REINHOLD ENVIRONMENTAL Ltd.

2014 NOx-Combustion Round Table & Expo Presentations

February 10 & 11, 2014, in Charlotte, NC / Hosted by Duke Energy

Evolution of Low NOx Burners and Efficiency and Versatility of the Latest Generation of Burners

Reinhold NOx Round Table

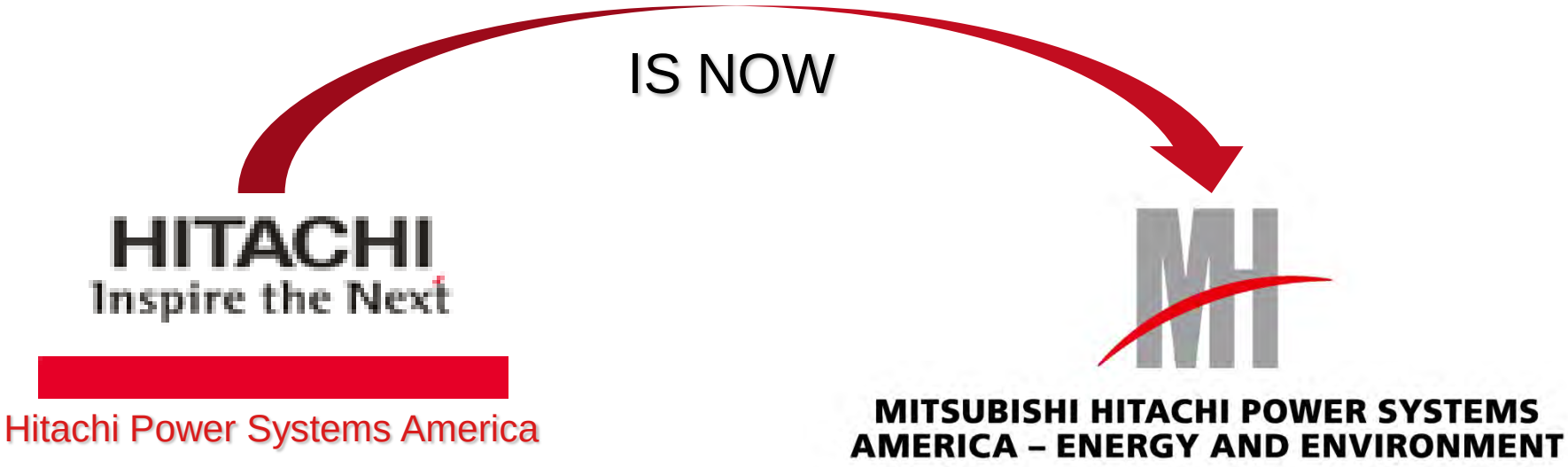
Charlotte, NC

February 10, 2014

Tony Favale

MITSUBISHI HITACHI POWER SYSTEMS AMERICA – ENERGY AND ENVIRONMENT, LTD.

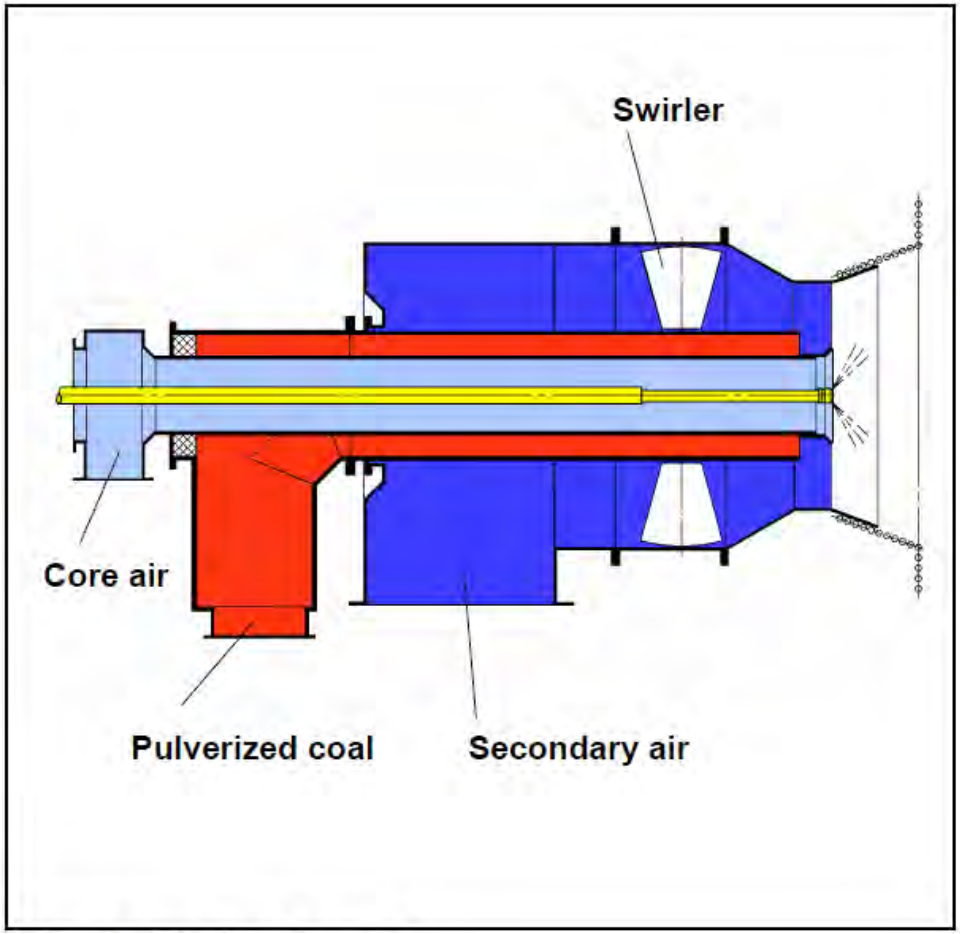
New Joint Venture Company



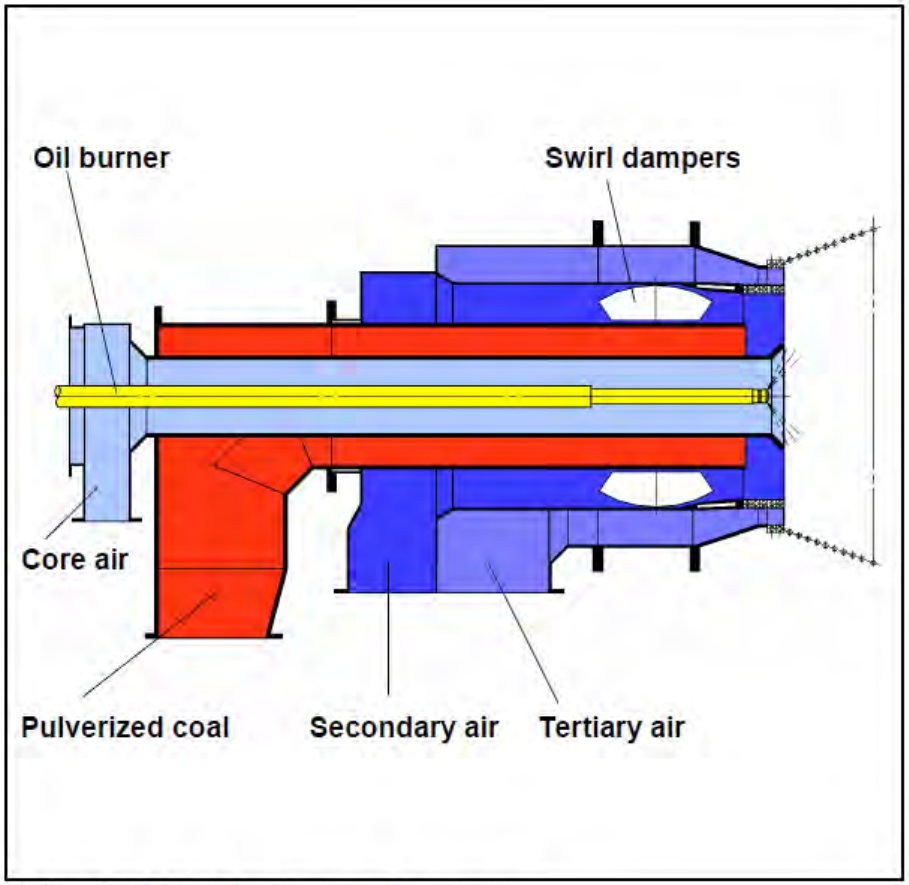
On Feb. 1, 2014 Mitsubishi Heavy Industries, Ltd. and Hitachi, Ltd. have officially merged their operations integrating the thermal power generation businesses of both companies into a single world class technology entity named Mitsubishi Hitachi Power Systems, Ltd. For the North American market, this will include our family of subsidiary organizations such as Mitsubishi Power Systems Americas Inc., Hitachi Power Systems Canada, Ltd, Mechanical Dynamics & Analysis, Ltd and Hitachi Power Systems America, Ltd. HPSA's new name will be "Mitsubishi Hitachi Power Systems America – Energy and Environment, Ltd."

- **Evolution of LNB Technology**
- **Latest Burner Design**
- **Burner Retrofit Experience**
- **Summary**

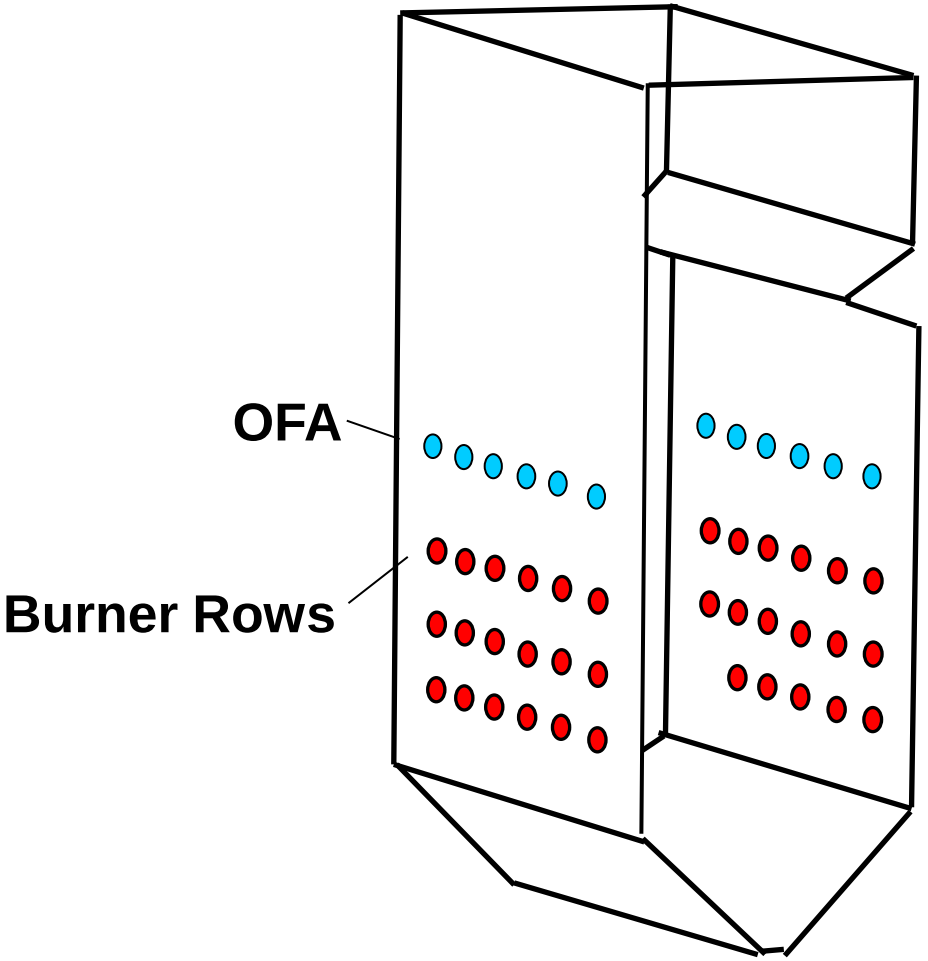
Vortex Burner



WS – Whirl Stage



NOx Control With Over Fired Air Ports (OFA)

