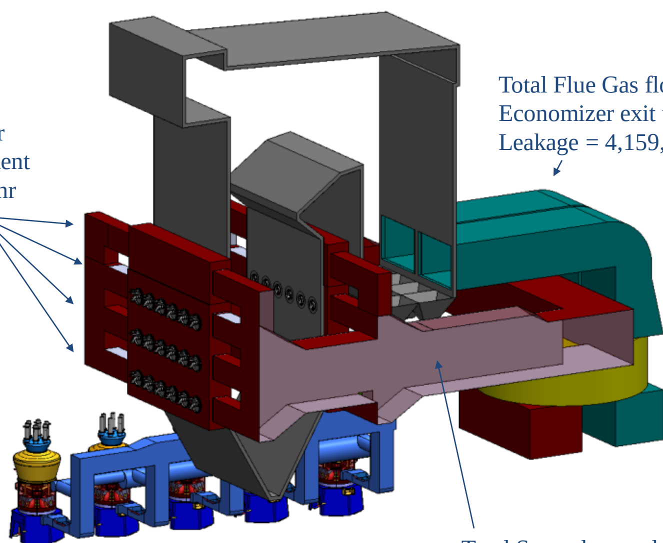
## Combustion Airflow Distribution & Control



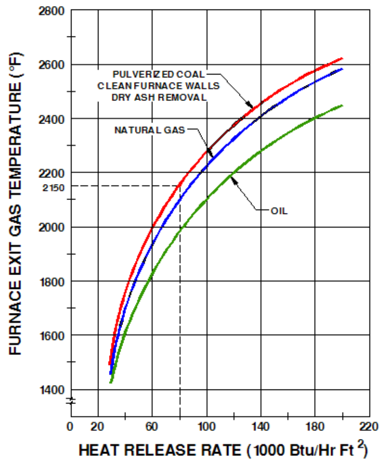
# CFD, Based on Actual Measured Results with Varying OFA Nozzle Sizes




# Total Airflow Measurement Example

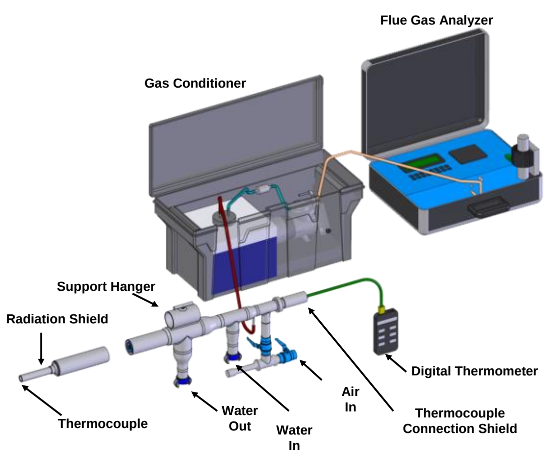


# The Furnace Exit Gas Temperature (FEGT)

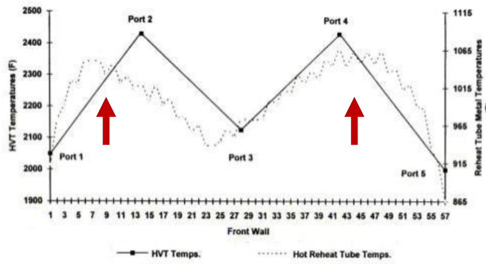



High furnace exit gas temperatures can contribute to overheated metals, such as these superheater alignment castings that only lasted 1 year due to greater than 2,500°F. furnace exit gas temperatures.

# Furnace Exit HVT Testing




# Tube Metal Thermocouples




Installation of PSH Tube Metal Thermocouples

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

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

# Online FEGT Monitors

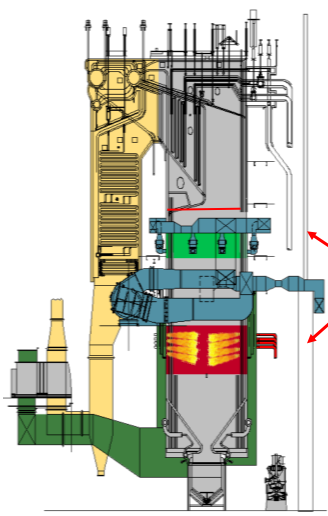
**FEGT Monitor**

**HVT Probe Test Port**

## Slagging or Fouling, in our experience, is likely to be from one of Five Common Root Causes:

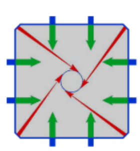
- Airflow Imbalances
- Oxygen Deficiency in the Furnace
- Fuel Flow Imbalances
- High Primary Airflows
- Poor Fuel Fineness

