Extended Low Load Boiler Operation to Improve Performance and Economics of an Existing Coal Fired Power Plant

Robert Murphy

NATIONAL ENERGY TECHNOLOGY LABORATORY

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Disclaimer

Agenda

Introduction

Plant Low Load Dynamic Simulation Study

Low Load Pulverizer Tests

Low Load Combustion Tests

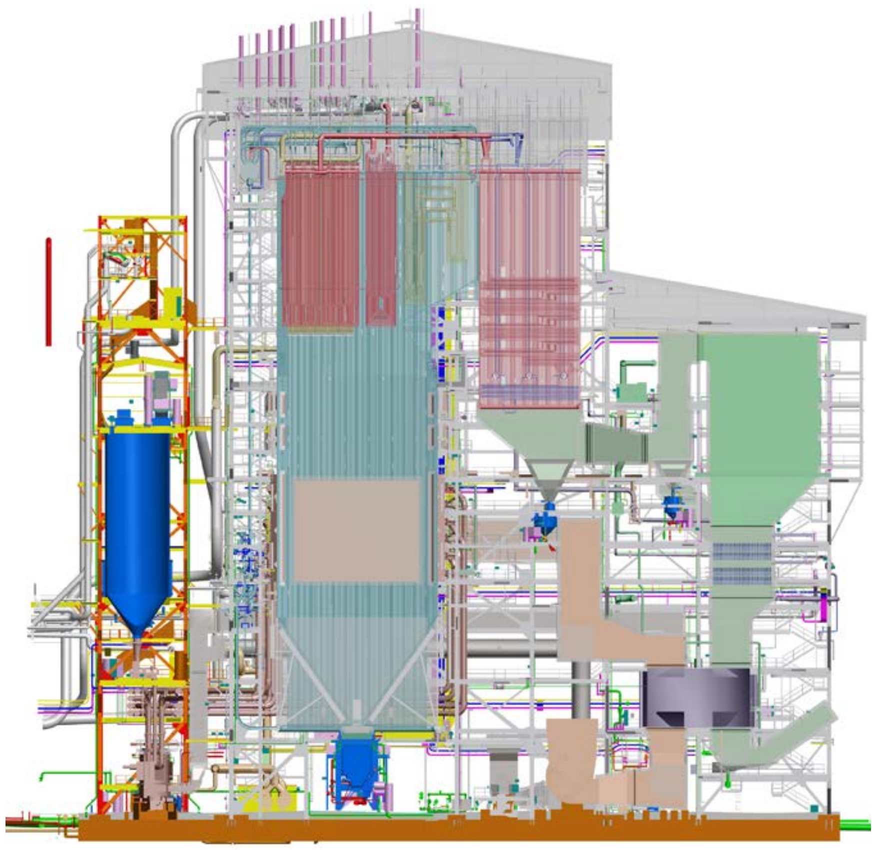
Phase II Discussion

Wrap Up

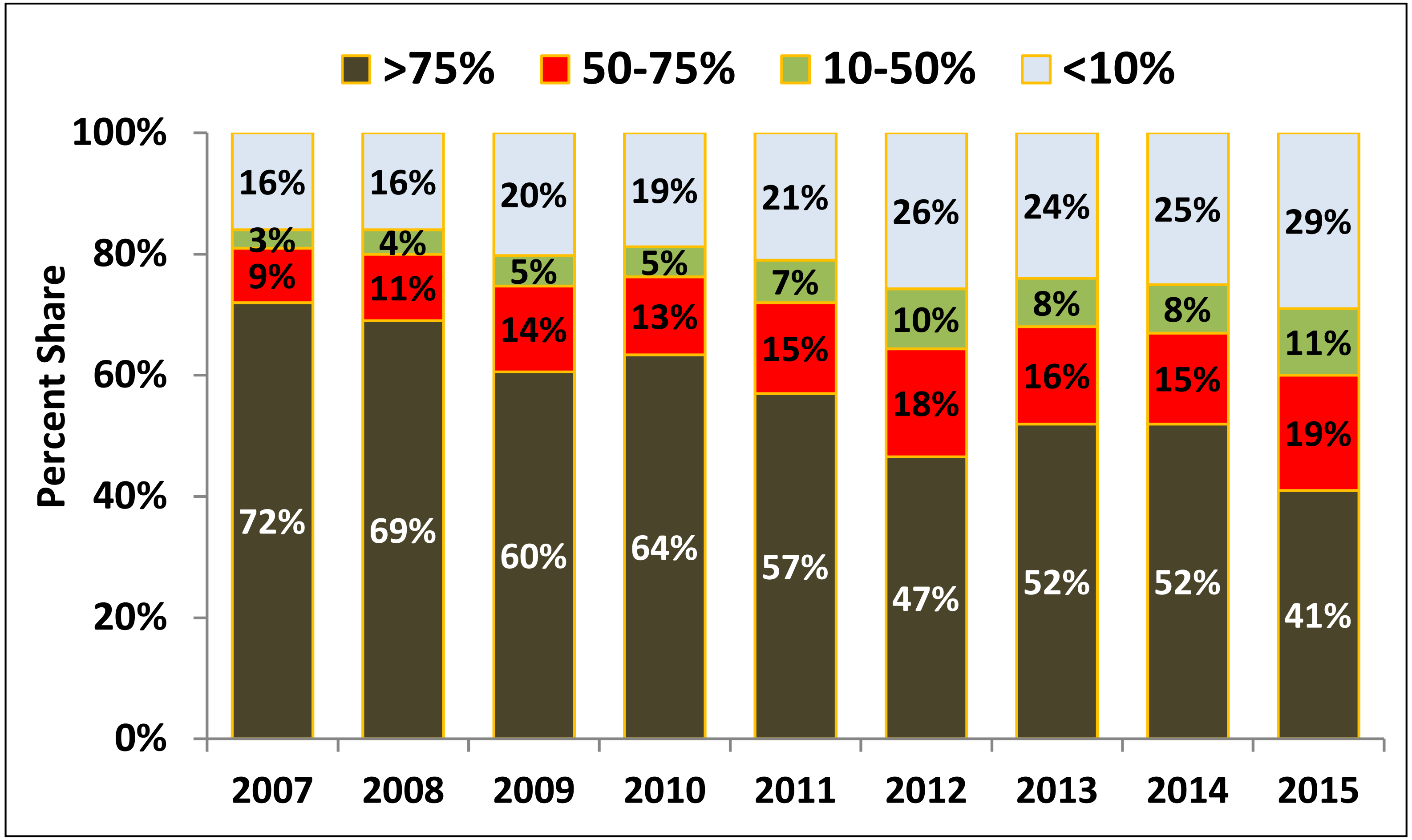
Low Load Boiler Operation
Introduction - Technical Background

- Increasing load from renewables, low natural gas price, and a flat load demand has caused many base load coal plants to become cycling plants.

- Dispatching of fossil-fueled power plants has changed to require increased flexibly.
  - More unit starts
  - Higher ramp rates
  - Increased layup status
  - Lower minimum loads



U.S. Coal Fleet
% hours within operating bands



Source: ABB/Ventyx

Low Load Boiler Operation Technical Background

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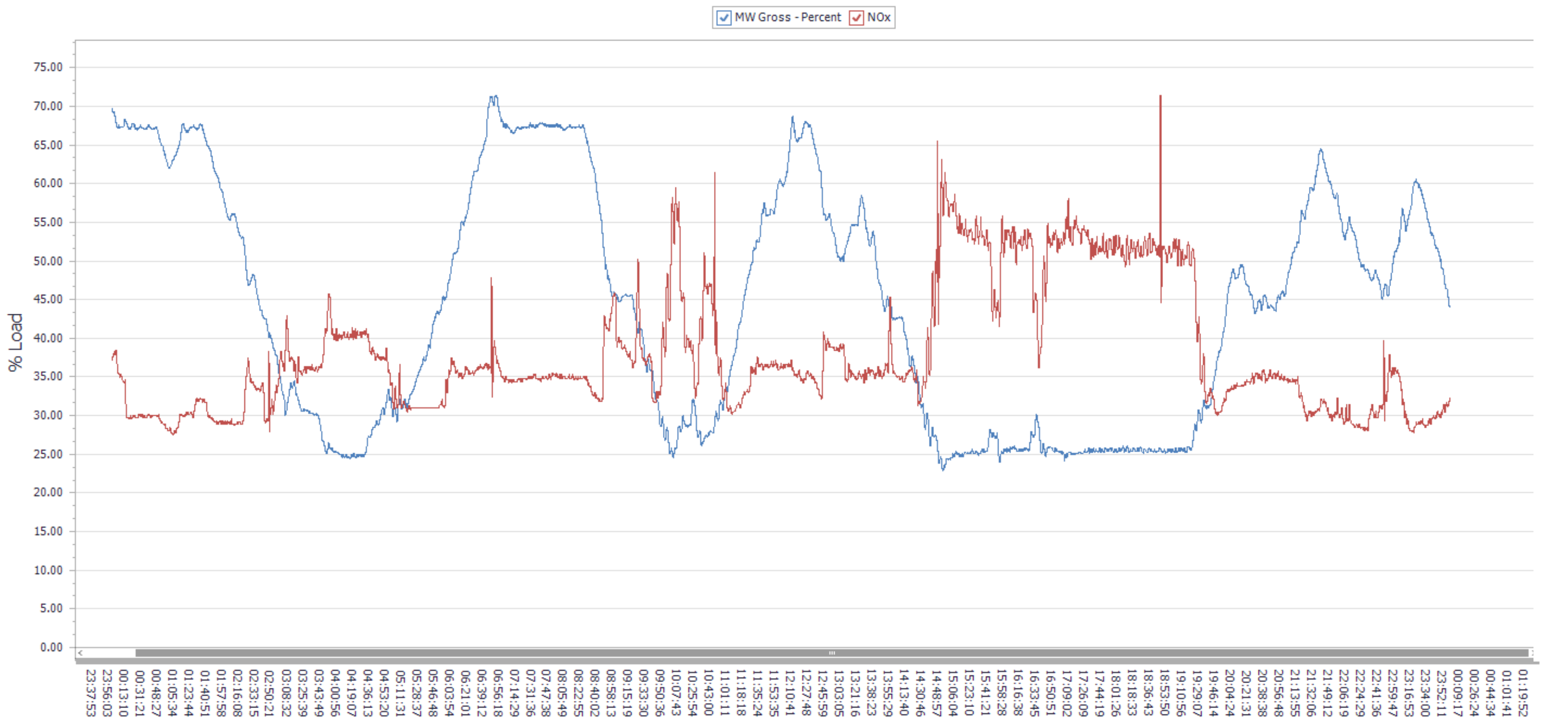
- 57% of units surveyed have been able to lower load below 35%
- Average minimum load reported was 40% for coal units (33% for all fossil)
- Minimum load appears to have no correlation with unit size
- Constraint on low load was often environmental or boiler design

Example Daily Load Demand



Ten (10) challenge areas identified

1. Steam Pressure and Temperature
2. Level Measurement and Control
3. Flow Control
4. Feedwater Chemistry
5. Boiler Water Chemistry
6. Chemistry Sampling
7. Combustion Control
8. Plant Controller & Instrumentation
9. Air Emissions
10. Component Condition Monitoring

Low Load Boiler Operation Technical Background

- Definition - Low Load :

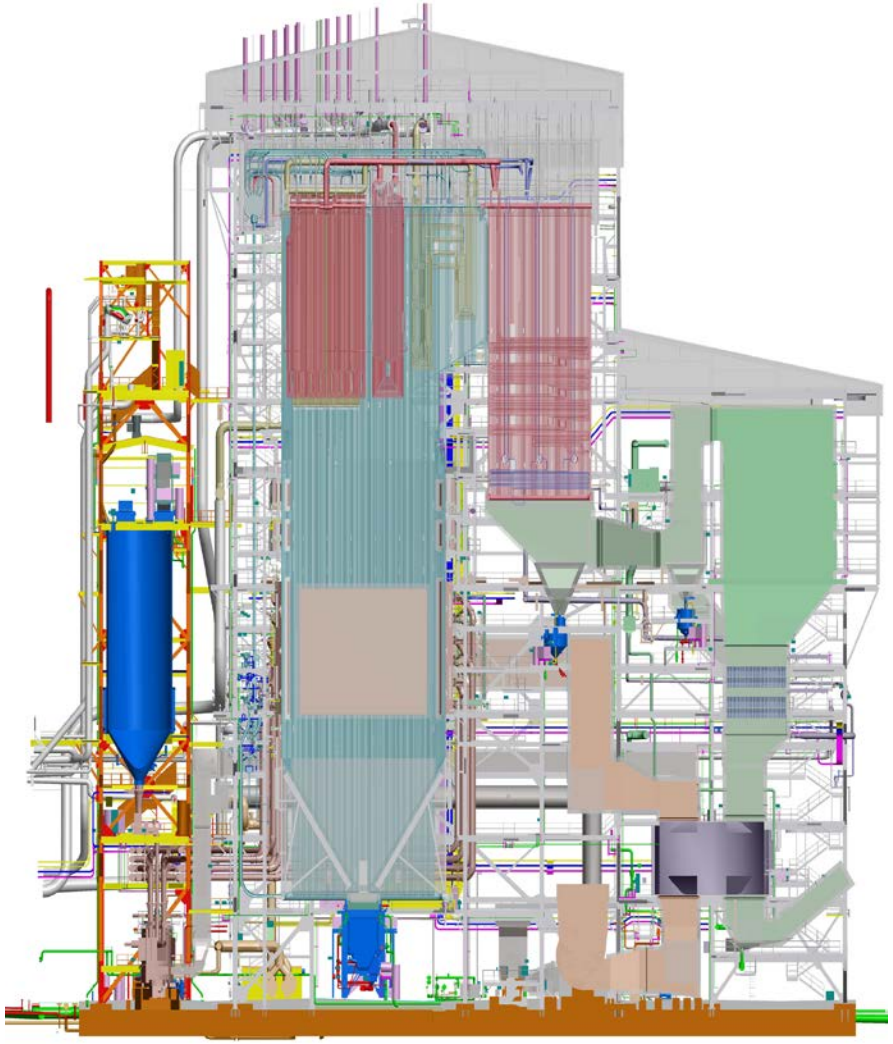
The minimum output level achievable without requiring support fuel and without compromising safety, reliability, emissions, or equipment.