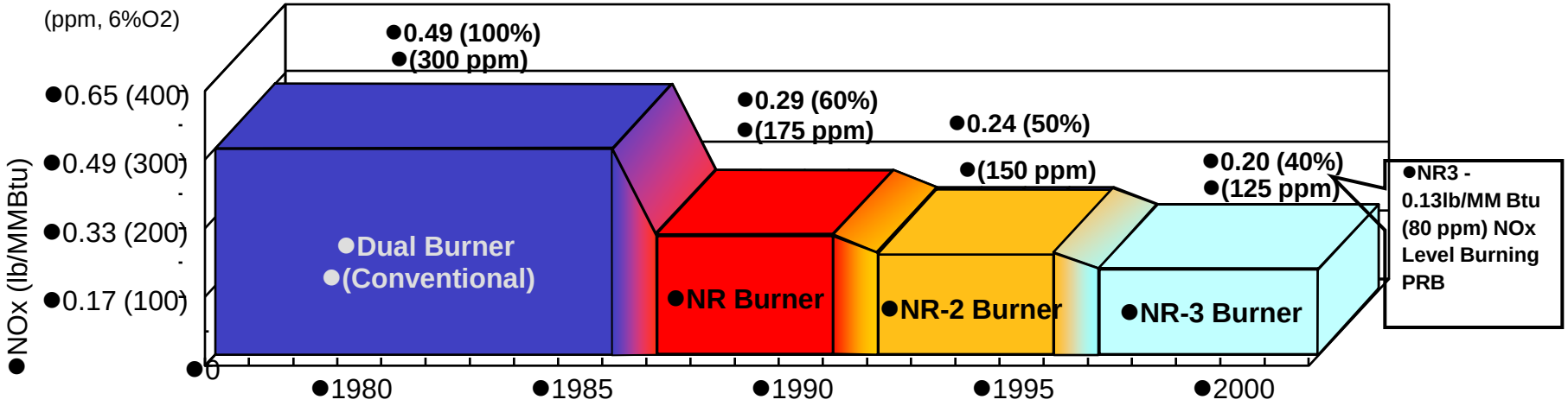


Early OFA Design

NOx Reduction (NR) Technology Evolution

Delayed Combustion → **Rapid Ignition In Flame NOx Reduction**

- Coal property
- FC/VM 2.2
- Nitrogen:1.8%
- Two Stage Combustion



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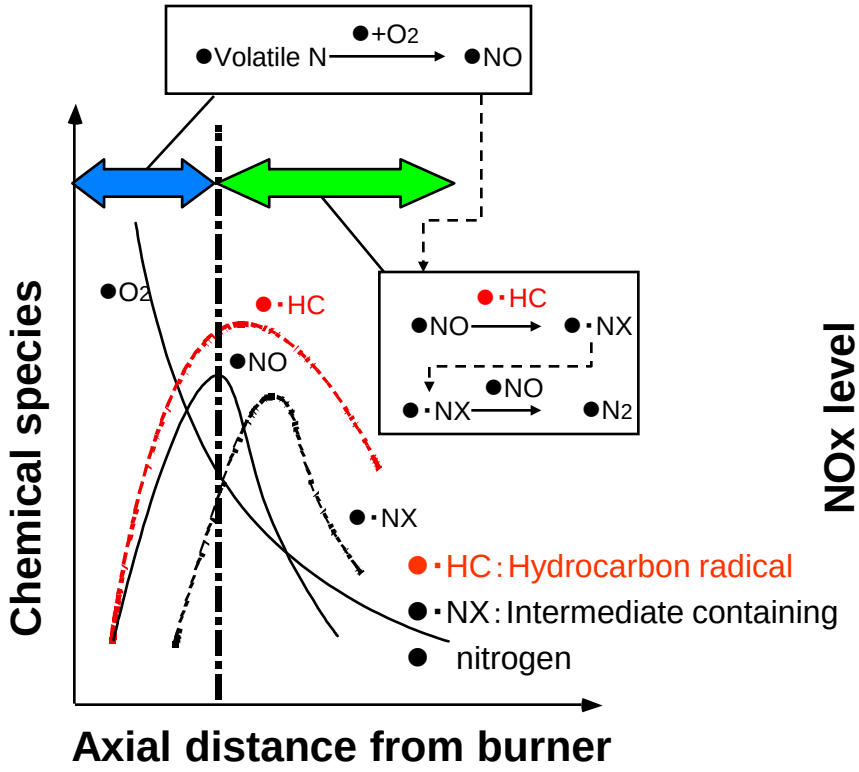
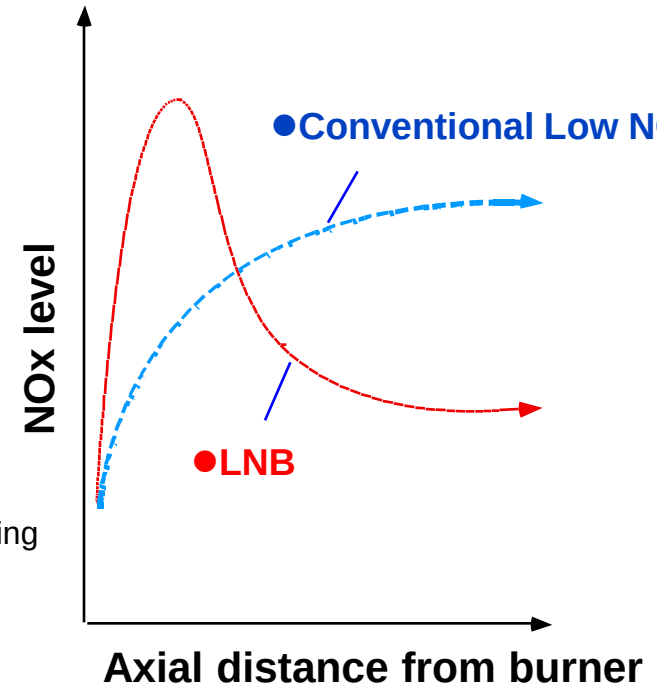
In-Flame NOx Reduction

Formation of Reducing Species



Difference of NOx performance

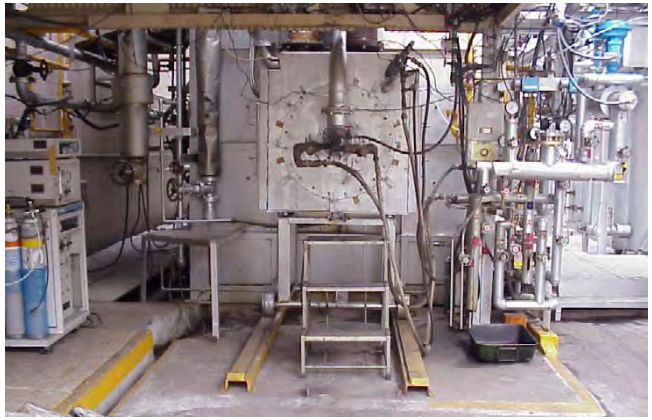


Rapid Ignition & Promotion of Combustion

O_2 consumption and formation of reducing species

Inflame NOx reduction with high combustion efficiency

Burner Combustion R&D Facilities

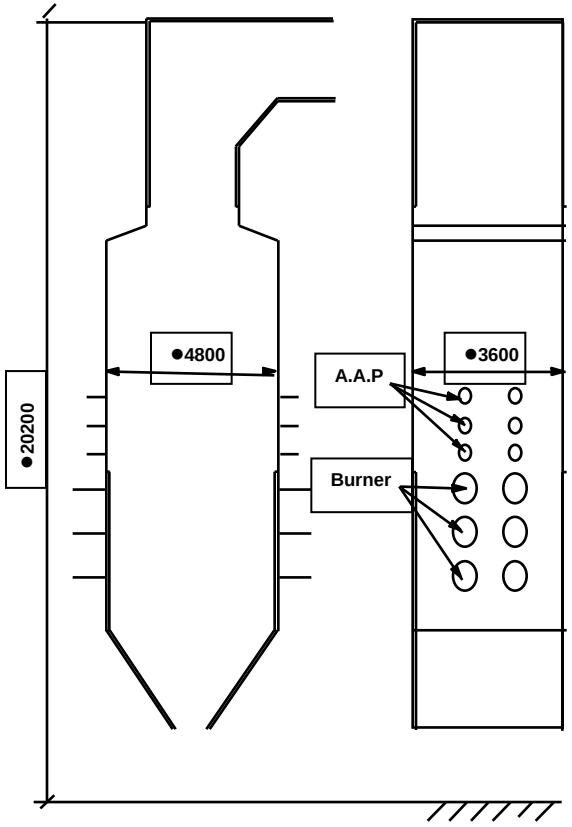


- **Medium scale**, low NOx burner combustion test facility
  - 500kg/h(1100lb/h) firing rate (15MMBtu/h)
  - Coal, oil, and gas capable
  - Used for the basic design development of Latest burner series

- **Large-pilot scale**, low NOx burner design combustion test facility
  - 4t/h(8800lb/h) firing rate (100MMBtu/h)
  - Coal, oil capable
  - Used for the development of Latest burner series

Large Scale Test Facility

- Evaluation of Large-capacity single burner
- Development of low-NOx combustion technologies
- Simulation of load change etc.