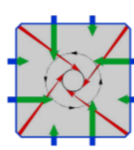
## Precise Combustion Air Staging

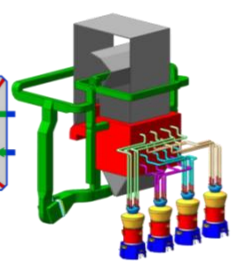


Controlled Burner Belt & Furnace Stoichiometry

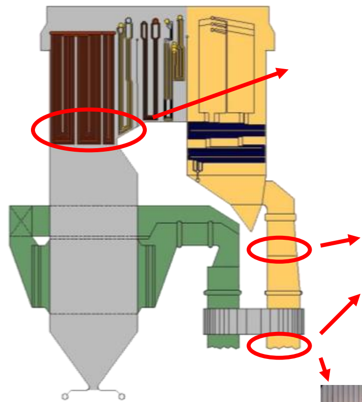
Airflow Control Stations should be designed such that all airflow paths are measured, controllable & most importantly ACCURATE. These flow rates should be periodically be measured for verification of accuracy.

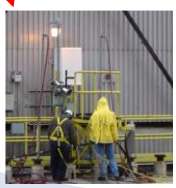






# Boiler Testing & Tuning
# First: Identify Opportunities





| | |
|---|---|
| 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% |

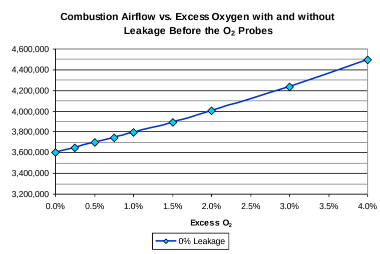
**500 MW Operation (100% MCR)**

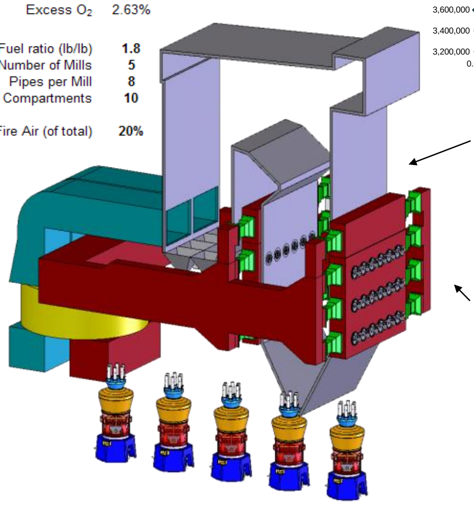
**10,000Btu/KwHr Heat Rate, 11,500Btu/Lb. Coal, 15% Excess Air & with 0% air in-leakage from the furnace to the Excess $O_2$ probes**

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

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

OFA: 828,942lbs/Hr.



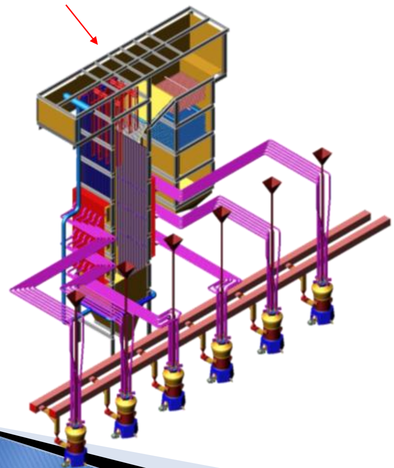



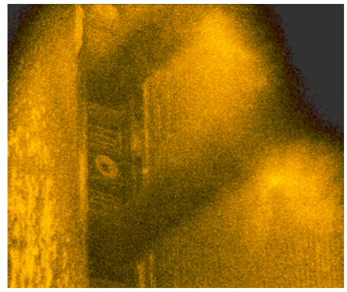
When assuming zero leakage, the Stoichiometry is 1.15 or 15.0% Excess Air at this point.

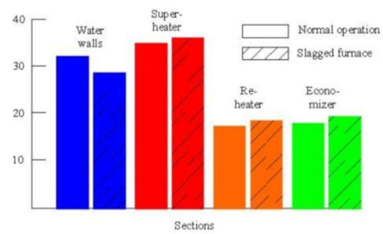
When assuming zero leakage, the burner belt stoichiometry is .92 (average) or -8% Excess Air.