Focus Areas:

Pulverizer, Main Burner Zone, Steam and Gas temperature control

Constraints:

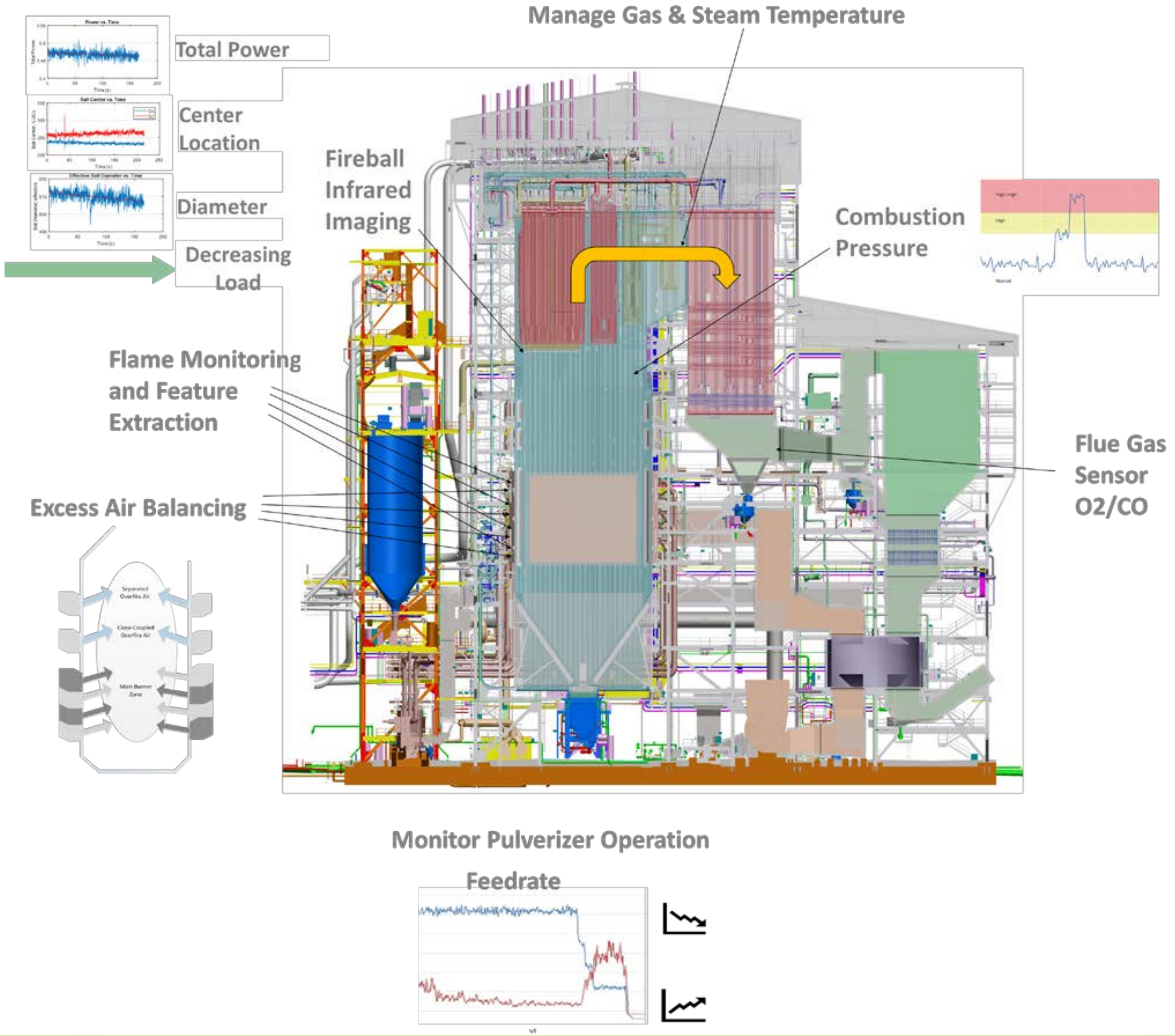
Minimal capital cost solutions



Low Load Boiler Operation
Statement of Objectives

- Identify control methods for steam and gas temperature regulation at low load
- Investigate Sensors and Analytics for monitoring pulverizer operation at lower loads to maintain/optimize coal distribution, mill outlet temperature, and fineness.
- Investigate flame monitoring techniques that quantify local and global flame stability. Classify burner to burner fuel-air balance to compensate with fuel or air distribution biases.
- Develop conceptual design of new sensors and algorithms required for full scale low load field test.

Low Load Boiler Operation
Plan View



Agenda for Project Presentation

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Dynamic Simulations on Low Load

Overall Objectives

- To explore the use of GE existing dynamic models for low load operation studies
- To identify the opportunities for optimizing boiler and plant operating flexibility performance for low load and wide range operations
- To identify the current constraints in low load operations
- To recommend further investigation on modeling and simulation studies to further improve plant low load operating performance – safety, reliability, efficiency and emissions

Low Load Thermal Performance Calculations

Information of Reference Unit

- 100% TMCR: 660 MW
- BMCR = 103% TMCR
- Mains Steam Capacity: 537.99/Kg/s
- SHOP(Superheater Outlet Pressure: 289 bara
- SHOT (Superheater Outlet Temperature): 603 Deg C
- RHOT (Reheat Outlet Temperature): 612 Deg C
- FW (Feedwater) inlet Temperature: 309.8 Deg C
- Steam Turbine and Generator
- SWFGD (Seawater Flue Gas De-suphurization)
- SCR (Selective Catalytic Reactor)
- ESP (Electric Precipitator)

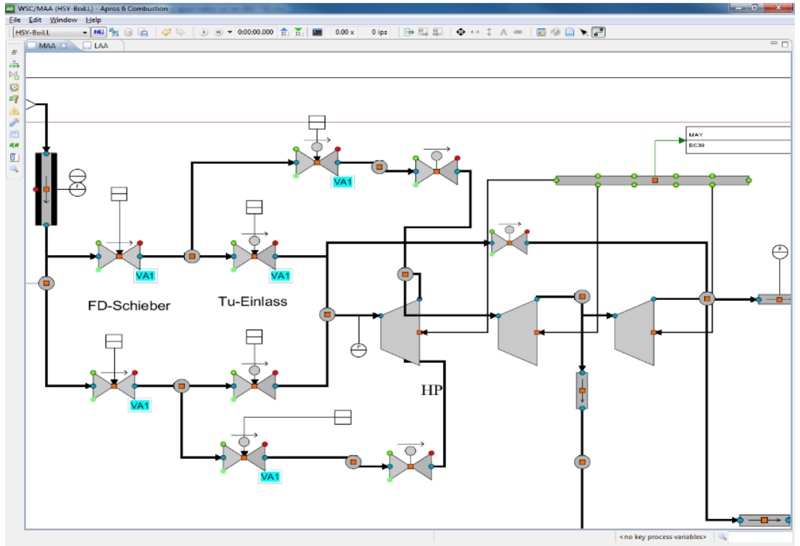
- **Fuel Analysis (% by Weight)**

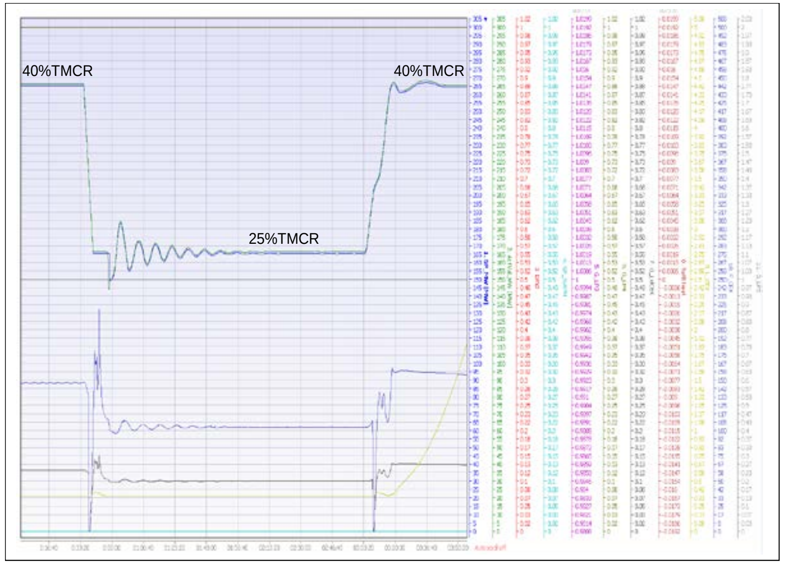
Carbon	62.76	
Hydrogen	3.41	
Nitrogen	1.59	
Oxygen	7.41	
Sulfur	0.53	
Ash	14.80	
Moisture	9.5	
Volatile Matter (VM)	23.30	
Sum of Constitutes	***100***	***%***

- High Heat Value (HHV as fired): 10796.0 BTU/LB

Plant Modeling for Low Load

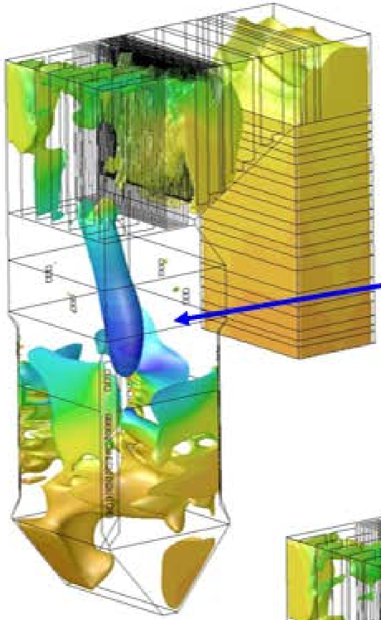
- The boiler model calibrated for low load (25%TMCR) was integrated with the plant cycle model with support from GE's Plants business unit
- The plant level model was calibrated using the plant cycle thermal balance calculation data for 25%TMCR
- The control loops were tuned for running load change simulations
- The unit control system is to be refined for better load ramp simulations between low load (25-30%TMCR and higher load levels (40-50%TMCR)