●Specification

●Furnace : Water Jacket, Vertical
●Heat Input : 30MWth Units
●Dimensions : Wide 4.5 m
● Depth 3.3 m
● Height 20.2 m

Latest Burner Technology

Developed in Early 1990's and Continuously Improved Through

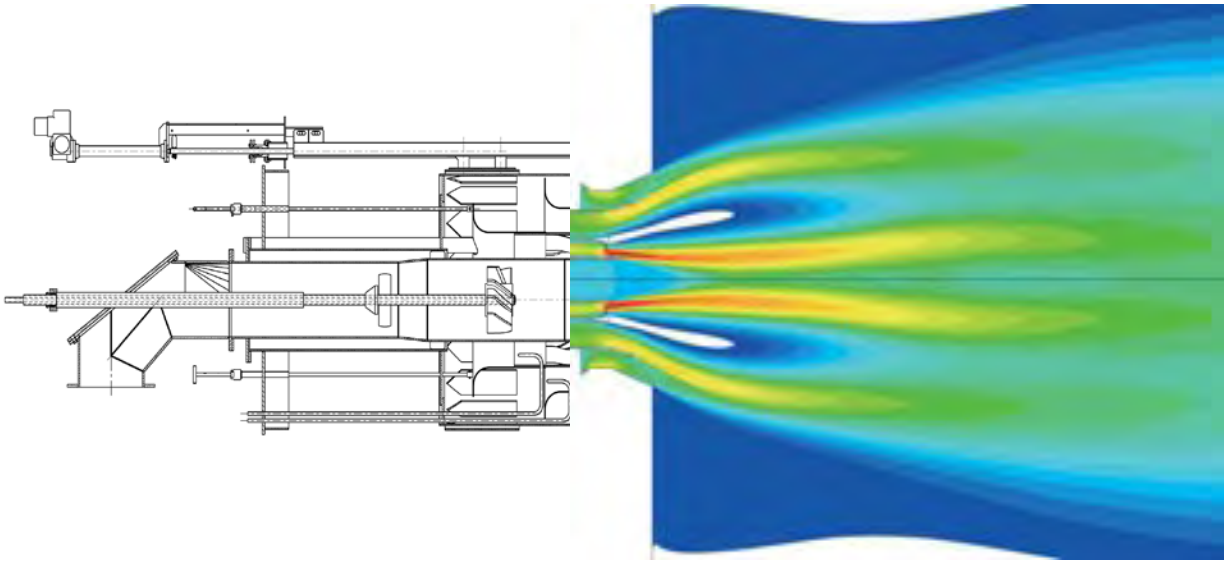
- In-house testing facilities
- Computational Fluid Dynamic (CFD) modeling
- Extensive Empirical Data With Over 1600 Burners Installed Worldwide

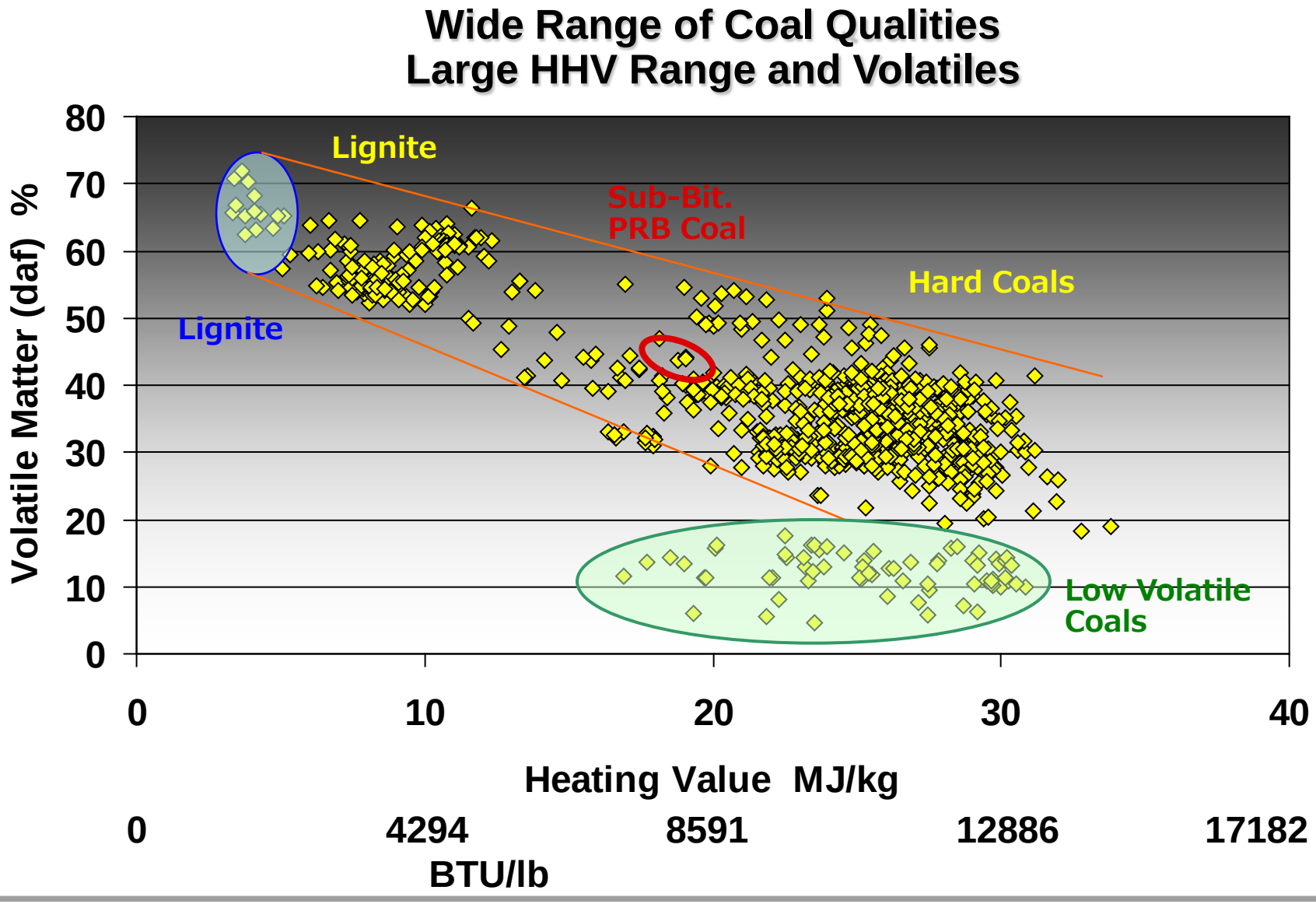
Flexibility for All Fuels including PRB, Bituminous, Lignite, and Biomass

Low-Load Operating Flexibility

Reliability

Long Cycle Life

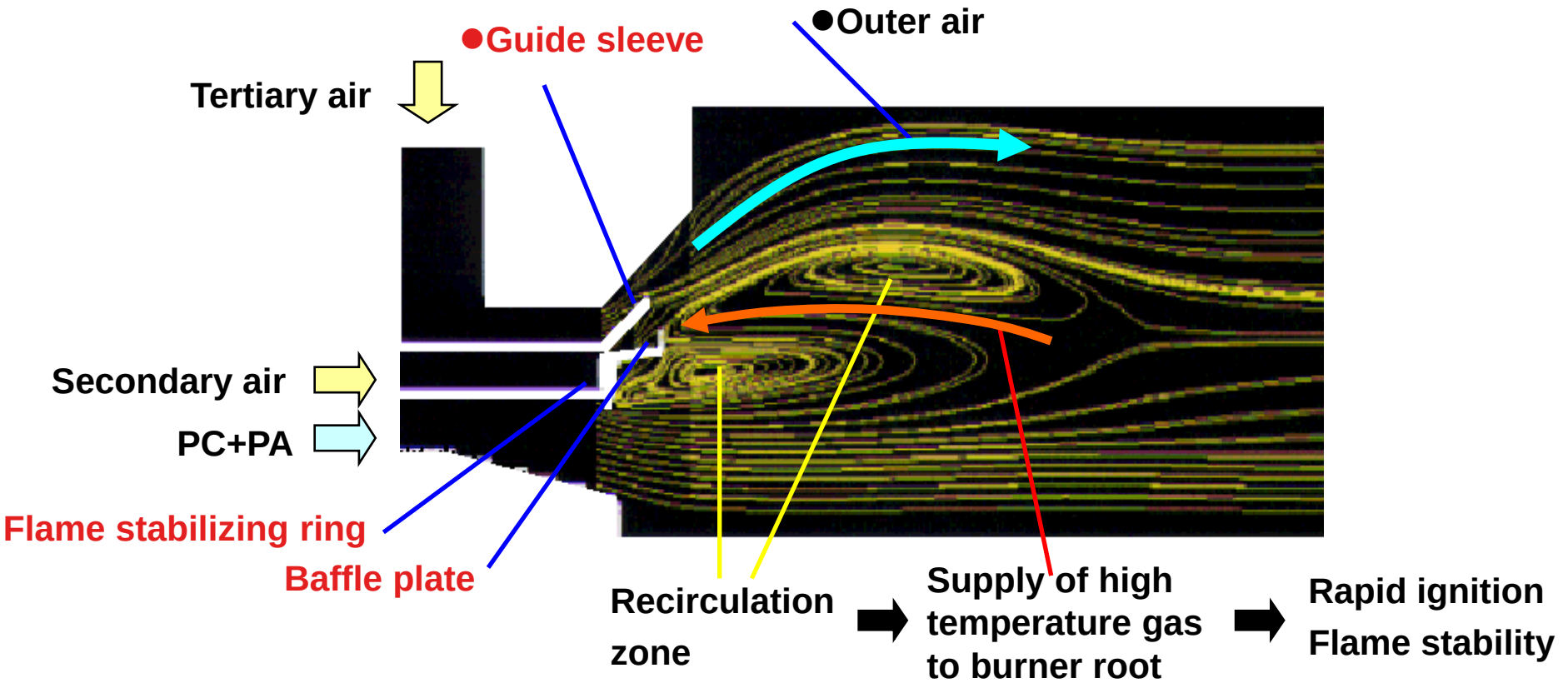



Wide Range of Coal Qualities
Large HHV Range and Volatiles
Volatile Matter (daf) %
80
70
60
50
40
30
20
10
0
Lignite
Sub-Bit.
PRB Coal
Hard Coals
Lignite
Low Volatile
Coals
0
10
20
30
40
Heating Value MJ/kg
0
4294
8591
12886
17182
BTU/lb