# Excessive de-superheating spray flows & heat rate

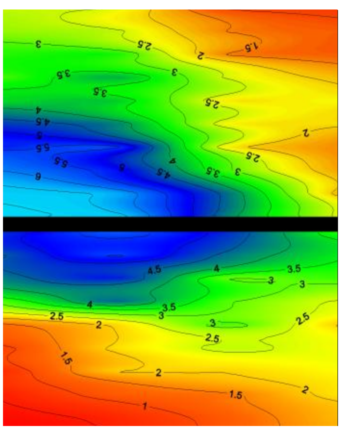
Too much heat absorption in the upper furnace will contribute to high de-superheating water spray flows

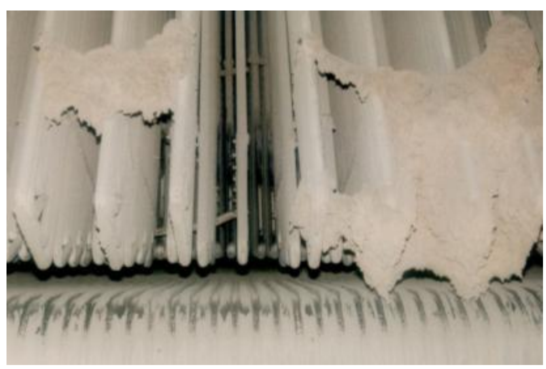







# Furnace Exit Gas Profiles

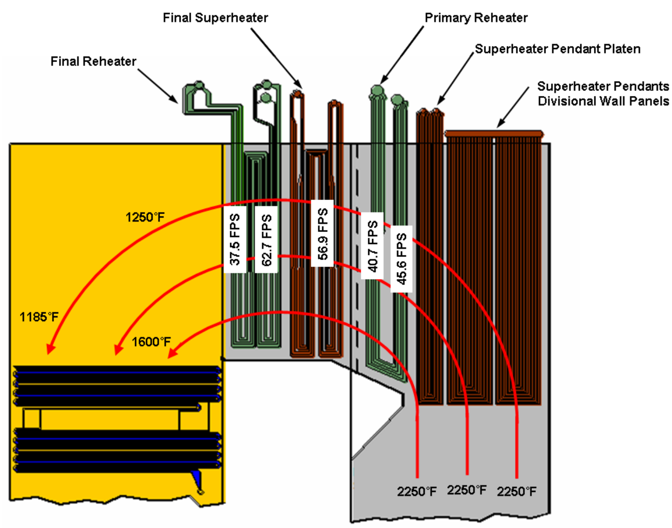




Minimization of Reducing atmospheres at the furnace exit is the Key to optimizing flue gas temperatures and reducing slag bridging, heavy levels of secondary combustion and hot tube circuits.

## Secondary Combustion (video)

## Typical Flue Gas Stratifications & Flue Gas Temperatures - Velocities



# Review of the Solution for the Associated Challenges with High Sulfur, Illiniois Basin Coal

## Three Basic Concerns to Mitigate:

- Waterwall Wastage
- Slagging from Secondary Combustion
- SCR or Airheater Fouling

SERVICE QUALITY RESULTS
STORM

## High Sulfur vs. Low Sulfur Coal

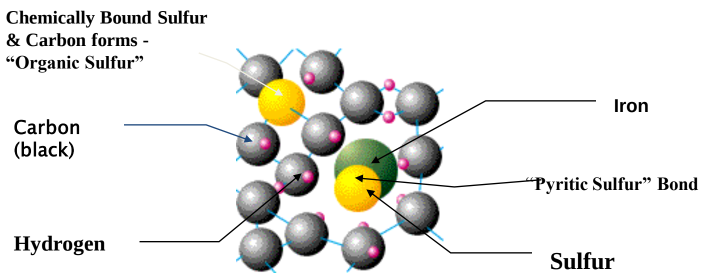
| Ultimate Analysis | High Slagging Coal | Low Slagging Coal | |
|---|---|---|---|
| Moisture | 6.09 | 2.2 | % by wt. |
| Carbon | 63.25 | 72.7 | % by wt. |
| Hydrogen | 4.32 | 4.7 | % by wt. |
| Nitrogen | 1.37 | 1.27 | % by wt. |
| Sulfur | 3.81 | 0.76 | % by wt. |
| Ash | 15.63 | 13.4 | % by wt. |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