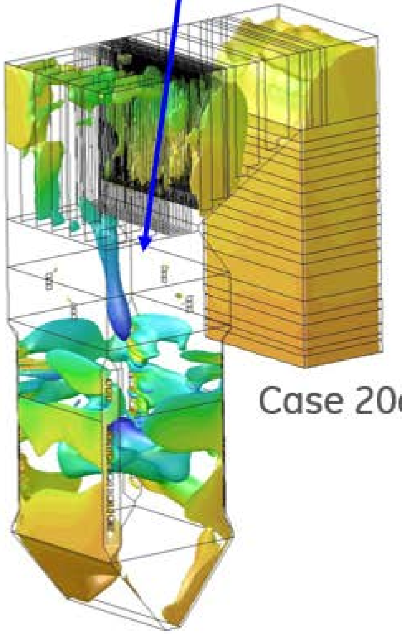


CFD Low-Load Simulation

Two highest coal elevations in service
Case 1j: 25% TMCR

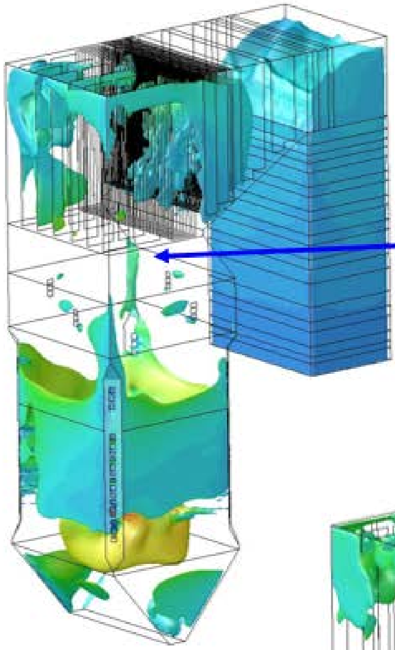


Large reverse flow zones that penetrate the HFOP

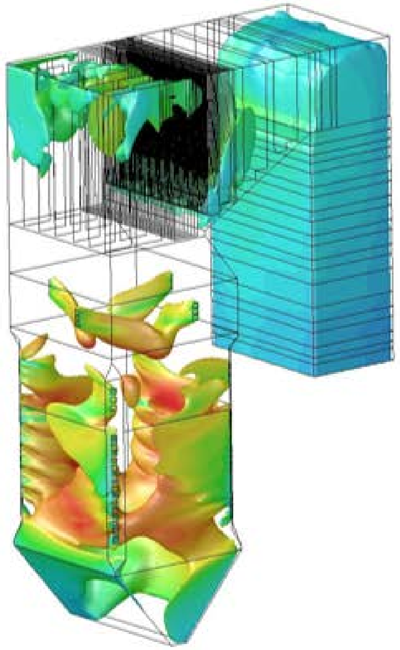


Case 20d: 35% BMCR

Two lowest coal elevations in service
Case 5a: 25% TMCR



Reverse flow zone at HFOP almost appears



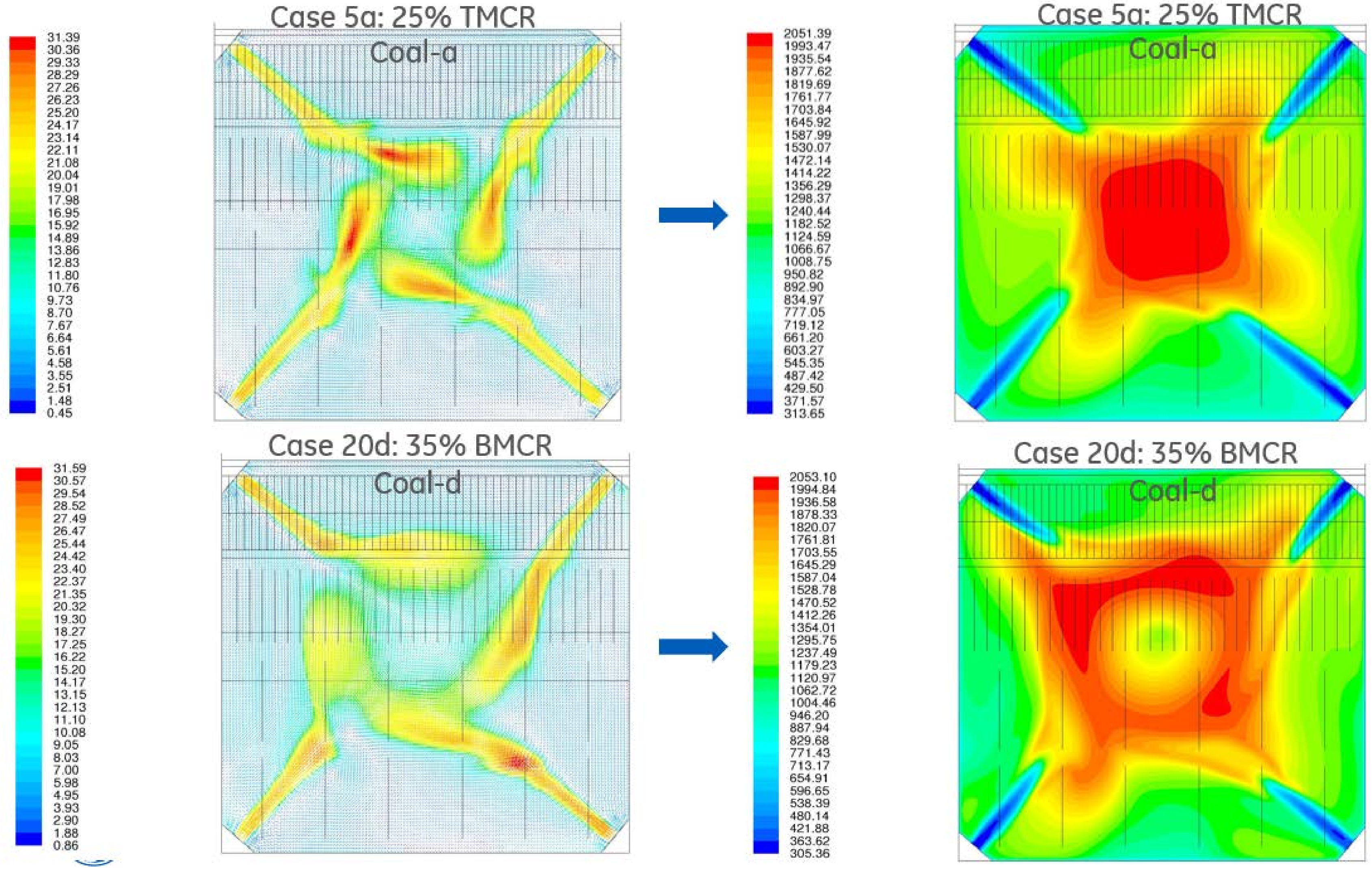
Hassyan Case 40a: BMCR, Perf Coal, Top 4 (of 5)

Iso-surface corresponding to vertical velocity = -1 m/s

CFD Low-Load Simulation

- **Jet Penetration**
  - Lower loads may have a higher ratio of jet-to-crossflow momentum
  - Induces greater jet penetration
  - Increased jet-to-jet interactions.

Two lowest coal elevations in service



CFD Low-Load Simulation

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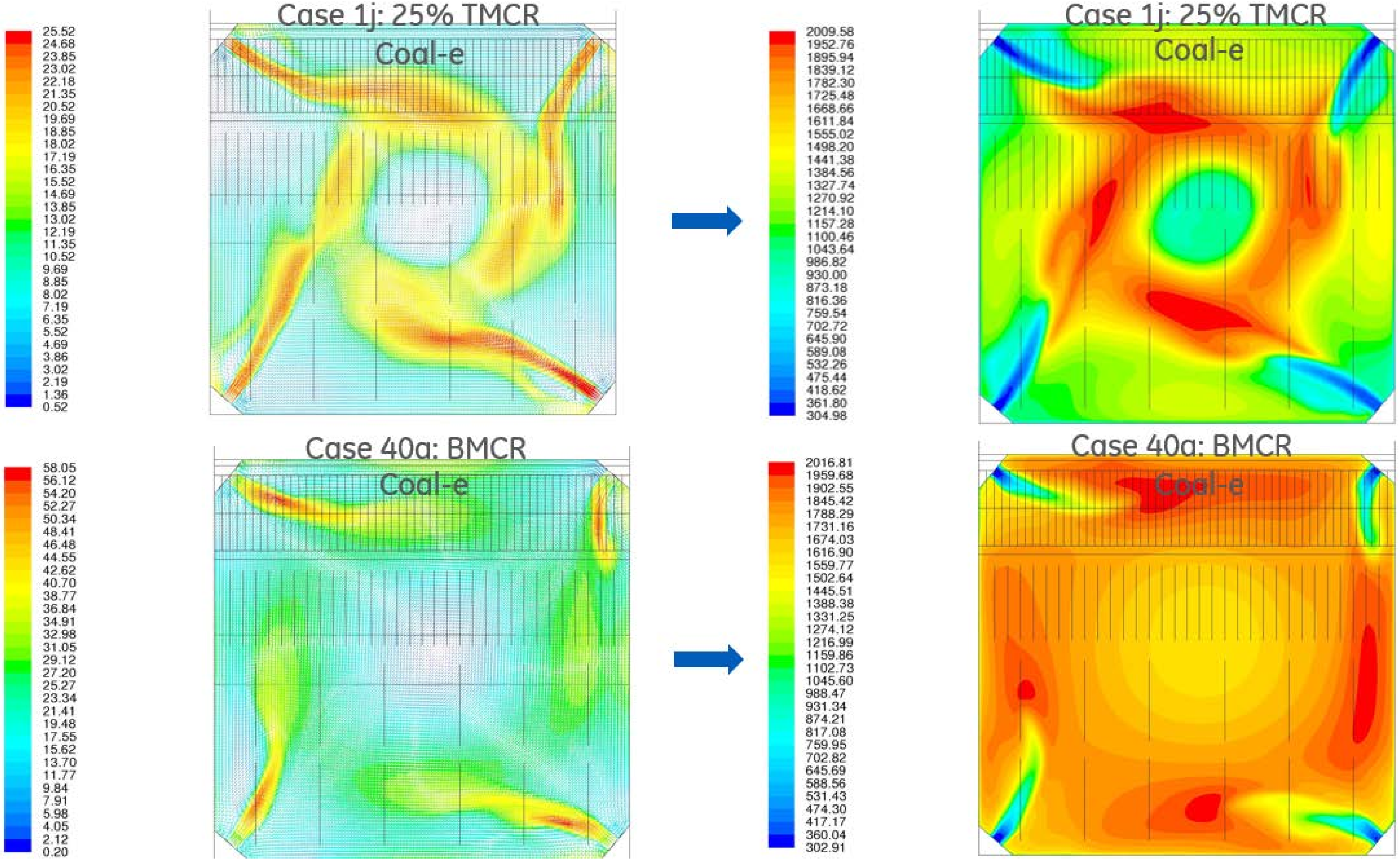
- **Jet Penetration**
  - Scope and extent of fireball formation at maximum load appears to be very different than that at low load.
  - This will have an impact on the temperature, heat flux and emissions profiles

Two highest coal elevations in service

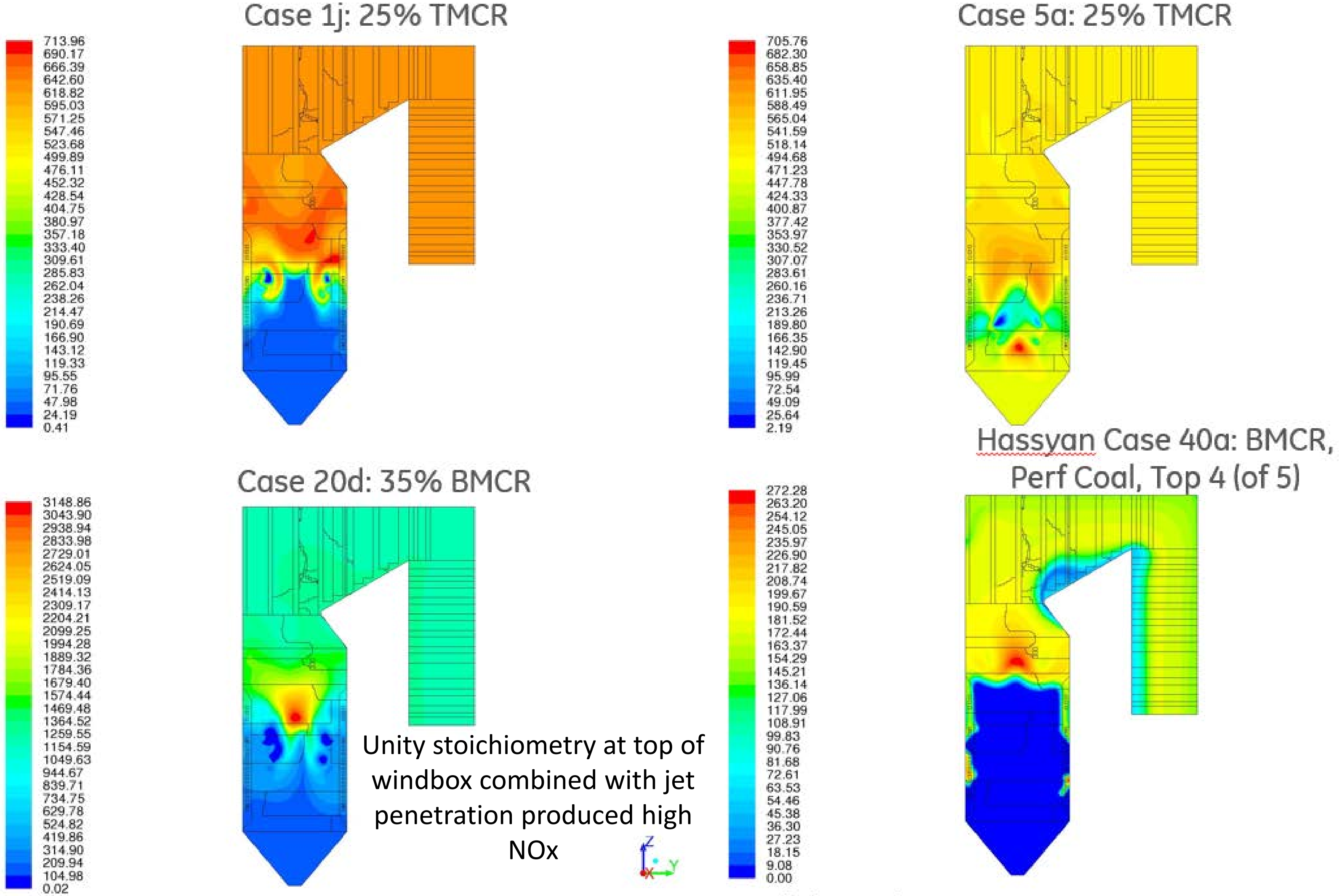


CFD Low-Load Simulation

- NOx can be higher in low-load operations, but must be validated by pilot and field tests.
- NOx is very sensitive to the stoichiometry distribution and excess air levels at low load.
- Flame stability was not assessed in the CFD simulations, but remains an area of study if staging is applied to low loads.