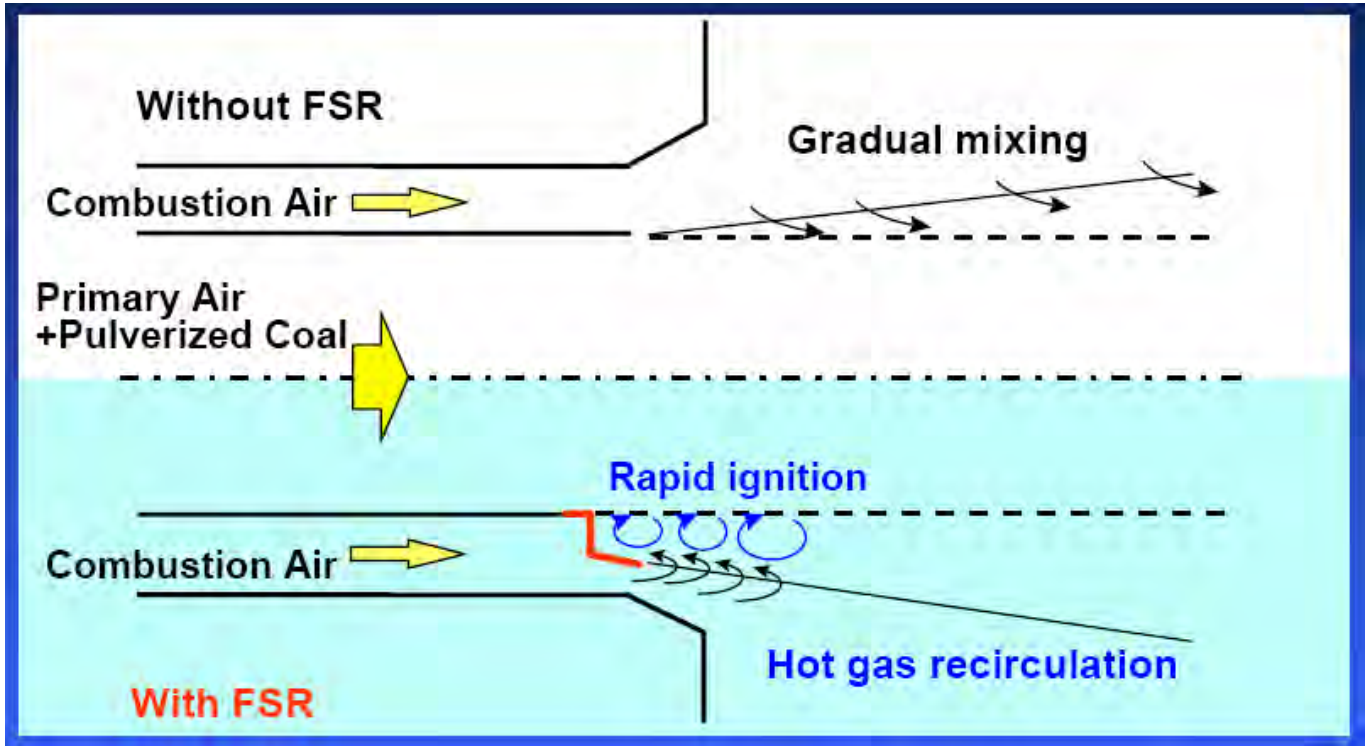
Latest Burner Design Features

- Concentric design with swirled flow streams in all burner sections (PA, SA, & TA)
- Well defined flame, excellent flame attachment and flame stability over a wide operating load range
- Easy combustion air balancing by using the adjustable sleeve dampers
- Refractory lining in the burner basket area is not required
- Low maintenance requirements as a result of
  - Advanced coal nozzle design with new material for high reliability and long service life
  - Chromium–carbide lining for wear protection
  - Minimization of internal moving parts

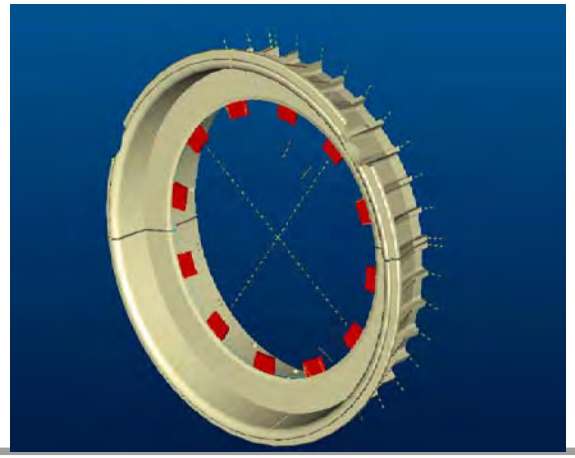
Recirculation Zone of Latest Burner



Recirculation Zone of Latest Burner

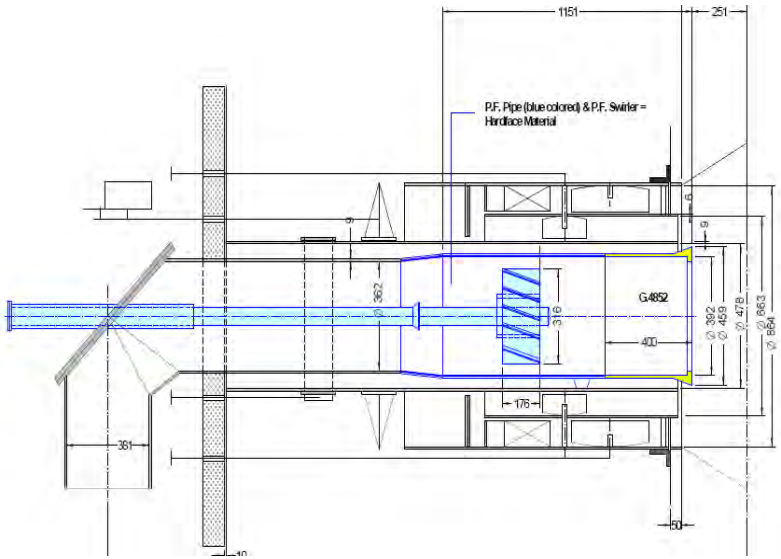


Flame Stabilizing Ring

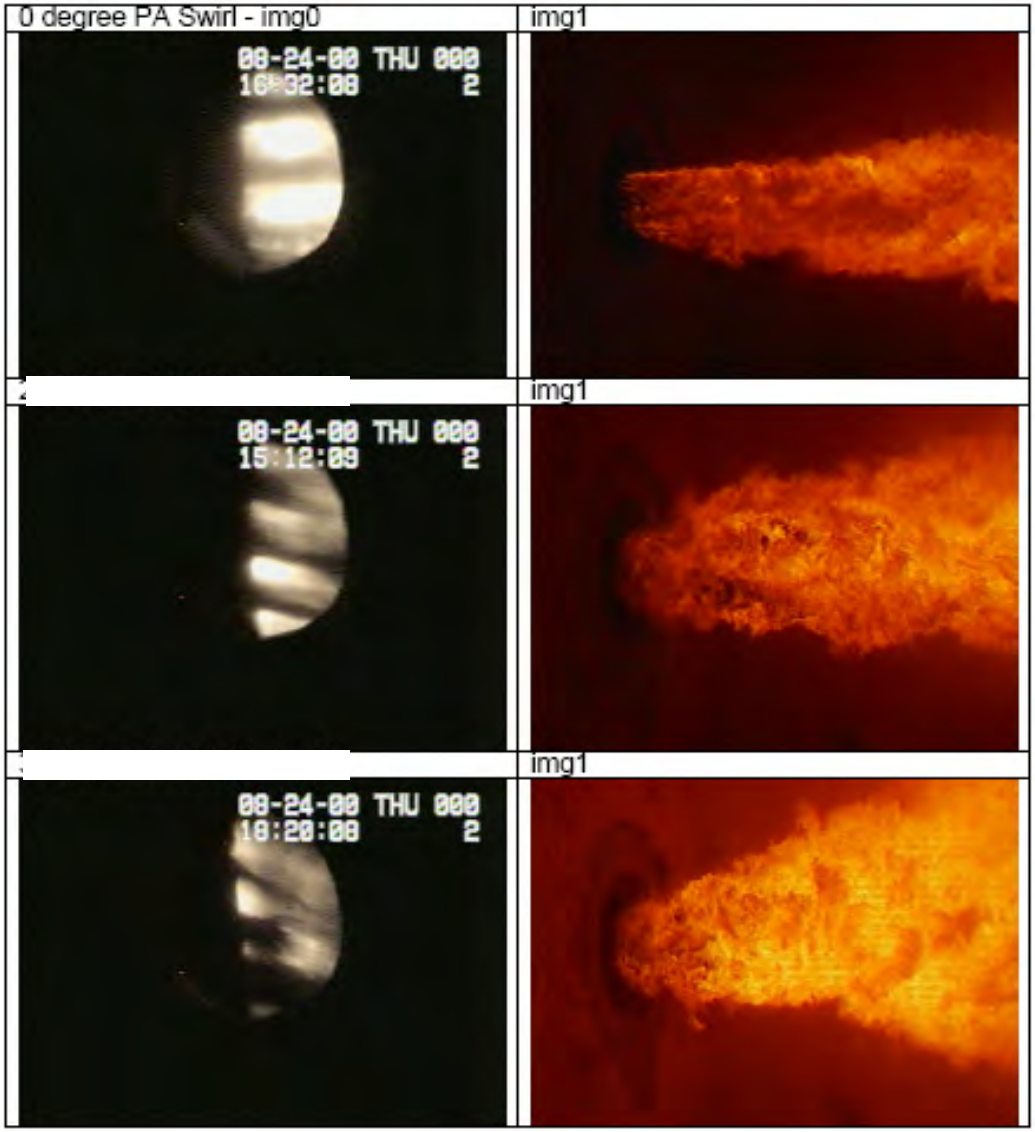


New Integrated Coal Nozzle Design

- The Coal Nozzle is Exposed to Severe Erosion and High Temperature.
- In 2004, a Centrifugal Casting Fuel Nozzle Was Developed Using a Chrome/Nickel Homogeneous Structure to Minimize the Maintenance and Increase the Performance.



Influence of PA Swirl Settings on Ignition Performance



Flame Measurement Program in the Test Furnace

Different Swirl Settings

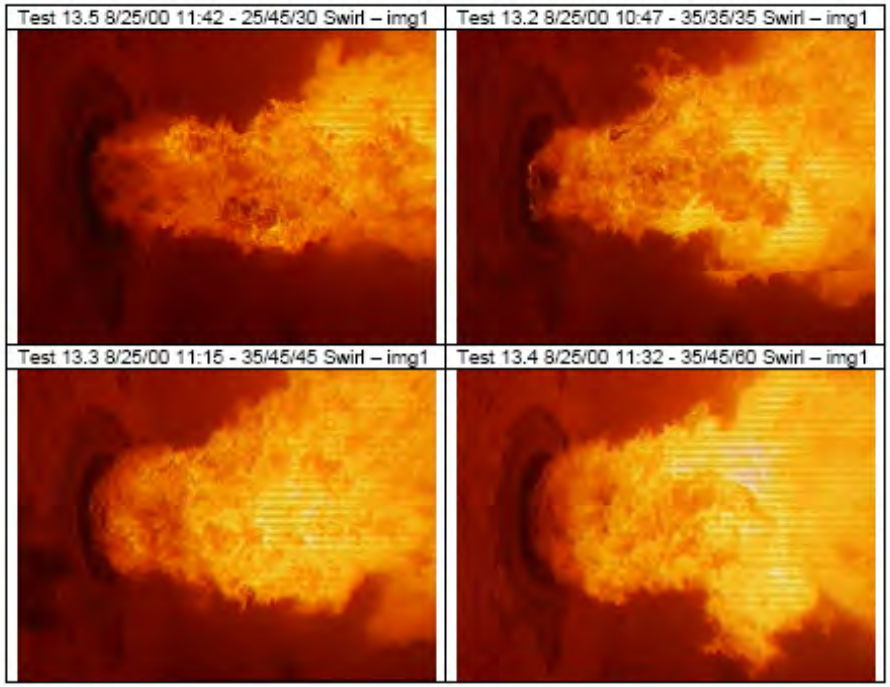


Figure 3-30 Comparison of Flame Video Images for Changes in Swirl Register Settings
During DS Burner Tests with Flame Stabilizer Ring No. 2.1 (21 mm step, 9.6 mm teeth-20)