# The Water Wall Corrosion Process

- Incomplete combustion causes sodium and potassium in the coal to become oxides
- Sulfur from the coal combines with oxygen to form sulfur dioxides.
- These compounds are then deposited on the tube surfaces.
- The deposited sulfur compounds combine with the sodium or potassium oxides to form pyrosulfates.
- **When the pyrosulfates, carbon, and iron combine, wastage will occur.**

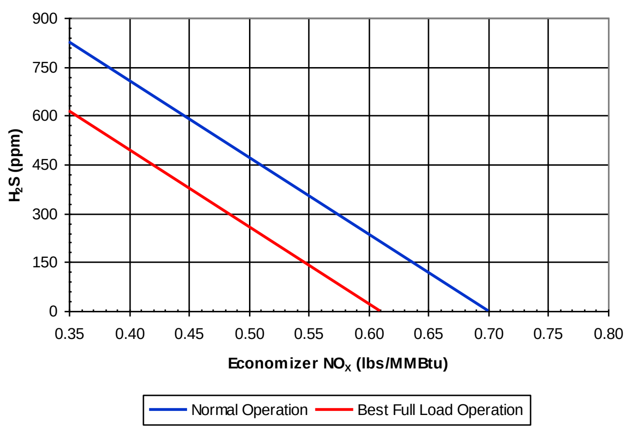



# $H_2S$ & $NO_X$ Correlation

The difficulties with lowering the production of $H_2S$ is that it is closely tied to the CO level in the furnace and inversely related to $NO_X$ production. Meeting $NO_X$ limits while simultaneously lower harmful levels of $H_2S$ require well staged and measured airflow.

**As you can see below –**

**Lower the $NO_X$ levels Often Result in Higher $H_2S$ Concentrations**

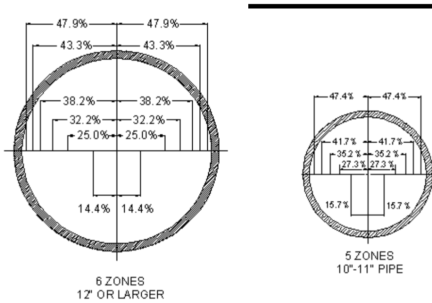


## Relationship of Poor Fineness w/ Water Wall Wastage

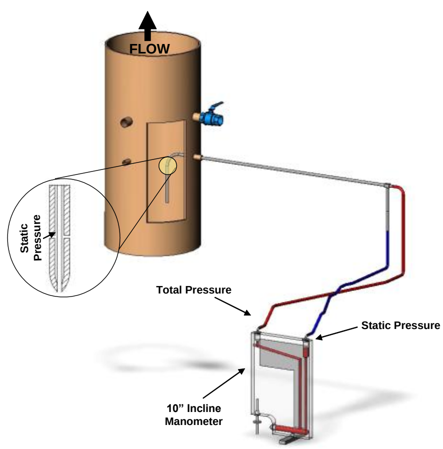
Microscopic Investigation of Deposits
**Source: Rod Hatt, CCI**

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

## The Clean Air Test



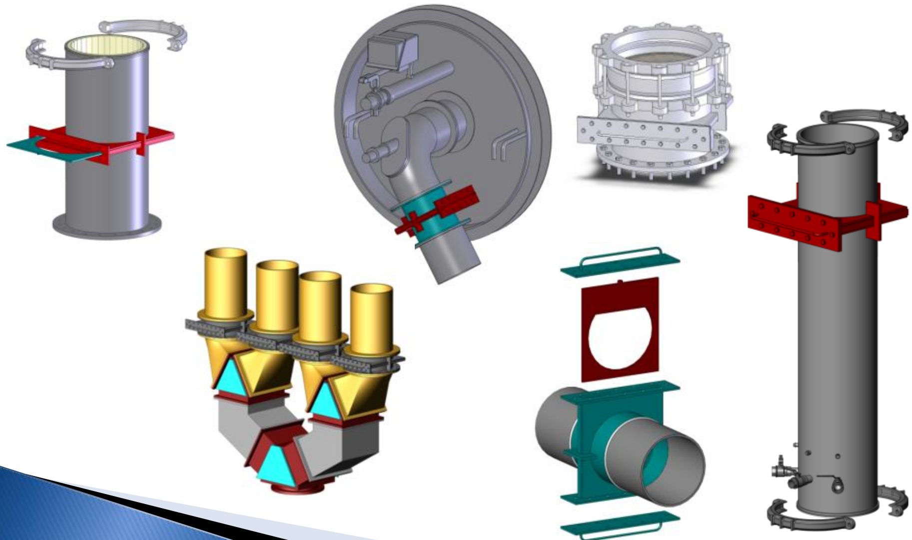

EQUAL AREA TRAVERSE GRID FOR CICULAR DUCTS AND PIPE
Dimensions are "Percent of Pipe Diameters"