Two highest coal elevations in service

Two lowest coal elevations in service



CFD Low-Load Simulation

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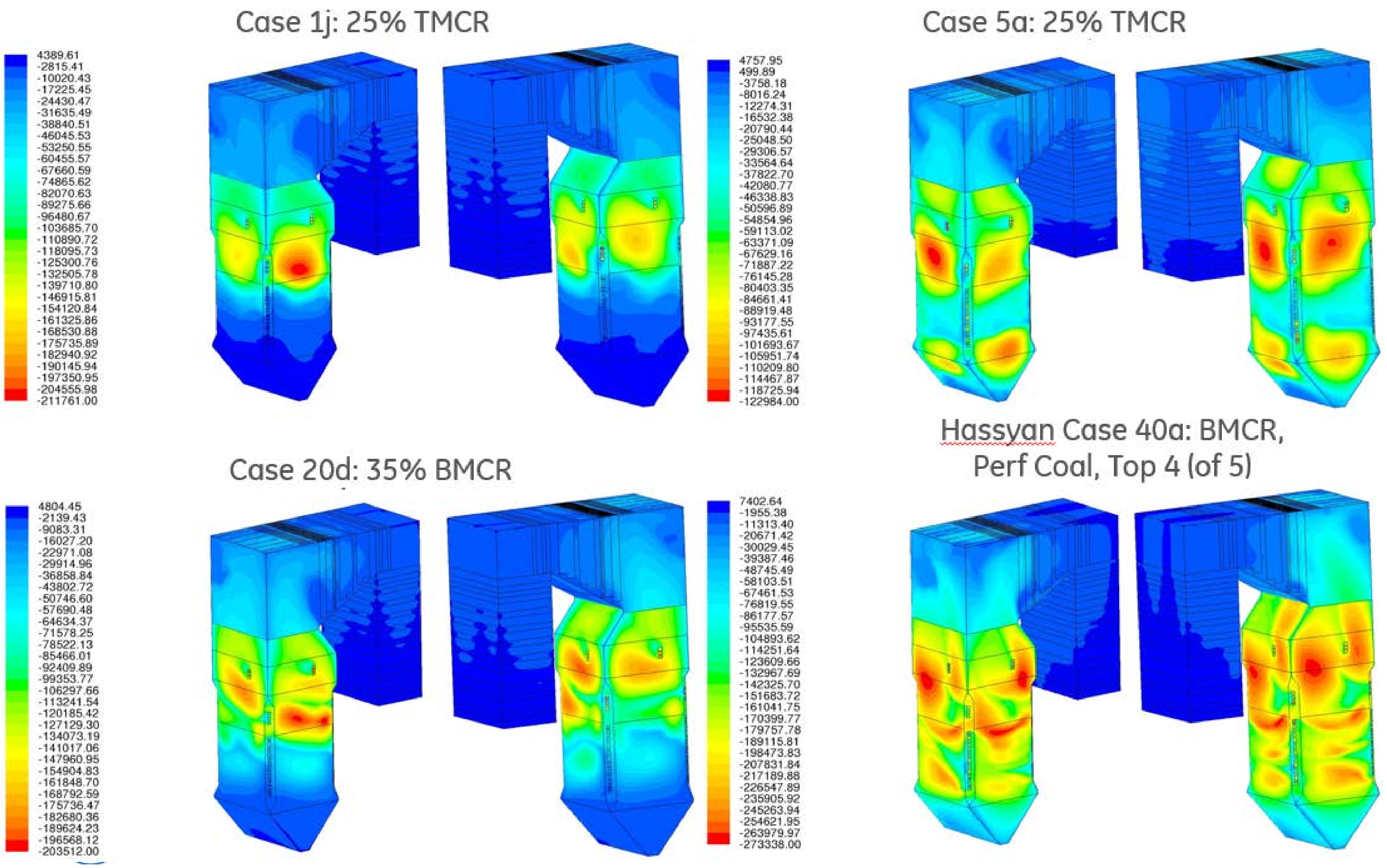
- The wall absorption patterns can change substantially as a function of load, stoichiometry distribution, and firing configuration.



CFD Studies

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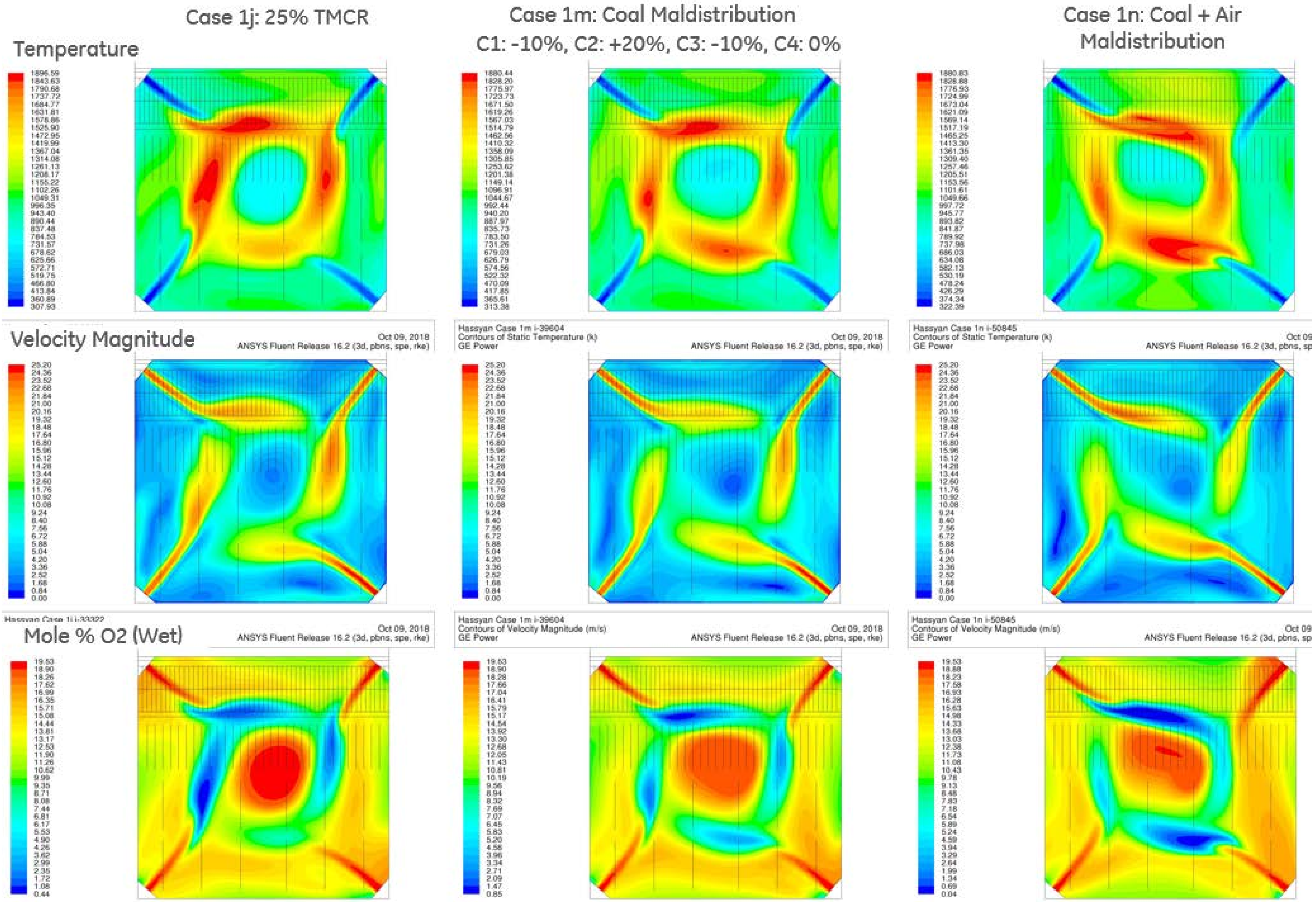
- Corner-to-corner imbalances were investigated with a maximum change of +20% in one corner, but the imbalances did not have a very significant impact on the flow patterns.



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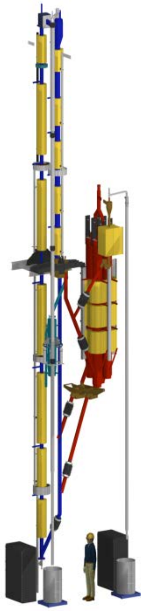
GE Clean Energy Center Overview

Department	Vision / Charter
Boiler Testing & Validation BT&V	To provide Power Businesses with world class pilot and bench scale test facilities for testing and validating boiler technologies

3 Mw Chemical Looping Facility



100 KW Pilot Facility CLC, CFB, transport, & BFB reactor system

Industrial Scale Burner Test Facility

- Balanced draft, front wall fired
- 15MWt, 50MMBtu/hr

Clean Energy Center – CT, USA

Drop Tube Furnace

HP Style Bowl Mill at the Pulverizer Development Facility

Low Load Boiler Operation
Pulverizer Tests

Sensor Selection

- Supplemental sensors
  - Vibration
  - Journal displacement
  - Humidity (Out)
  - Coal Distribution (4 pipes)
  - Spillage
  - Motor Torque (Bowl/Classifier)
  - Bowl Speed (control)
  - Additions Pressure measurements
  - Moisture (In)

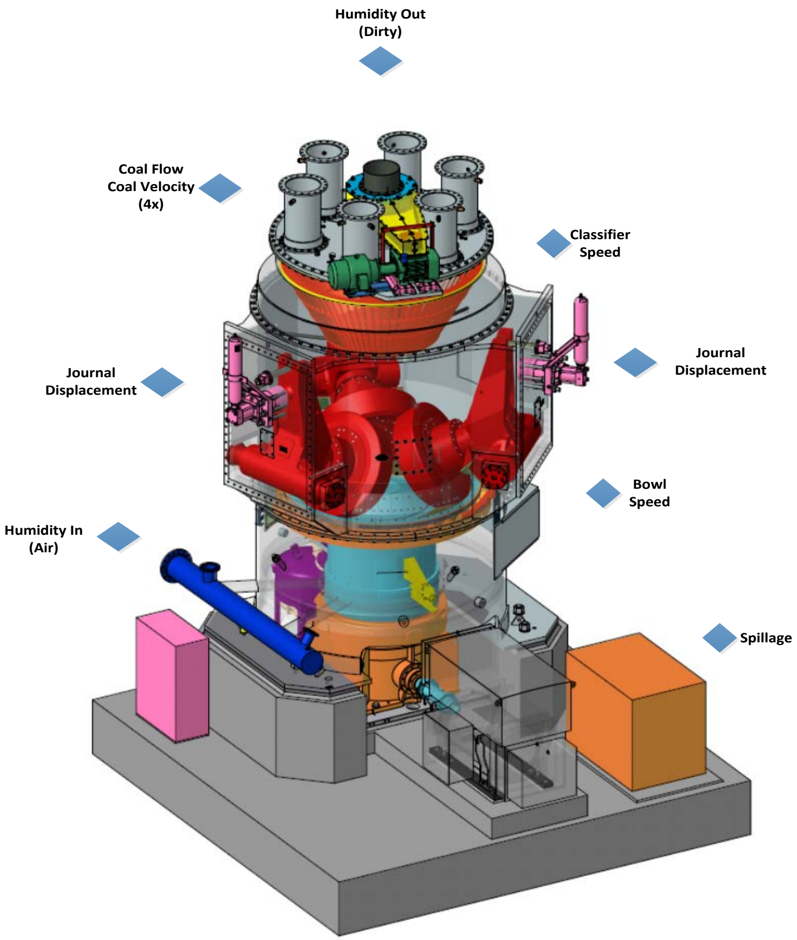
- Targeted Analytics
  - Vibration (Smooth-Rough, Rumble)
  - Coal Velocity/Flow
  - Correlations (Humidity, Air-Fuel slip)
  - Distribution versus feed rate, classifier speed, bowl speed, etc..

Low Load Boiler Operation
Pulverizer Tests

Sensor Selection

Pulverizer Development Facility (PDF)

- 323 HP Pulverizer
- Nominal capacity – 10,000 lbs/hr
- Fully Instrumented
- Modular Design to Test



Low Load Boiler Operation
Pulverizer Tests

Coal Flow/Velocity Sensors

- (1) Flow + (1) Velocity per Mill outlet pipe.
  - Measure coal flow in each outlet pipe.
  - Measure velocity in each coal pipe.
  - Measure temperature in each coal pipe.
  - Investigate usage as fineness indicator
    - Moved sensor down stream to avoid interference with Classifier.