Different Burner Capacities

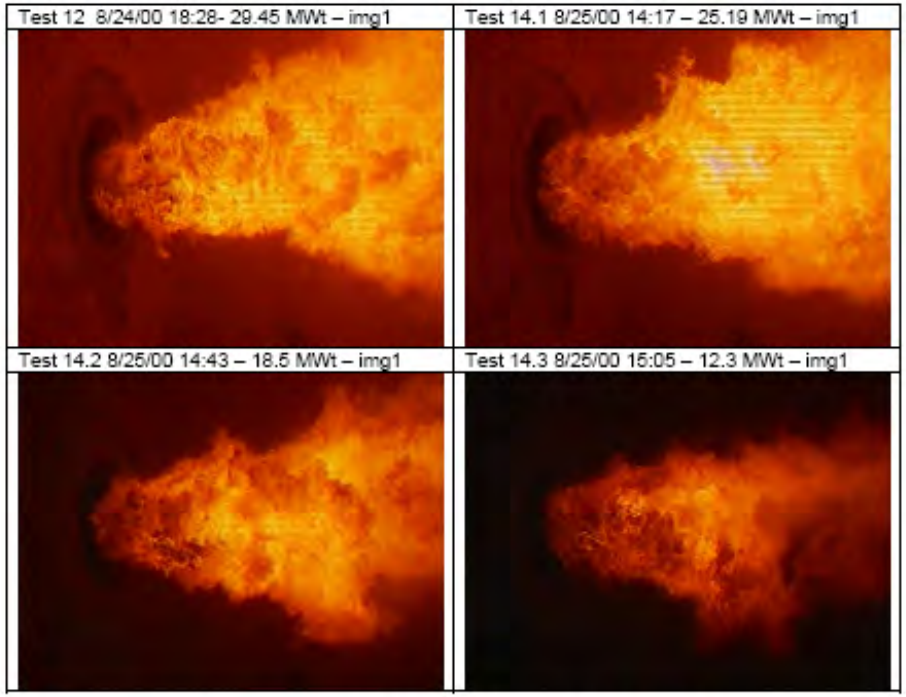
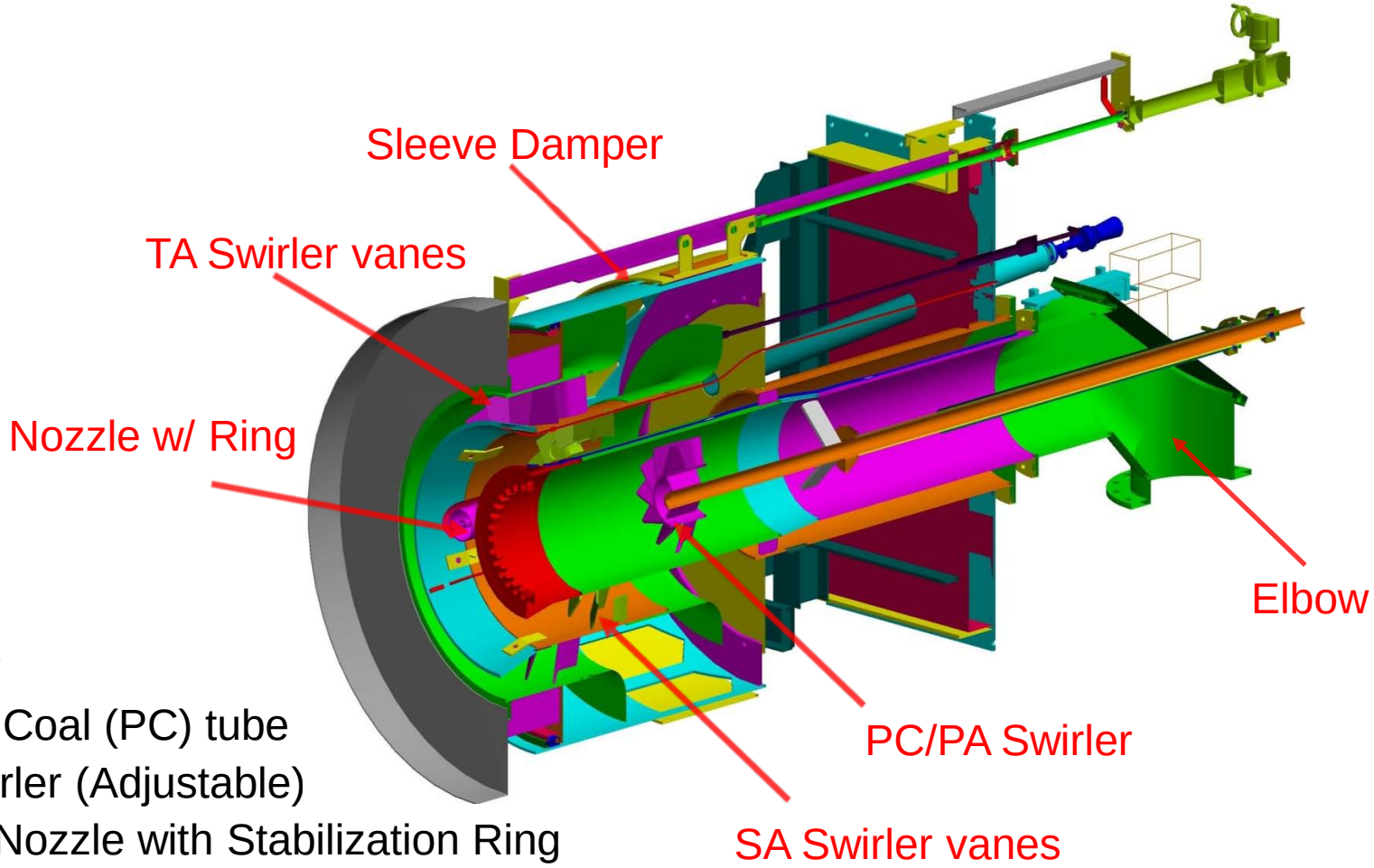


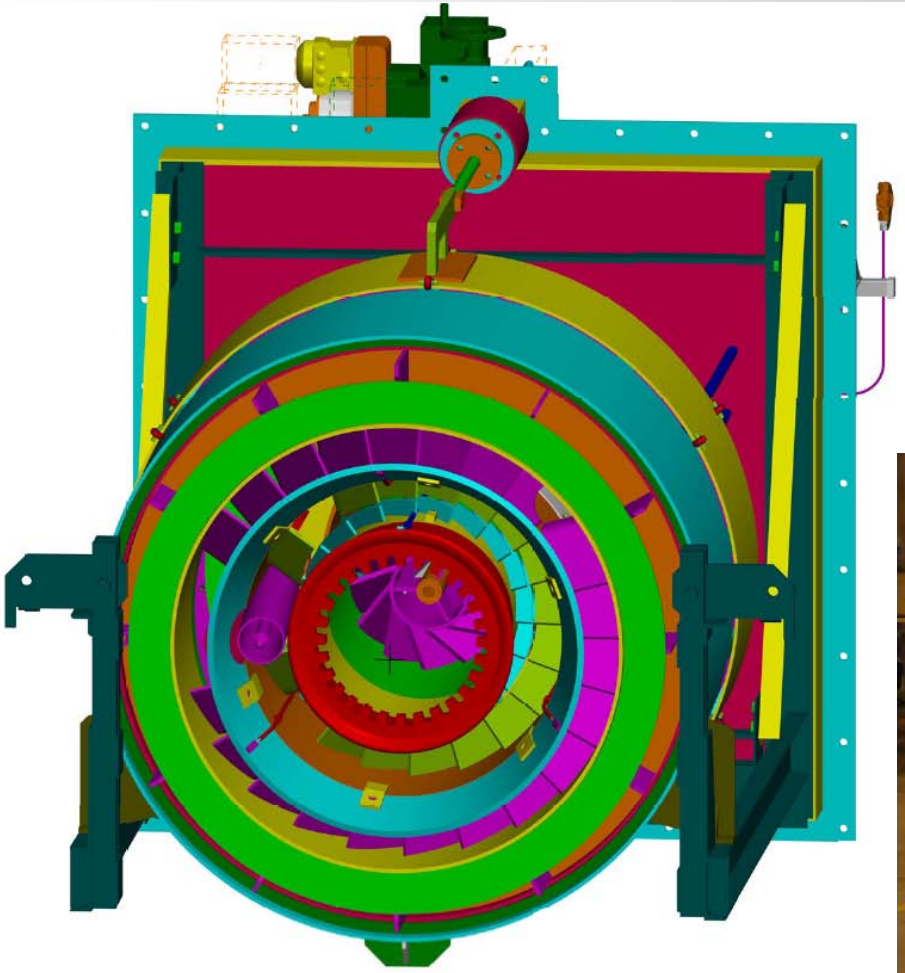
Figure 3-31 Comparison of Flame Video Images for Changes in Load
During DS Burner Tests with Flame Stabilizer Ring No. 2.1 (21 mm step, 9.6 mm teeth-20)