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

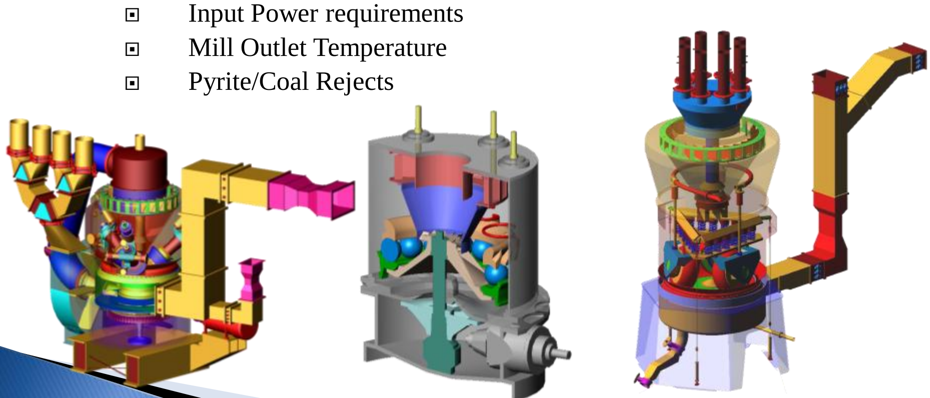
## Balancing the fuel lines by Clean air

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

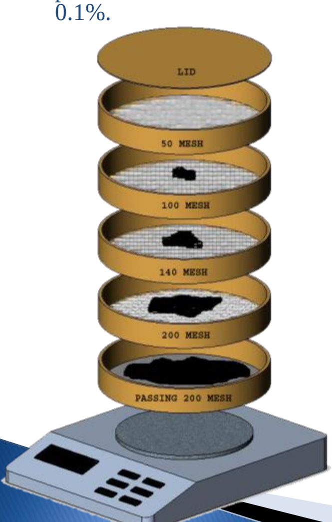


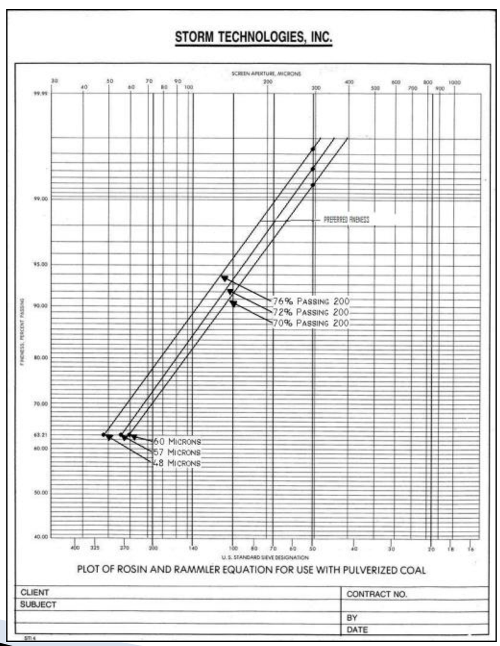
# Dirty Airflow Testing & Isokinetic Coal Sampling

- 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

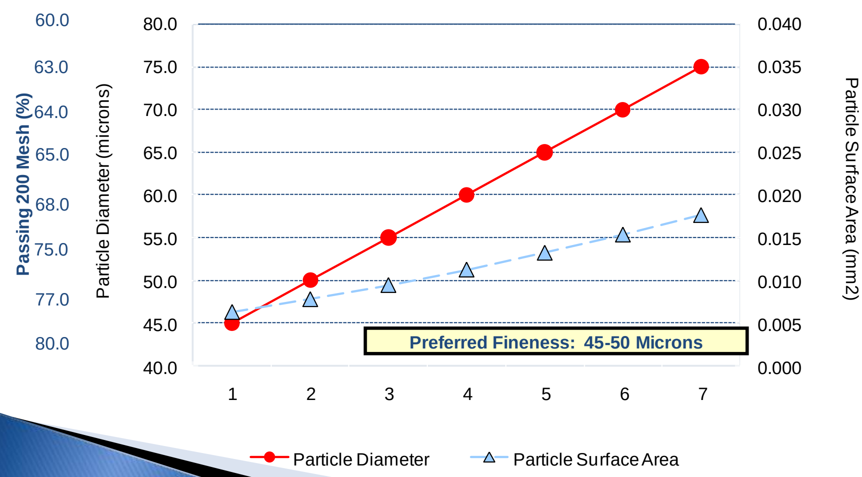
Fuel line fineness shall be 75% or more passing a 200 mesh screen. 50 mesh particles shall be less than 0.1%.