Low Load Boiler Operation
Pulverizer Tests (Low Feed Operation)

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Test Objectives

Low Feed Rates

- Identify operational issues at low feeder rates – extend traditional limits
- Extend Turndown with operational changes (Air Flow, Bowl Speed, etc..)
- Experiment with new Primary Air control philosophy

Coal Distribution

- Evaluate Coal Flow Sensors for Pipe-to-Pipe Distribution + Velocity
- Investigate Velocity sensor usage as fineness indictor (air – fuel slip)

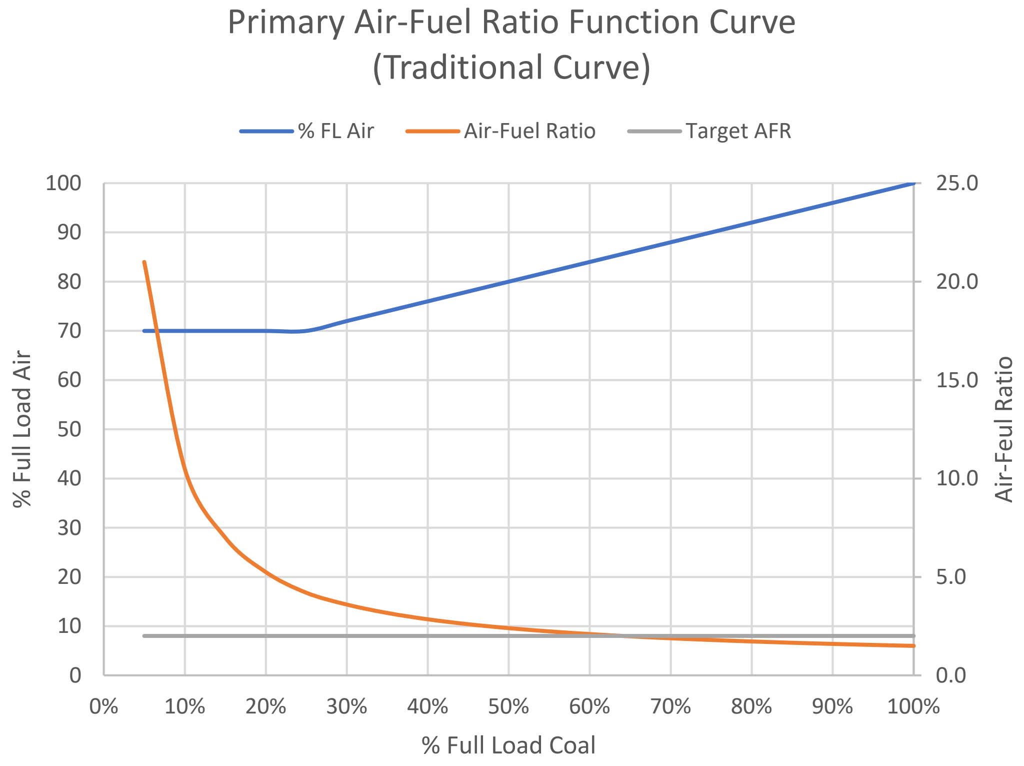
Sensors

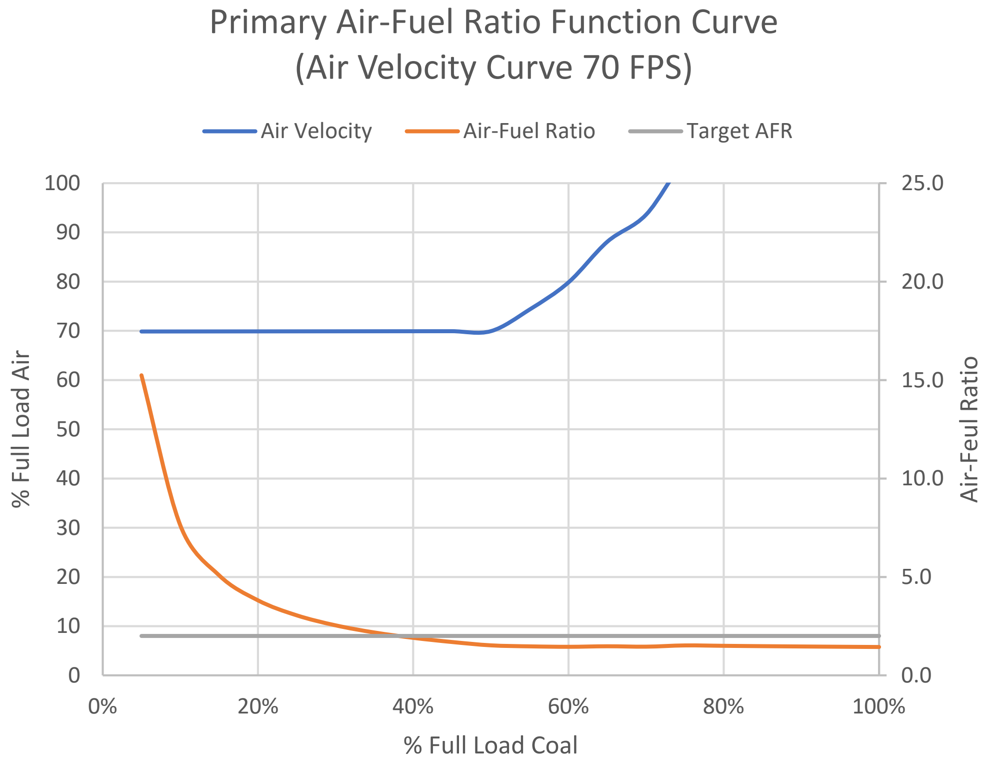
- Characterize abnormal/undesirable behaviour with Sensors + Analytics
- Evaluate Humidity sensor measuring outlet humidity
- Evaluate Spillage + Vibration sensors for detecting abnormal operation

Low Load Boiler Operation
Pulverizer Tests (Low Feed Operation)

Low Feed Rate Operation – Air Fuel Ratio

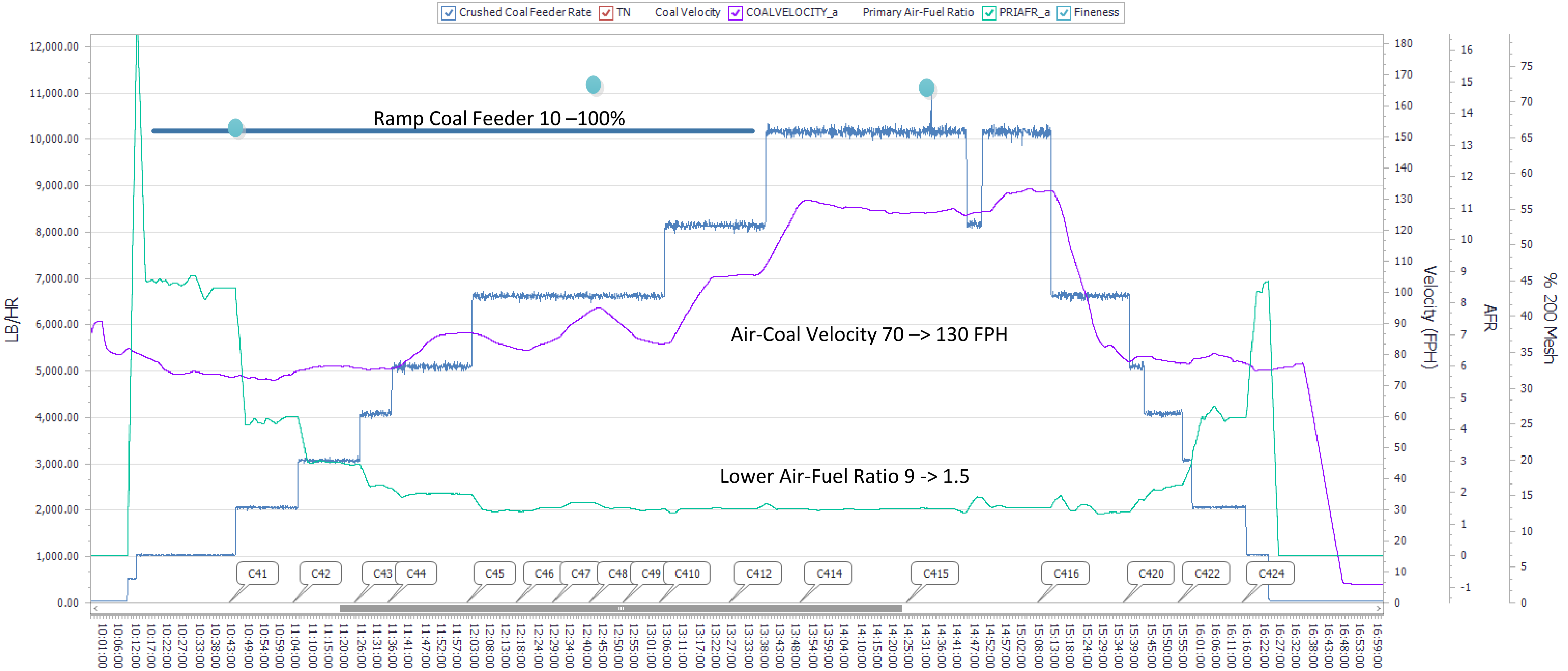
- Calculate Primary Air demand based on fixed velocity instead of fixed curve
  - Calculation based on coal flow, humidity, temperature, pressure
  - Calculation value limited by 1.5 minimum AFR and 70 FPS minimum velocity





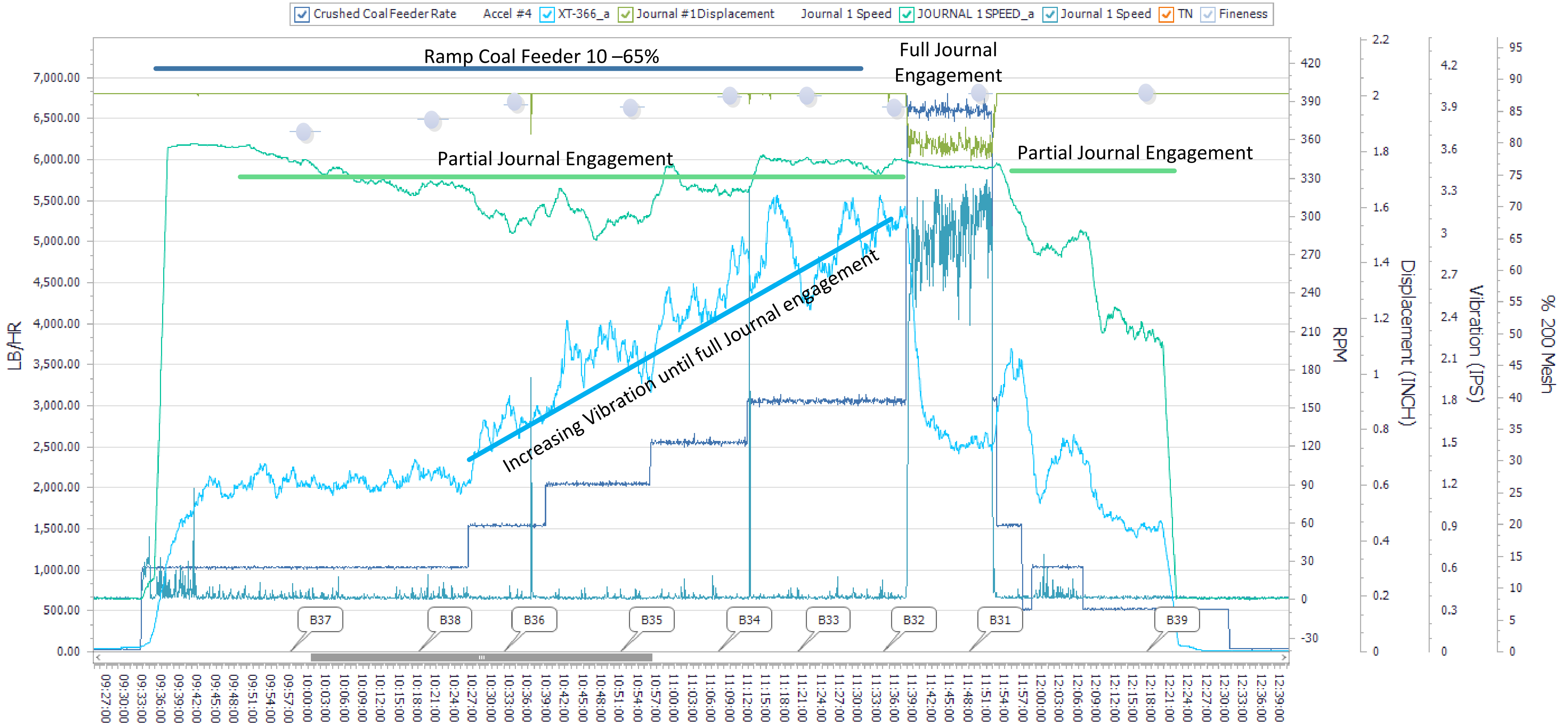
Low Load Boiler Operation
Pulverizer Tests (Low Feed Operation)