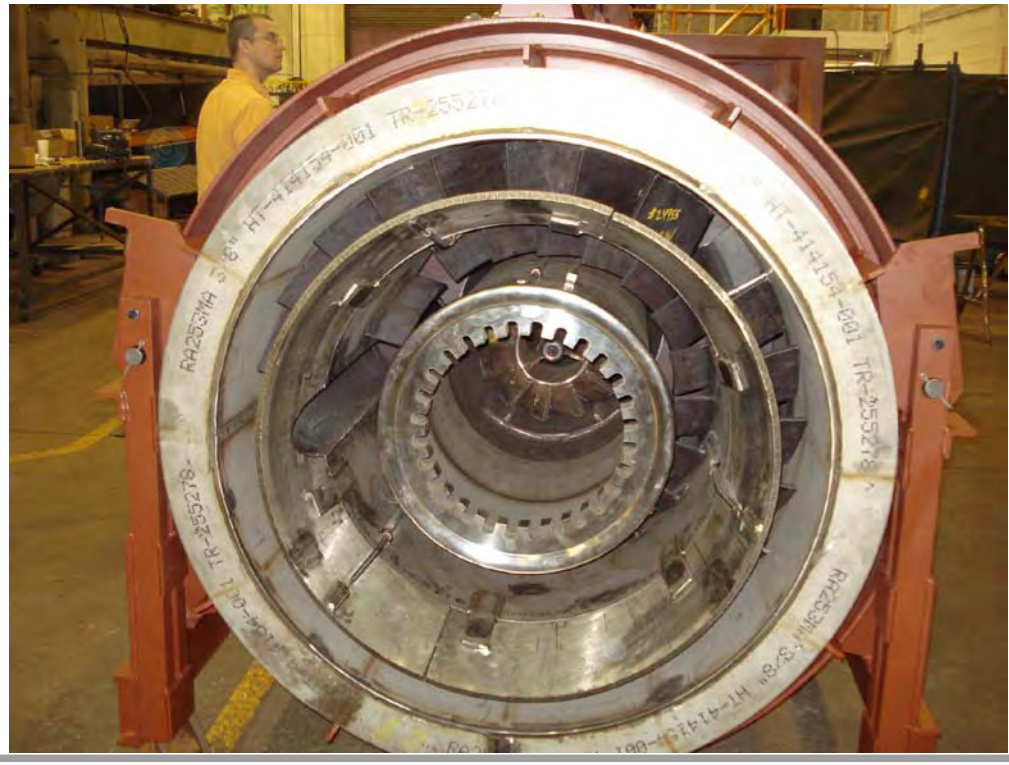
Latest Burner Components



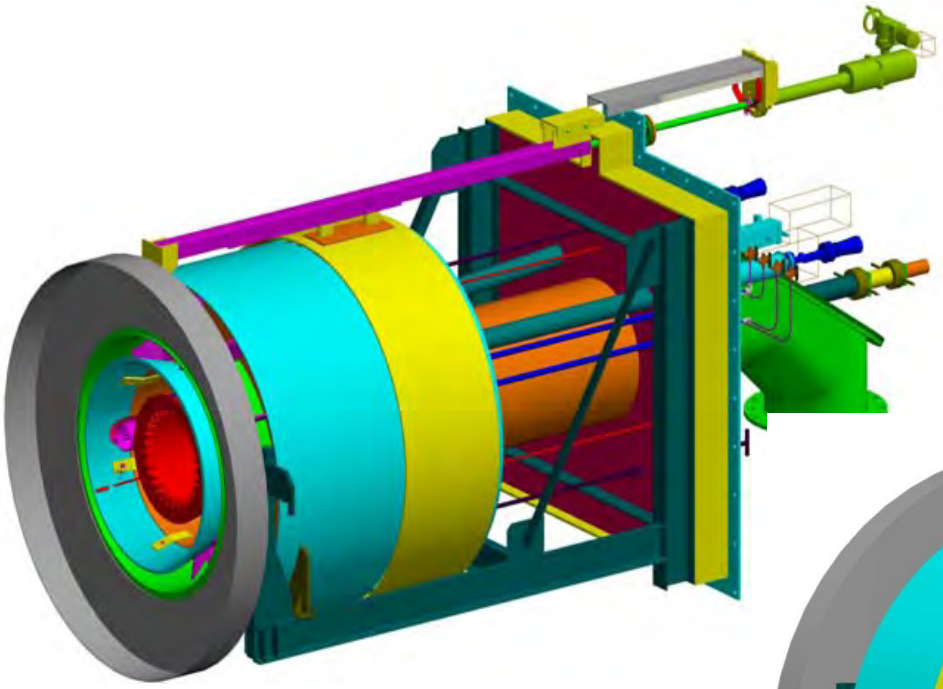
1. Inlet Elbow
2. Pulverized Coal (PC) tube
3. PC/PA Swirler (Adjustable)
4. Advanced Nozzle with Stabilization Ring
5. Secondary Air (SA) Swirler vanes
6. Tertiary Air (TA) Swirler vanes and Diverter (Adjustable)
7. Sleeve Damper (Adjustable)

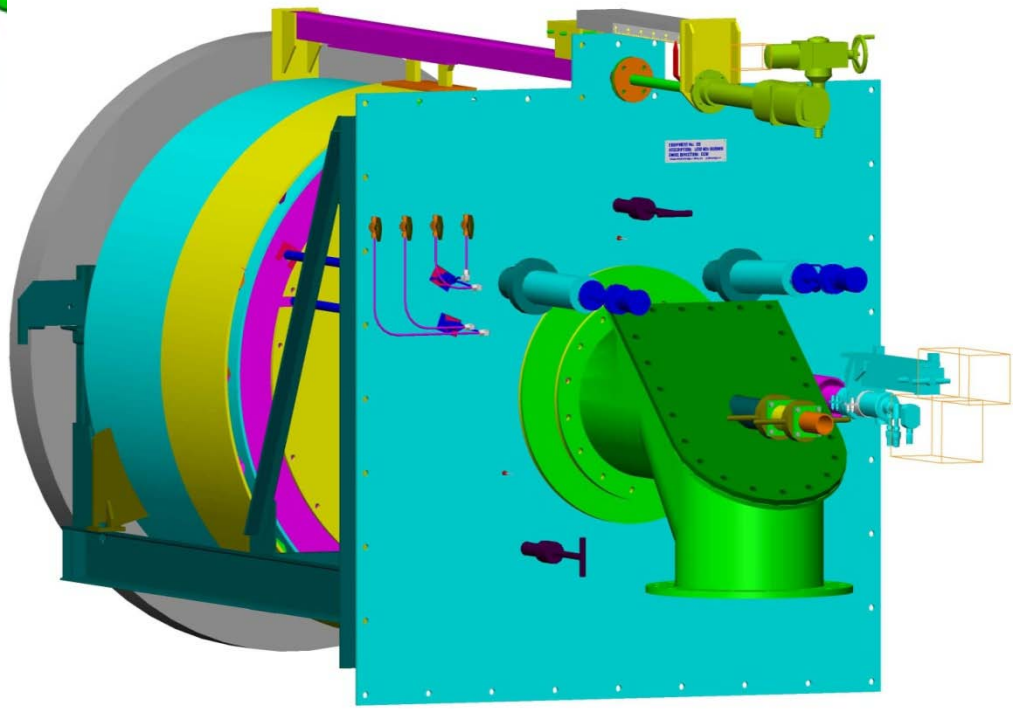
Burner Components





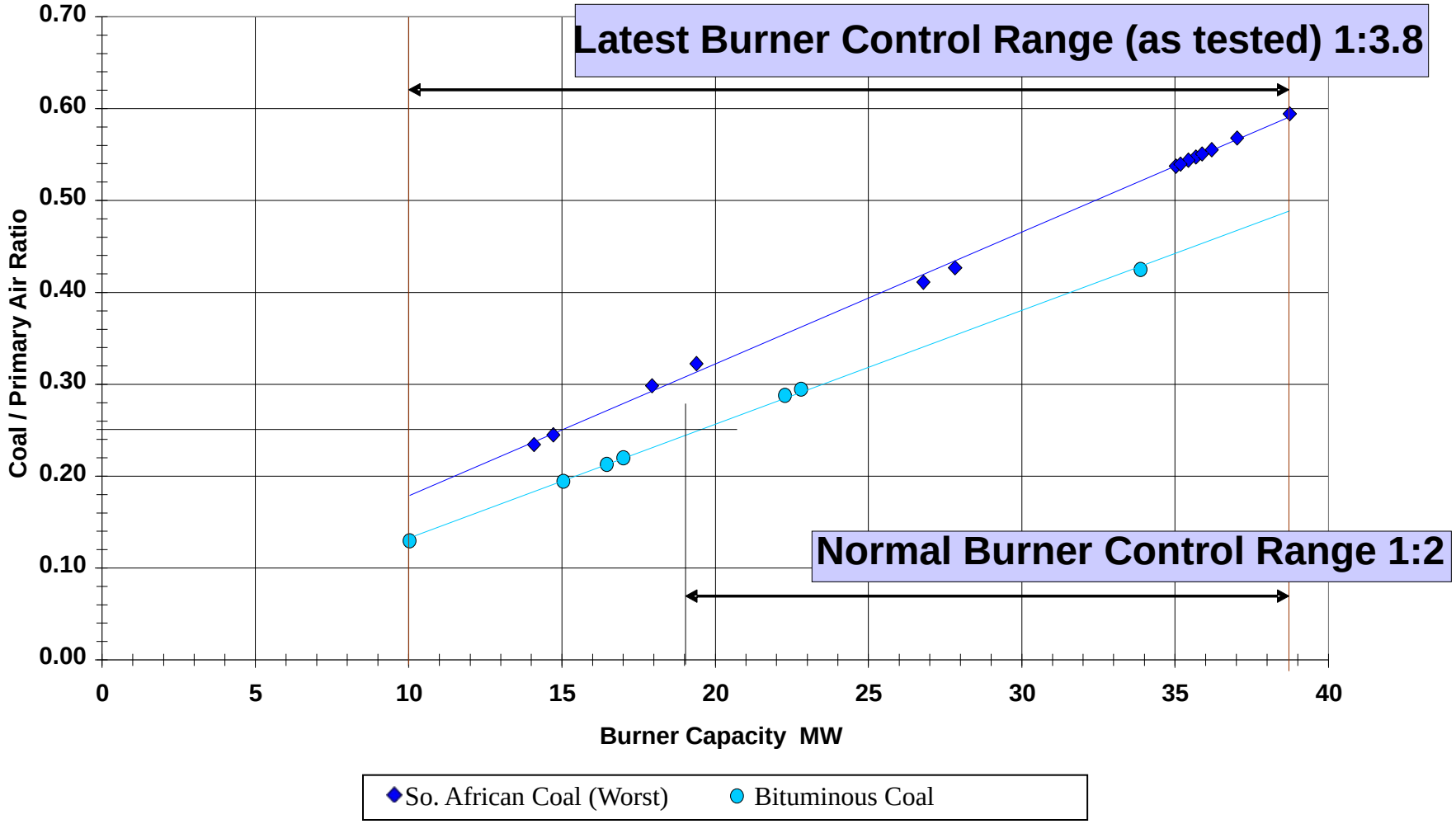
Latest Coal Burner Model





Load Operating Flexibility

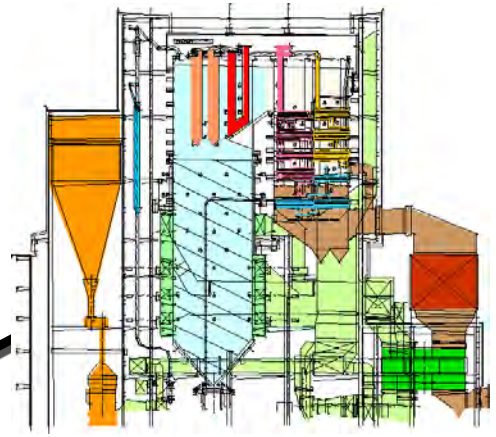
Latest Burner Control Range

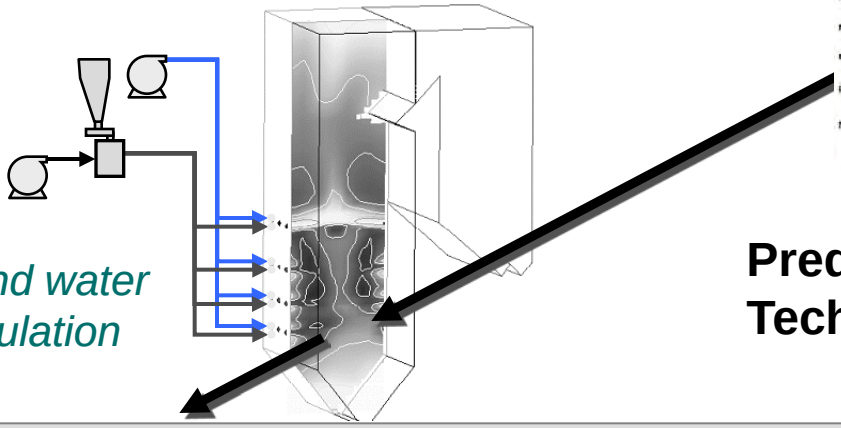


Unique CFD Model - CRAFT Simulation

Original Simulation Models

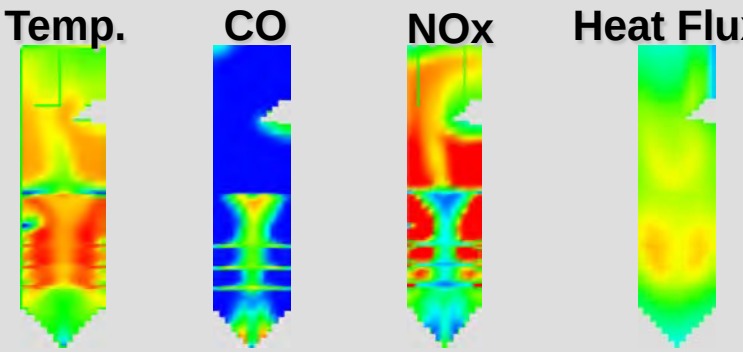
1. Char gasification model
2. Hydrocarbon NOx reduction model
3. Multi-grid discrete transfer radiation model