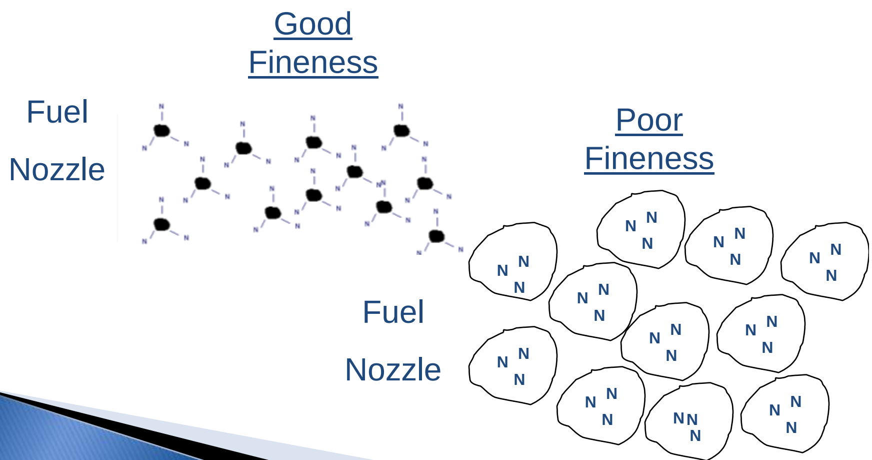
# Average Collected Particle Size (from Isokinetic Coal Sampling)

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




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

"Release of Fuel Bound Nitrogen in the De-Volatilization Zone"