Low Feed Rate Operation – Air Fuel Ratio



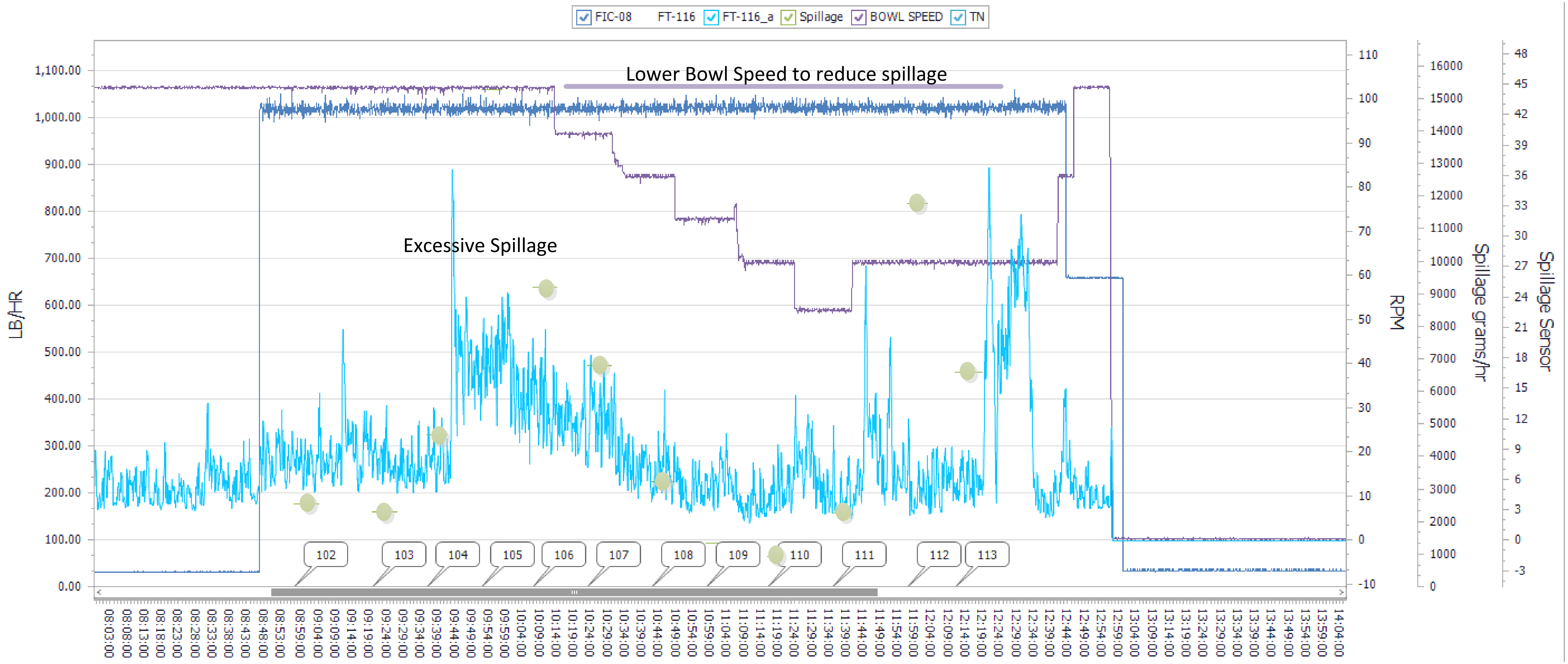
Low Load Boiler Operation
Pulverizer Tests (Low Feed Operation)

Low Feed Rate Operation – Vibration



Low Load Boiler Operation
Pulverizer Tests (Low Feed Operation)

Low Feed Rate Operation – Spillage



Low Load Boiler Operation
Pulverizer Tests (Low Feed Operation)

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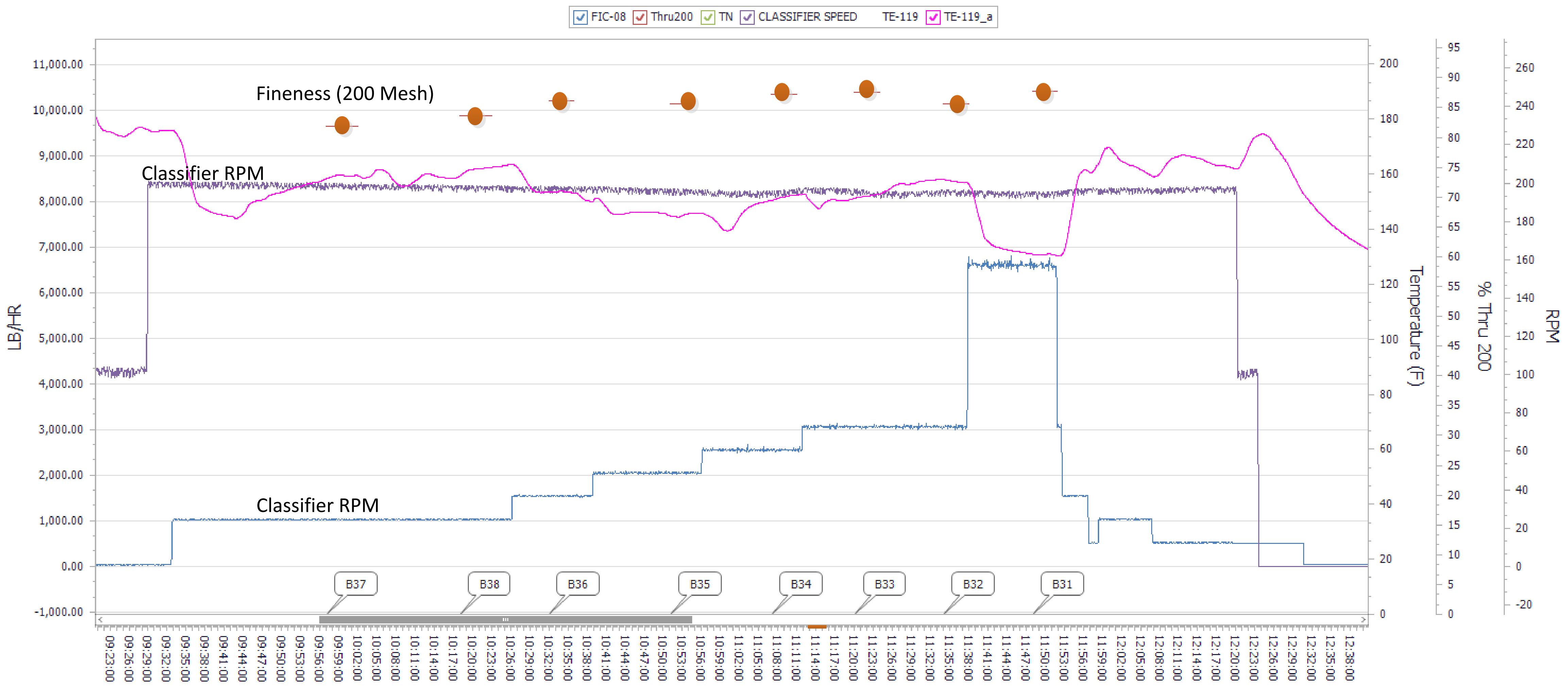
Low Feed Rate Operation – Fineness



Low Load Boiler Operation
Pulverizer Tests – Coal Distribution

Test Results		
Low Feed Rates	Successful down to 5%	• Partial journal engagement • Moderate Vibration • Good fineness control • Fineness distribution degrades at very low feed rates
Coal Distribution	Good results at >50% feed rate	• Good tracking (>10%) at feed rates > 50% • Good low load performance
Humidity	Good results tracking humidity changes due to coal flow and temperature.	• Data to be compared with sample results • Investigating use as fineness indicator
Vibration	Good results monitoring general machine vibration.	• Could not establish rumble for vibration test
Spillage	Good results detecting excessive spillage at low air flow rates	

**Example field data to emphasize typical pipe-to-pipe coal distribution.*

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Low Load Boiler Operation
Technical Approach (Flame Stability)

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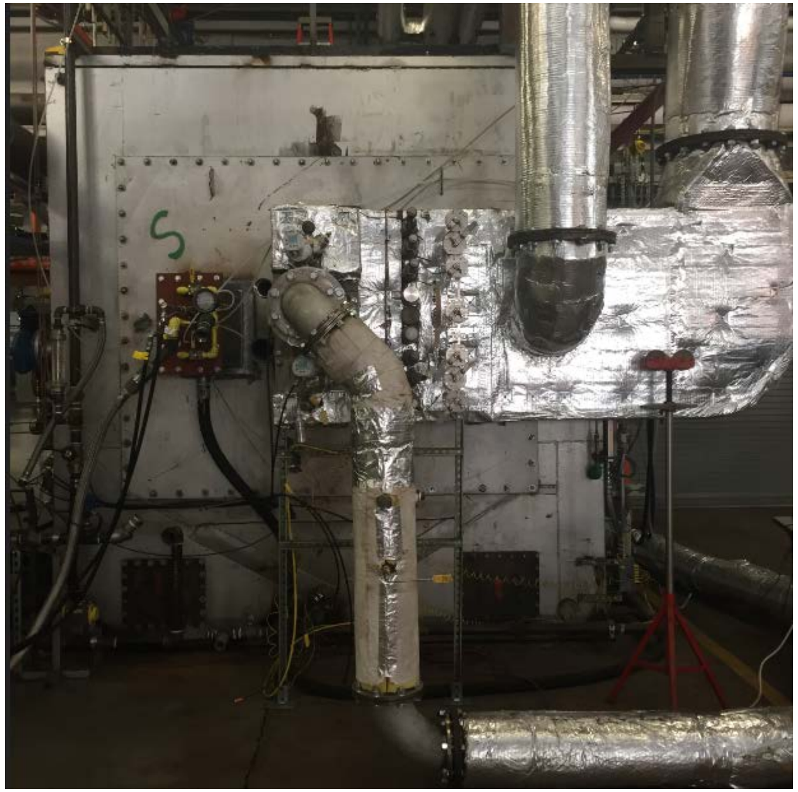
Sensor Selection

- Added sensors for Low load burner testing
  - Near furnace O2, CO, NO sensor grid
  - Static / Dynamic combustion pressure
  - High turndown flame scanner
  - 2D Temperature furnace camera

- Targeted Analytics
  - Burner flame stability (local and global)
  - Fuel/Air balance classification
  - Flame emissions

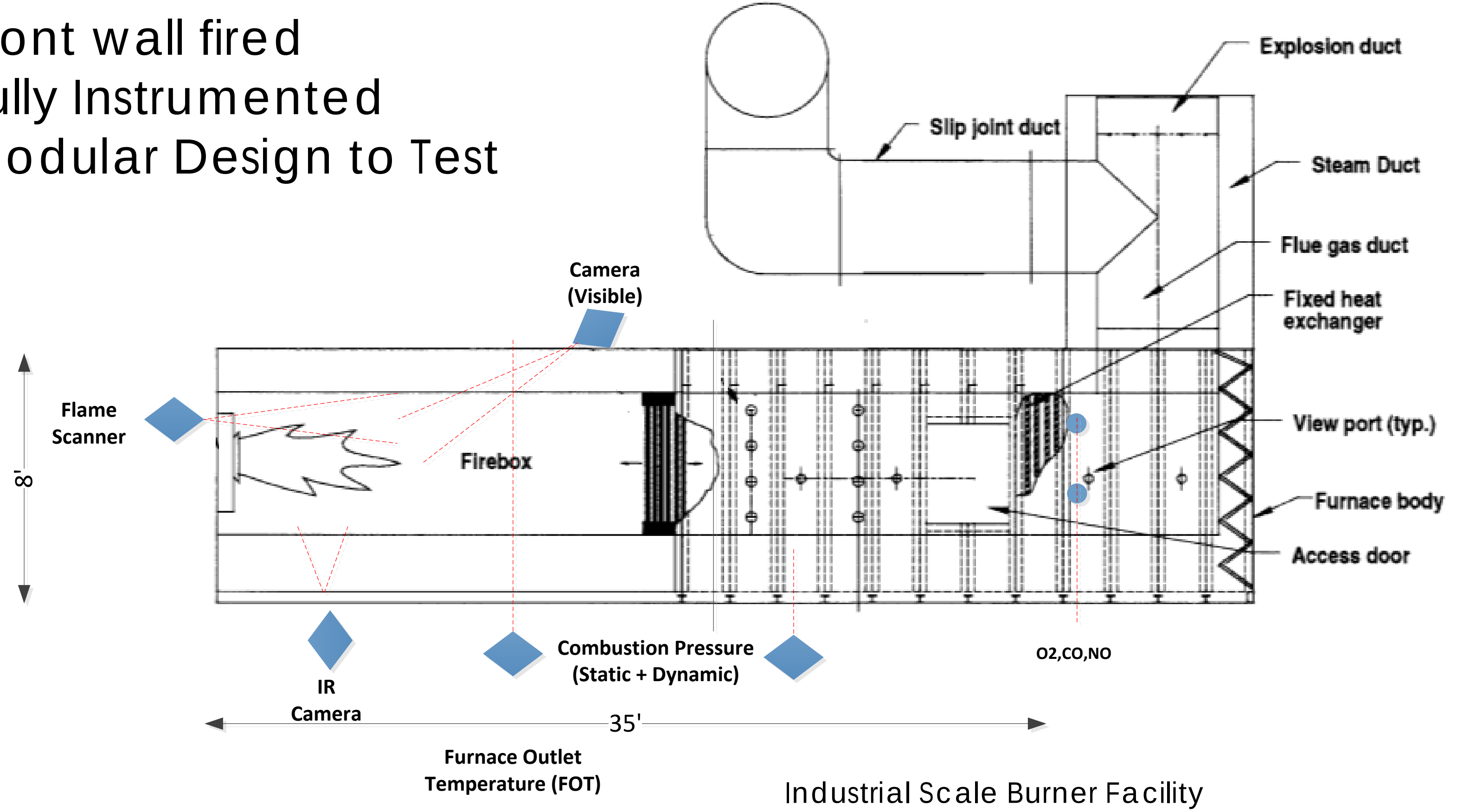


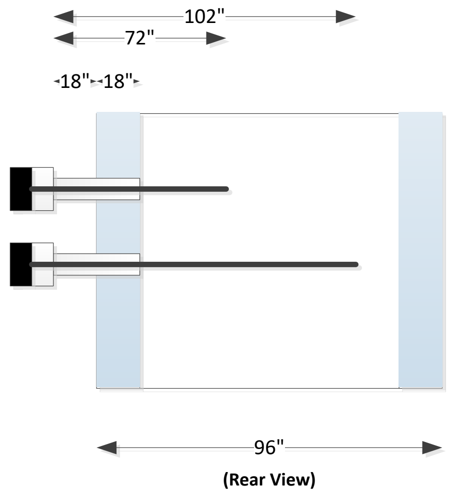
Industrial Scale Burner Facility
(ISBF)