- ***C**ombustion,*
- ***RA**diation and water **F**low simulation*
- ***T**ool*

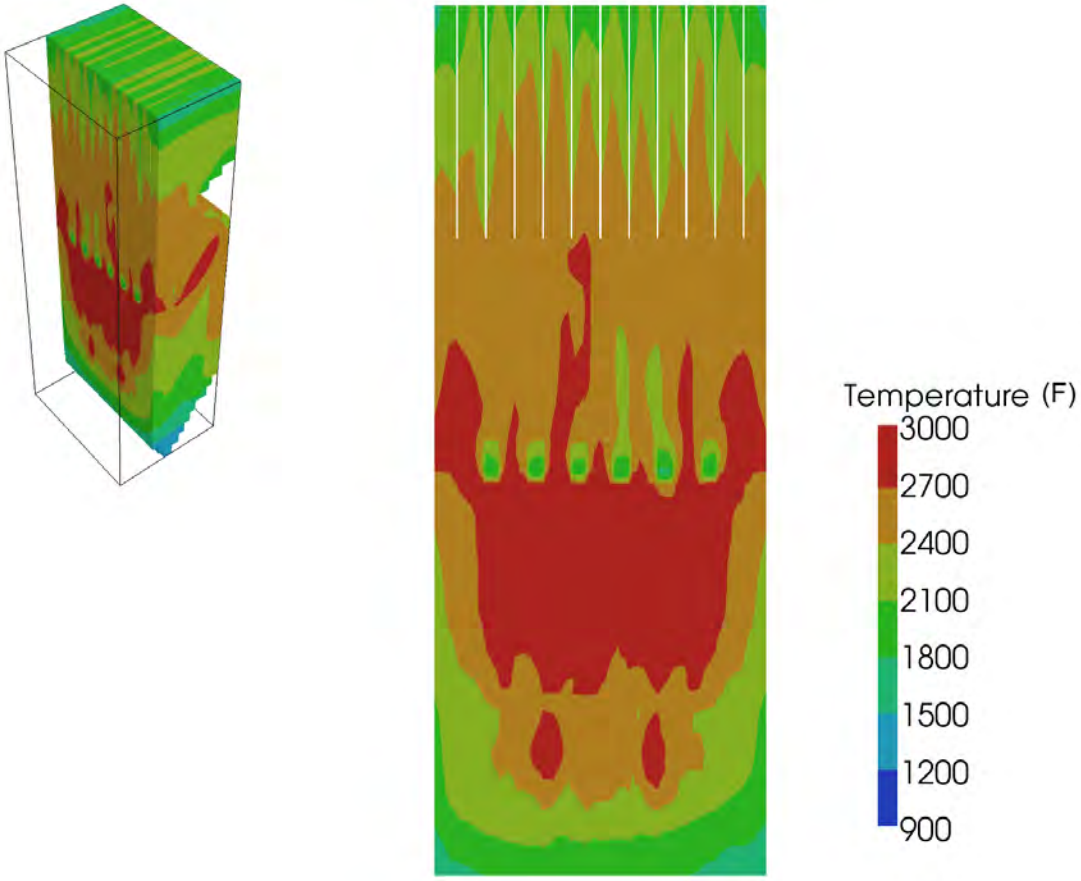
Predicted Performance Lead to Technical Solutions



- **- VOC emission**
- **- Unburned carbon**
- **- Burner blowing off**
- **- Furnace exit gas temperature**
- **- Slagging**
- **- H_2S and SO_2 corrosion**

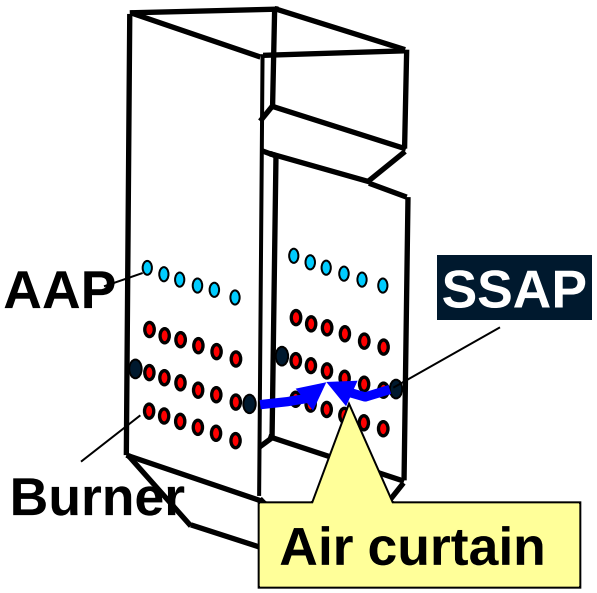
Furnace Temperature Model – Cross Section

Cross-section through the middle of platen superheater

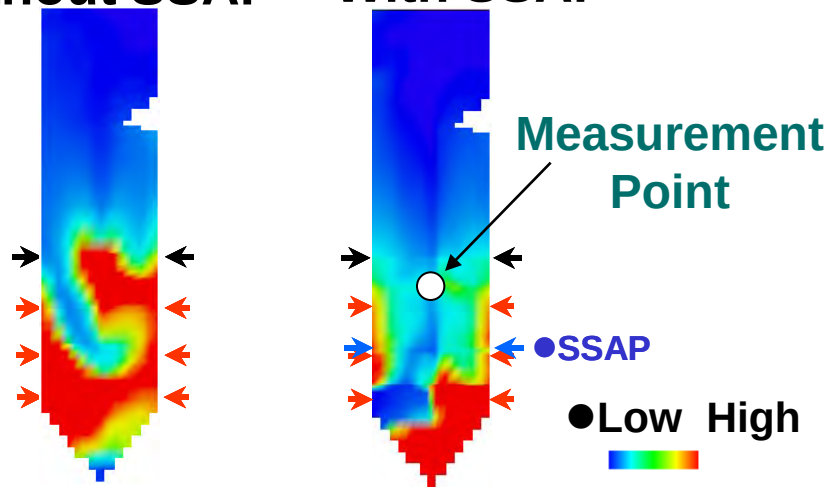


Eastern Bituminous Coal – with OFA

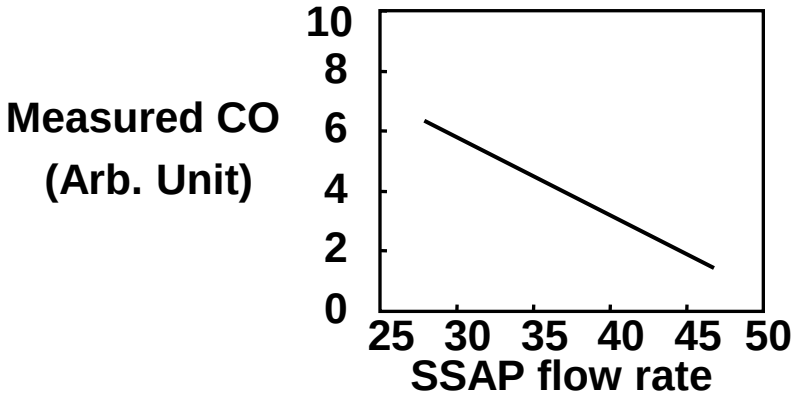
Side Stream Air Port (SSAP)



- Prediction of CO Concentration



- Validation Results



Plant Name: Hitachinaka #1

Unit Output: 1000 MW

Load: 100%

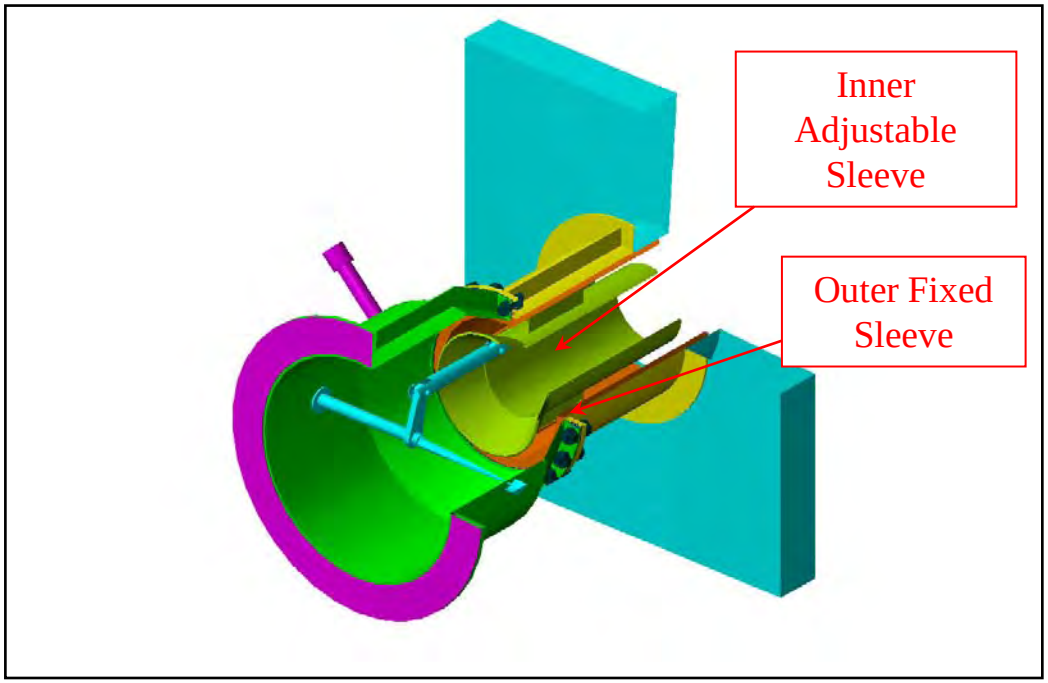
Coal : Rio Tinto (hv bituminous)

Over Fire Air (OFA) System

Double Nozzle Design - A Sleeve Within a Sleeve

The inner sleeve is adjustable and can manually be moved into or away from the furnace. This serves to bias air flow between the inner adjustable sleeve and the annulus formed with the outer fixed sleeve.

This design can also be used to bias more air flow to the outer OFAs, to protect the furnace sidewalls against the formation of a reducing atmospheric condition.