# 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:**

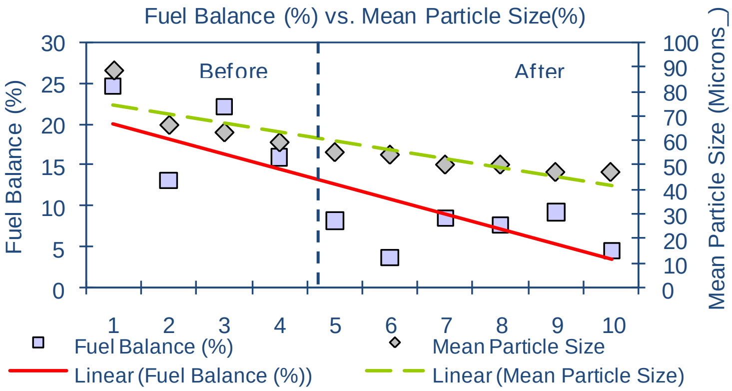
Slagging propensity

Upper furnace slagging & fouling

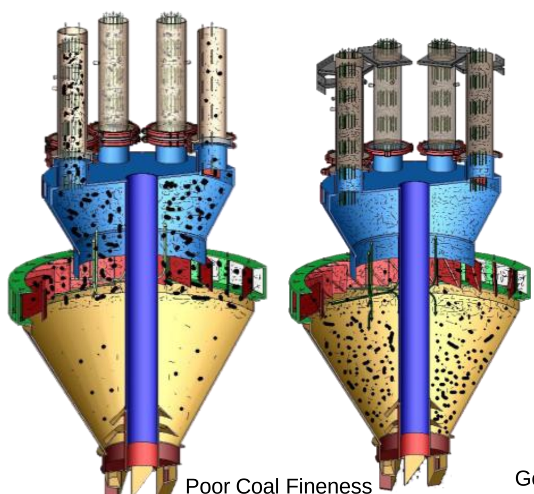
Fuel Imbalances

Water wall Wastage

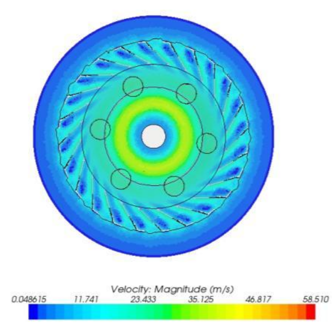
$NO_X$




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

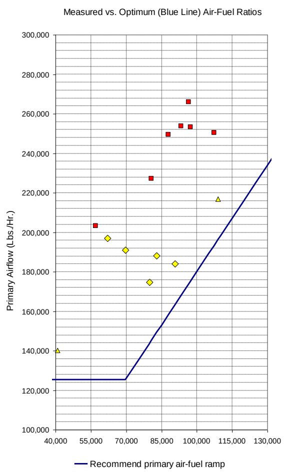


Poor Coal Fineness often yields poor distribution



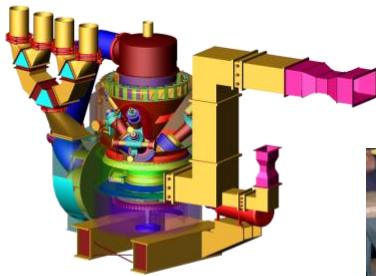

Good Fineness Creates a homogenous & balanced mixture & will produce a more homogenous mixture if mechanical synchronization is optimum

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



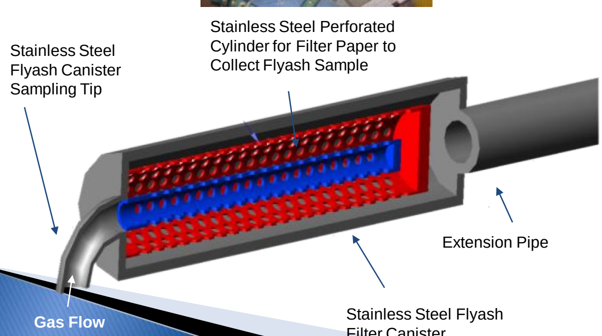

Typical "As Found" Performance

Optimum Primary Airflow Contributes to Best Heat Rate Operation

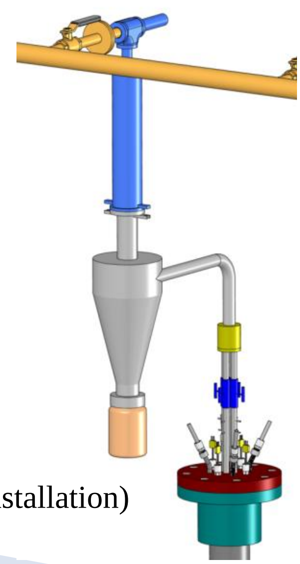


High Tempering Airflow Bypasses the Air Heater and contributes to a less desirable "X" Ratio. Therefore, the mills must be optimized to insure that optimum performance is compatible with a desirable air-fuel ramp

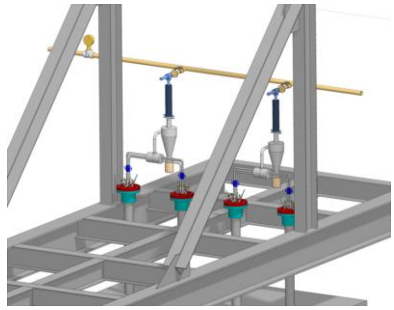
# STORM® Flyash Samplers (Traditional)



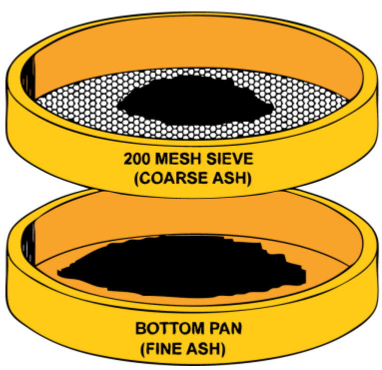

# Storm Technologies, Inc.
# Multi-Point Flue Gas & Ash Sampler



(Permanent Installation)