Low Load Boiler Operation
Technical Approach (Flame Stability)

Industrial Scale Burner Facility (ISBF)

- Balanced draft
- Front wall fired
- Fully Instrumented
- Modular Design to Test



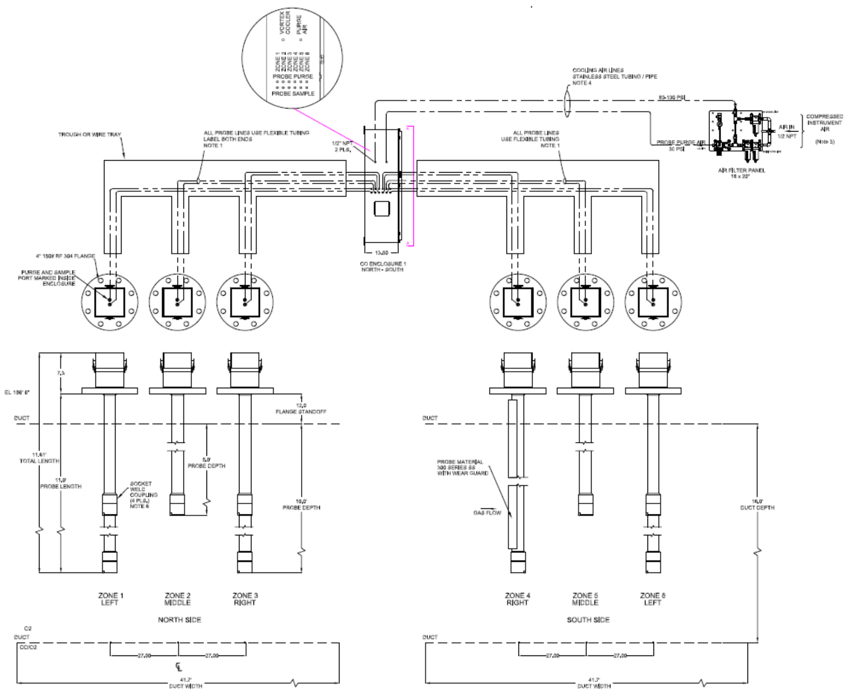


Industrial Scale Burner Facility (ISBF)

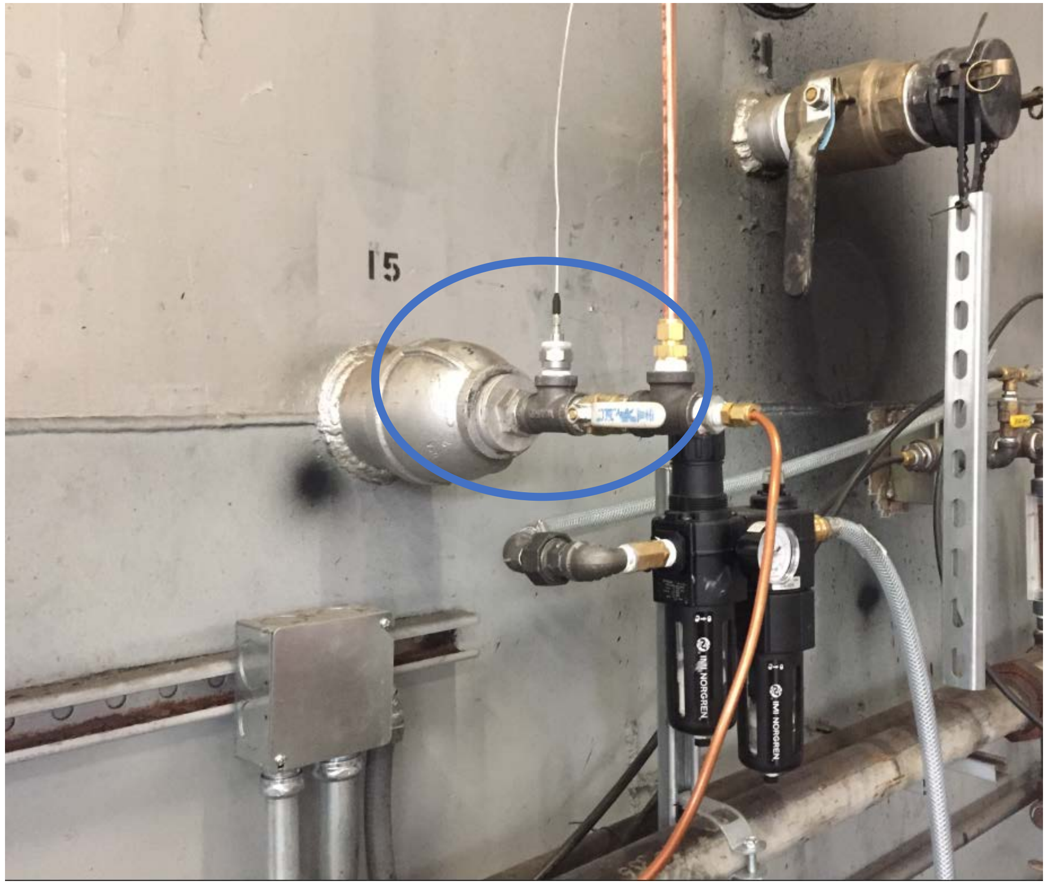
Low Load Boiler Operation
Technical Approach (Flame Stability)

Fluegas CO\O2\NO Sensors

- Measures CO\O2\NO at 4 locations
- Continuous (1 per second) readings at (2) locations
- Time sliced readings at (4) locations.



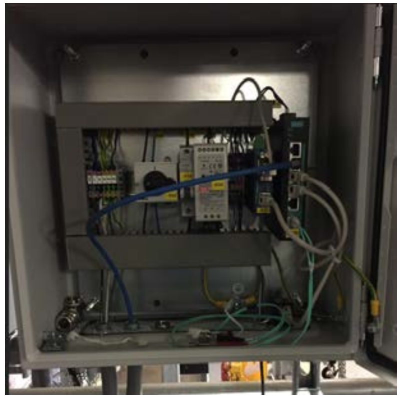
Low Load Boiler Operation
Technical Approach (Flame Stability)



Combustion Pressure Sensors

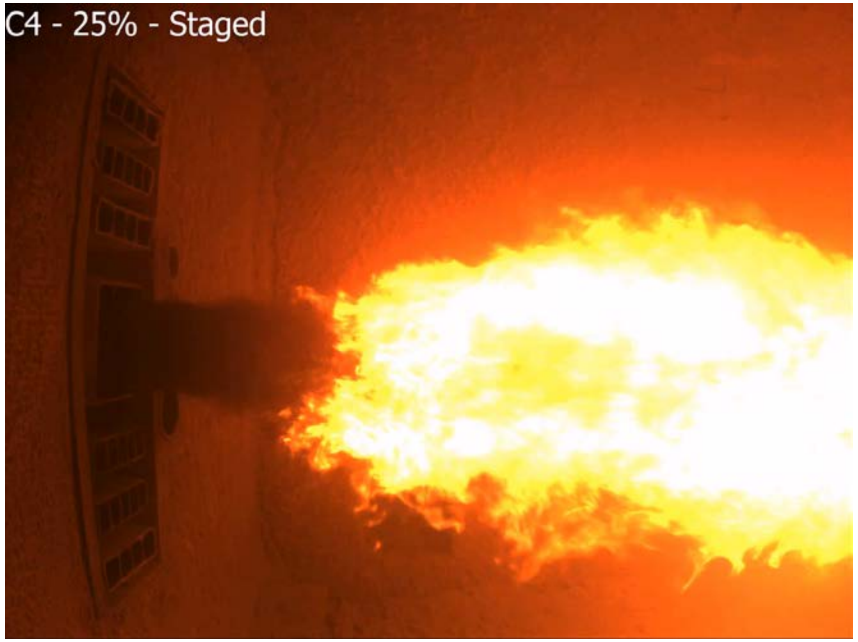
- Measure Static and Dynamic pressure
- Measure pressure pulsations caused by combustion instability

Low Load Boiler Operation
Technical Approach (Flame Stability)

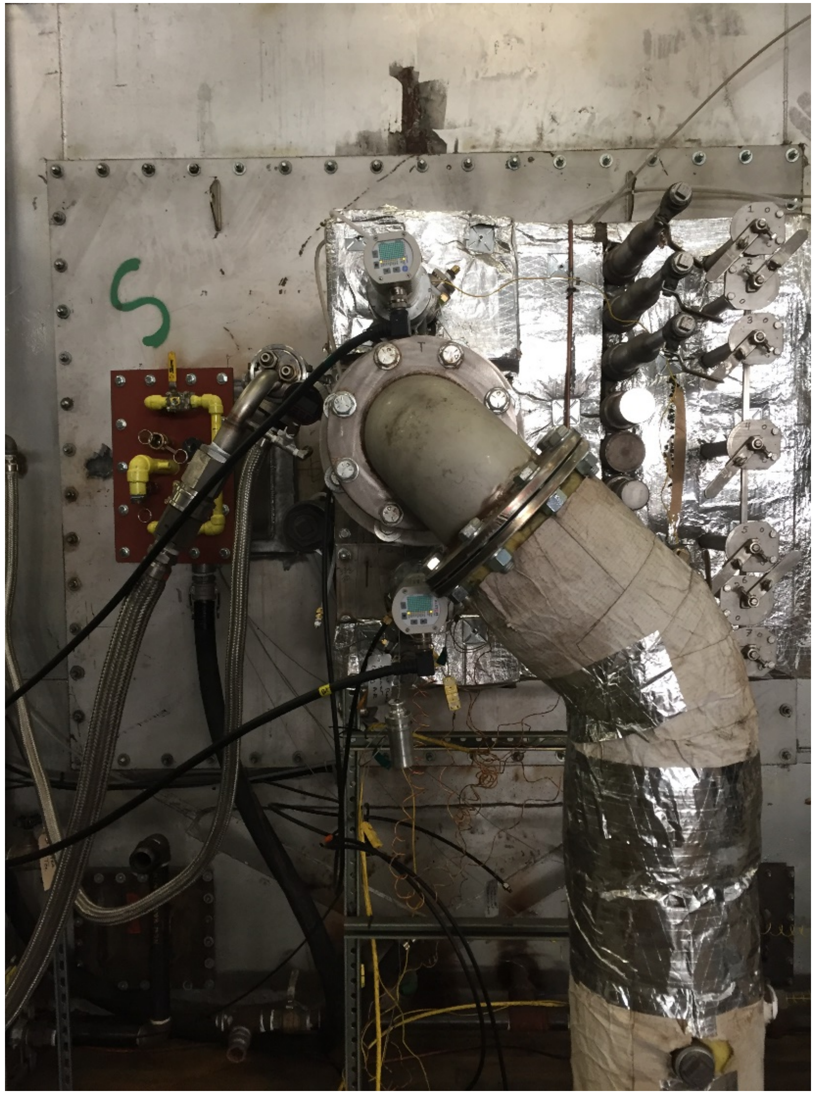


Flame Temperature Camera

- Process visualization
- Flame attachment monitoring
- Input to Global stability Analytics
- 2D Temperature map

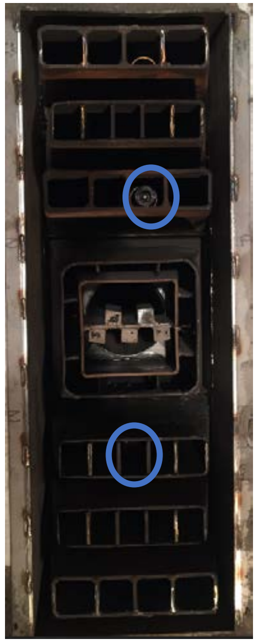


Low Load Boiler Operation
Technical Approach (Flame Stability)



Flame Scanners

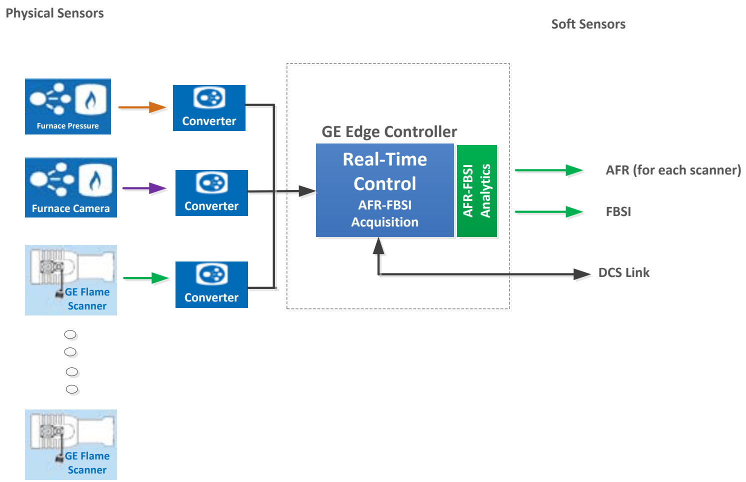
- (2) Scanners in Aux air tip
  - Flame proving – safety function
  - Provide local flame stability indication



Low Load Boiler Operation
Technical Approach (Flame Stability)

Data Acquisition System

- Mounted in area adjacent to ISBF
  - Acquire and store all signal data from sensors
  - Perform Analytics
  - Bi-direction DCS Communication



Low Load Boiler Operation
Combustion Tests (Low Feed rate Operation)

Test Objectives	
Low Feed Rates	• Identify operational issues at low firing rates – extend traditional limits • Extend Turndown with operational changes (Air Flow, Air Distribution, etc..) • Experiment with Staging Air at low firing rates
Coal Distribution	• Evaluate Coal Flow Sensors for Velocity
Sensors	• Characterize abnormal/undesirable behaviour with Sensors + Analytics • Evaluate Flame Scanner for evaluating stability • Evaluate Flue gas sensor (CO,O2,Temperature,Nox) for detecting flow imbalances

Low Load Boiler Operation
Combustion Tests (Low Feed rate Operation)

- Visualization of flame attachment versus % Load.