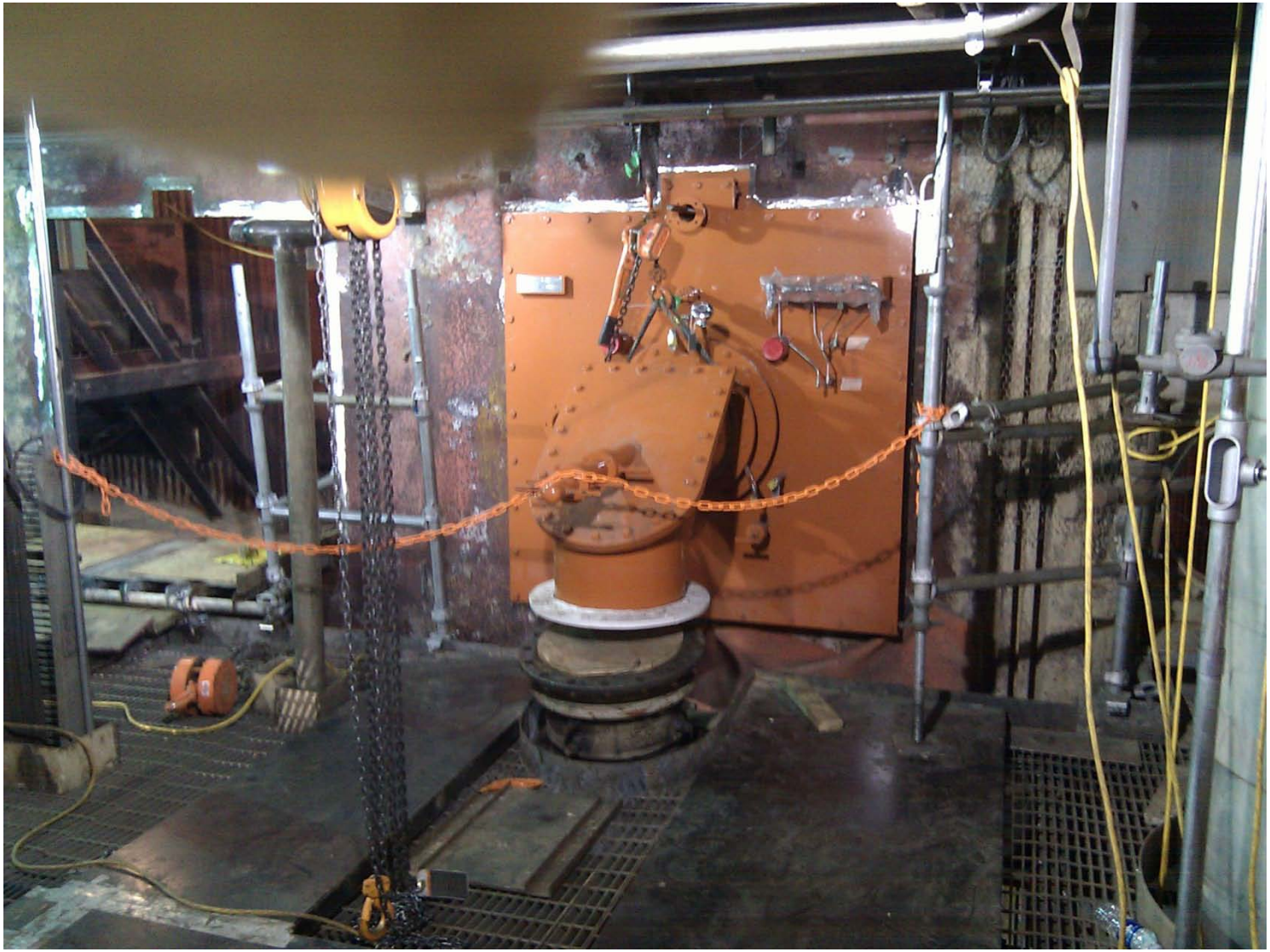
- Evolution of LNB Technology
- Latest Burner Design
- **Burner Retrofit Experience**
- Summary

Latest Burner – Ready to Ship

Retrofit Burner Opening – Windbox Side

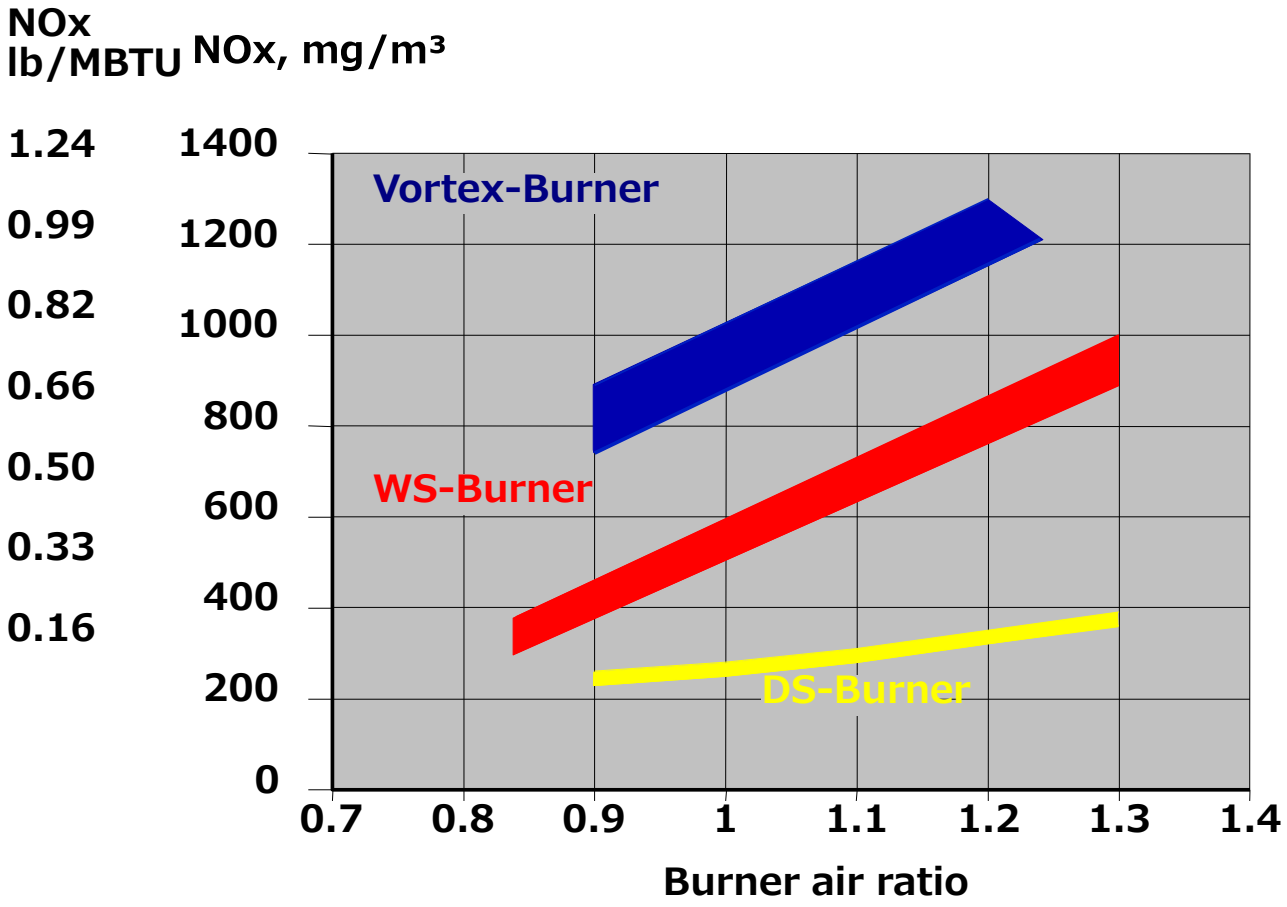
Retrofit Coal Burner – Furnace Side

Retrofit Coal Burner Installation



Weld Overlay at PC Tube Transition

Burner Development, NOx Emission



Burner and OFA Design Evaluation Summary

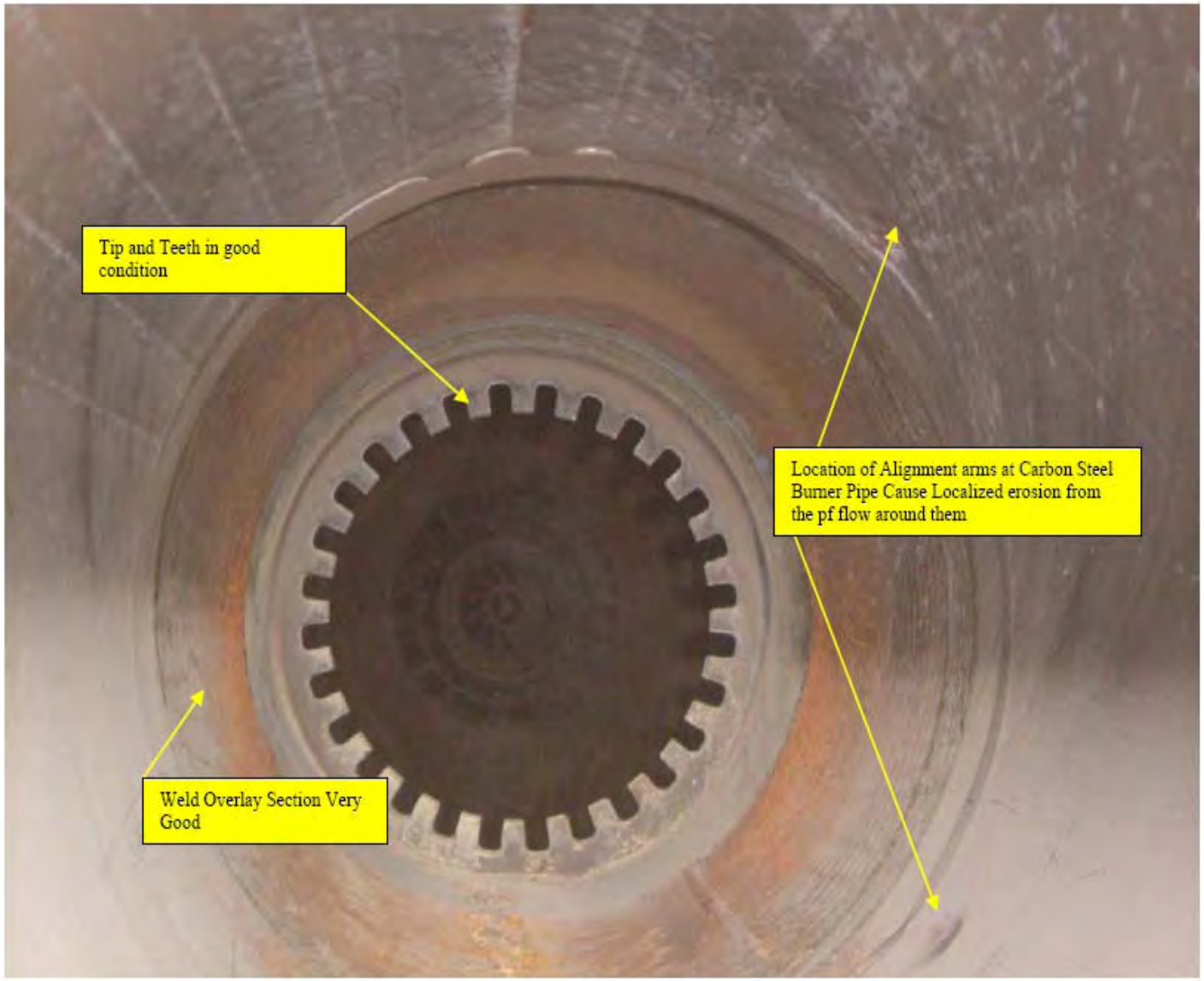
- Use the Existing Furnace Opening for New Coal Burners
- Verify Pulverizer Performance such as A/C Ratio, Product Fineness, etc.
- Design Burners to Match Pulverizer Operating Conditions, such as A/C Ratio
- Furnace Heat Input/Plan Area Evaluation
- CFD Furnace Model to Predict Emissions & FEGT
- Determine OFA Port Location to Optimize Combustion

Results: All Design Parameters Achieved

Low Maintenance and Longer Service Life

Inspection After 2-year Operation

Inspection After 2-year Operation



Inspection After 5-year Operation

Furnace Side

Windbox Side

Summary

- Optimum NOx Reduction
- High Combustion Efficiency (Low LOI and CO)
- Maximum Fuel Flexibility
- Maximum Operating Flexibility (High Turndown Ratio)
- Low Maintenance and Longer Service Life