## Flyash Analysis

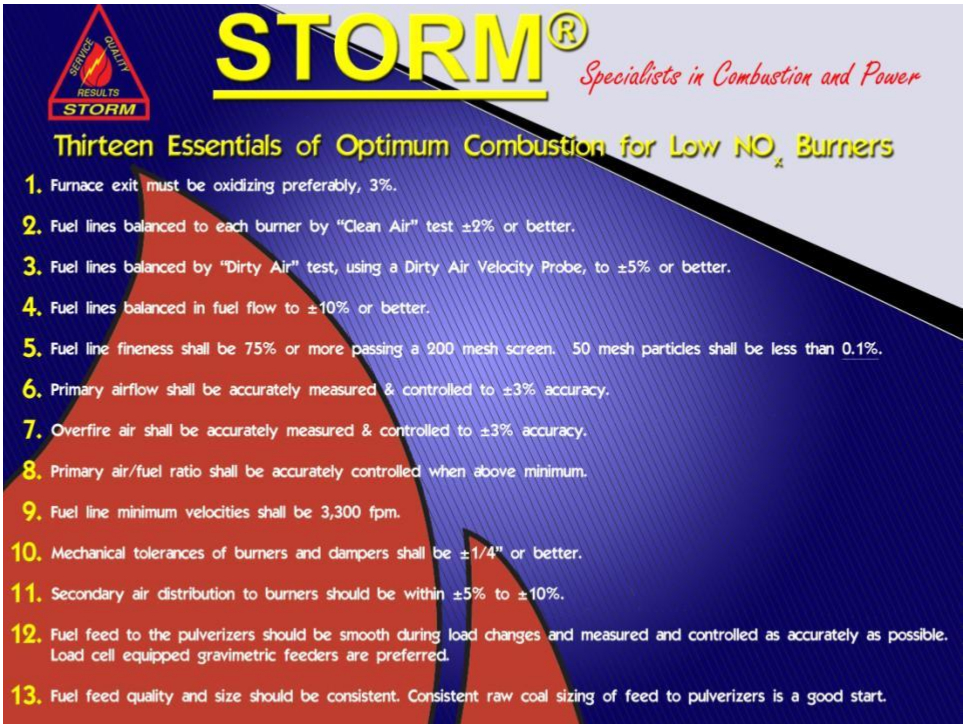



**Place Sample of Ash on the Stacked 200Mesh Sieve/Pan and Shake for 20 minutes.**

**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)**




# Getting **RESULTS!**

- **Test to Identify and Quantify Opportunities**
- **Combine Test Data with Outage Planning (Performance Driven Maintenance)**
- **Implement Improvements**
- **Tune, Balance and Calibrate Airflows and Fuel Flows**
- **Practice Performance Preservation Throughout the Year**

# Typical Outage Activities

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

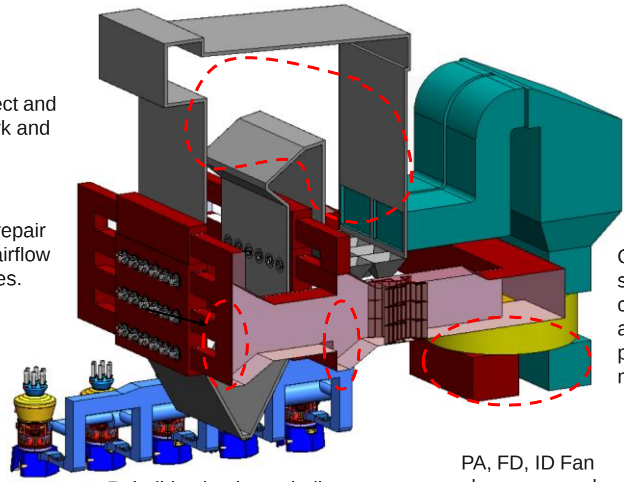
Air-in leakage inspections and repairs.

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.

Refurbish burners.



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

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

Rebuild pulverizer grinding elements.

# Performance Driven Maintenance Techniques

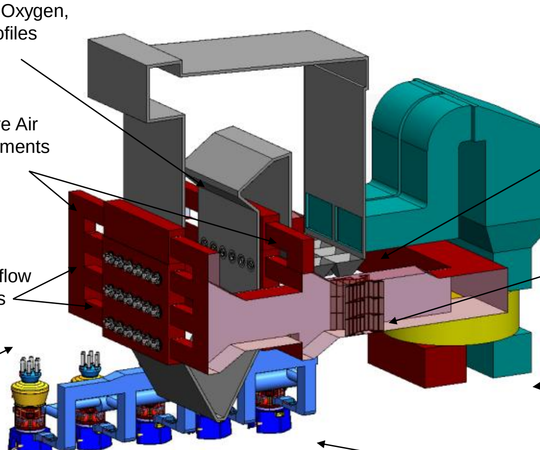
Furnace Exit Flue Gas Temperature, Oxygen, CO & NO Profiles

Over fire Air Compartments

Flue Gas Oxygen & CO Measurements

Secondary Airflow Calibrations

Main Secondary Air Ducts



Fuel Line Performance Tests

Flue Gas Oxygen & CO Measurements

Primary Air Venturi Calibrations

# Thank You!

Any Questions?

Wishing you a very good year of  high capacity factor, low generation cost, high reliability and environmentally sustainable power generation.