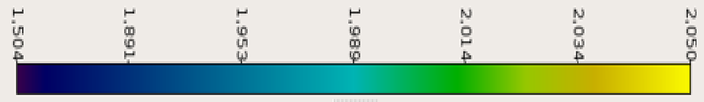
(30% Load)

(25% Load)

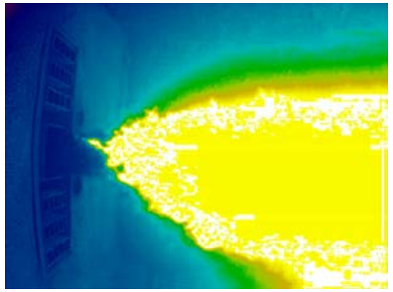
(12% Load)

Low Load Boiler Operation
Combustion Tests (Low Feed rate Operation)

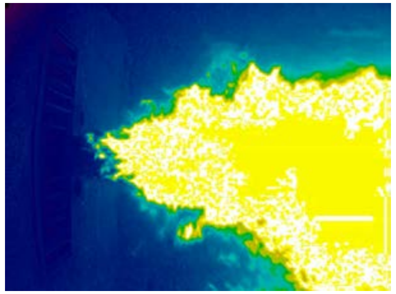
- Visualization of flame attachment versus % Load.

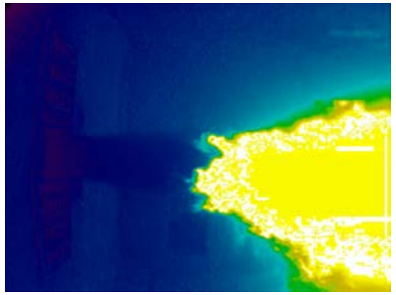


(30% Load)

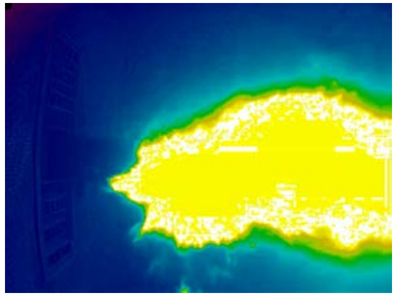


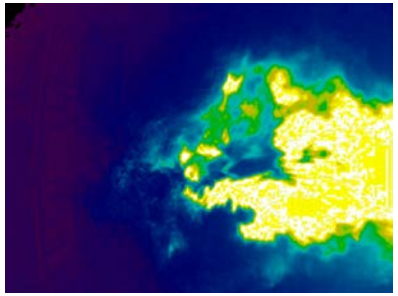
(25% Load)

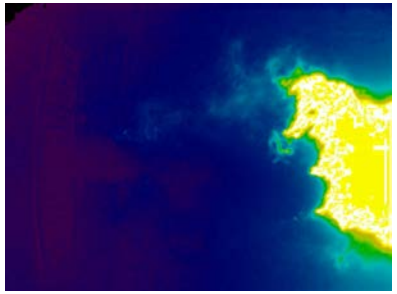


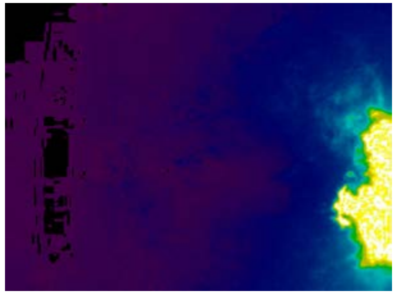


(12% Load)





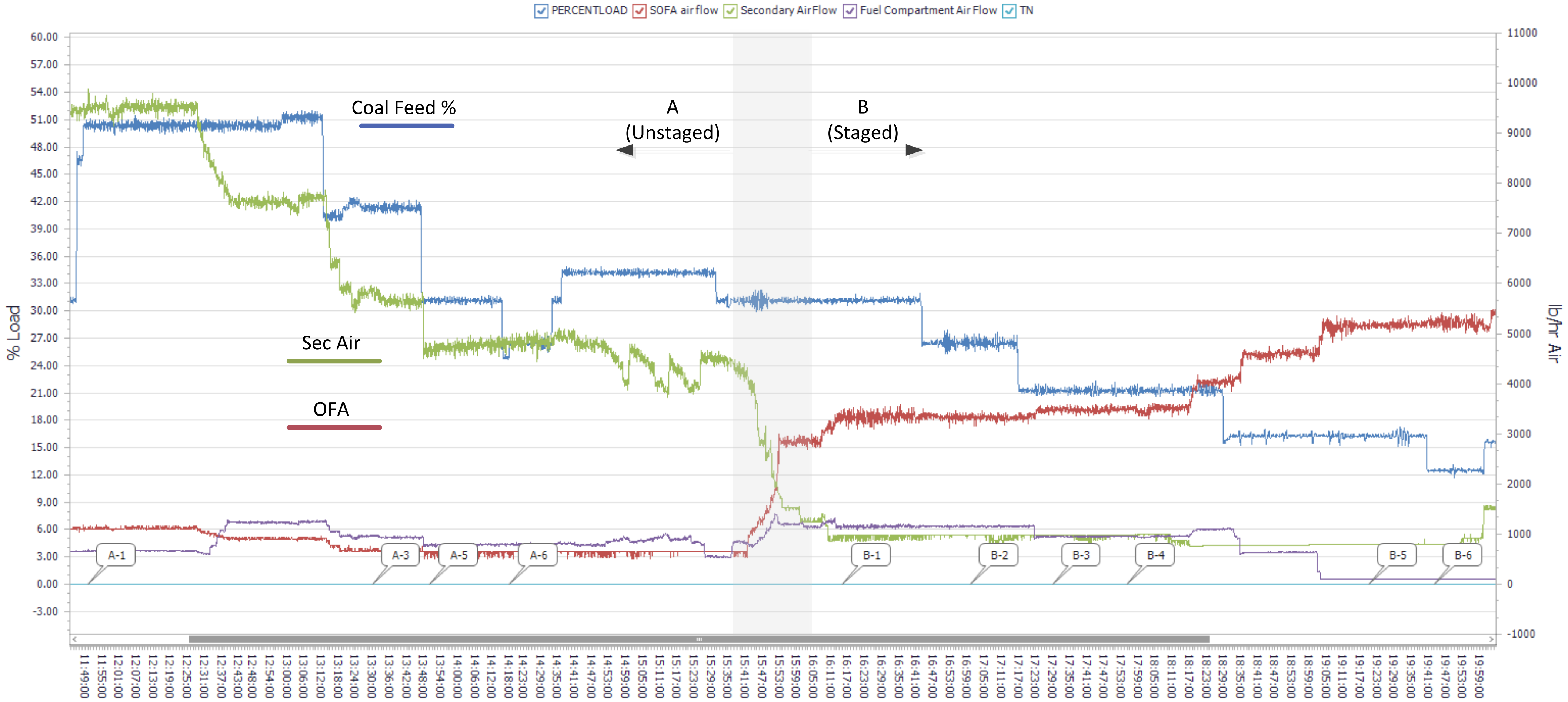




Low Load Boiler Operation
Combustion Tests (Low Feed rate Operation)

Combustion Air Distribution

❖ Unstaged versus Staged Combustion at Low Load.



Low Load Boiler Operation
Combustion Tests (Low Feed rate Operation)

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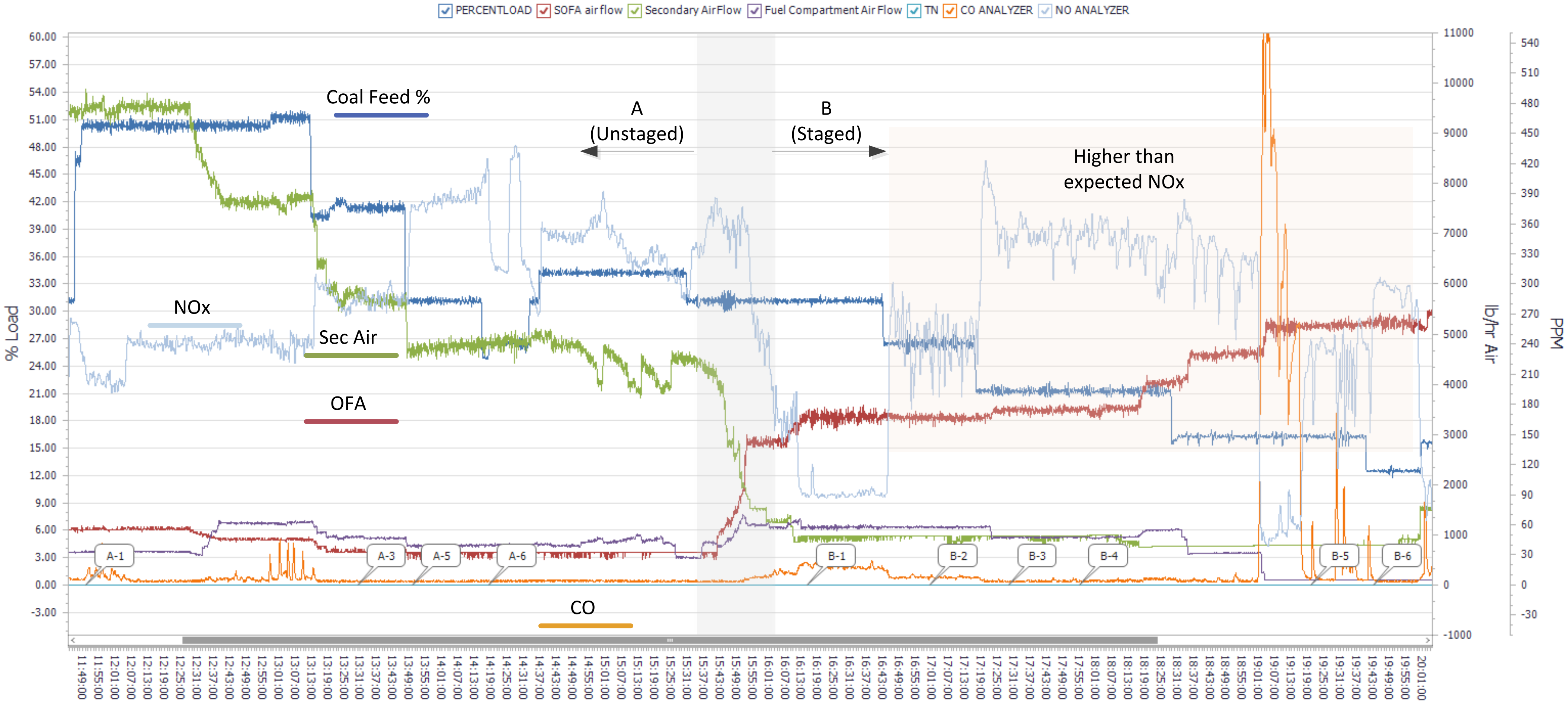
Combustion Air Distribution

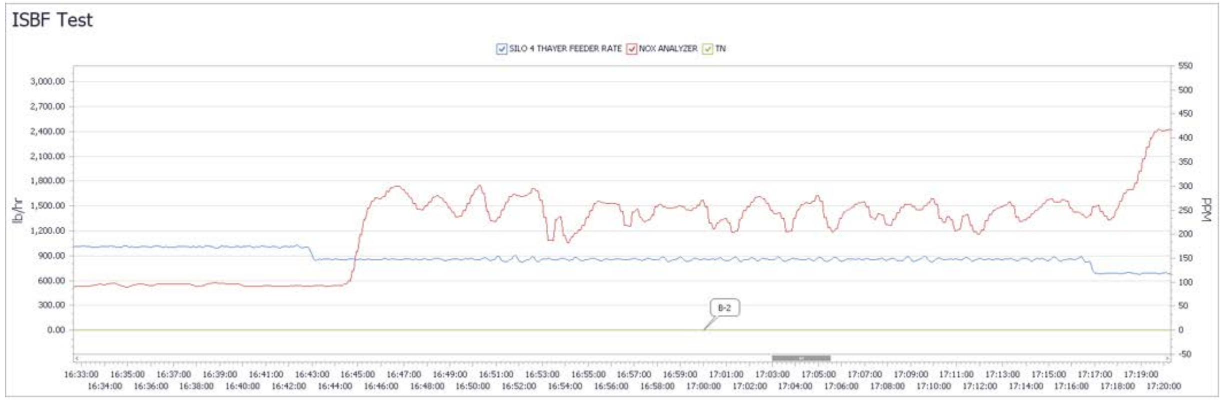
- Unstaged versus Staged Combustion at Low Load.

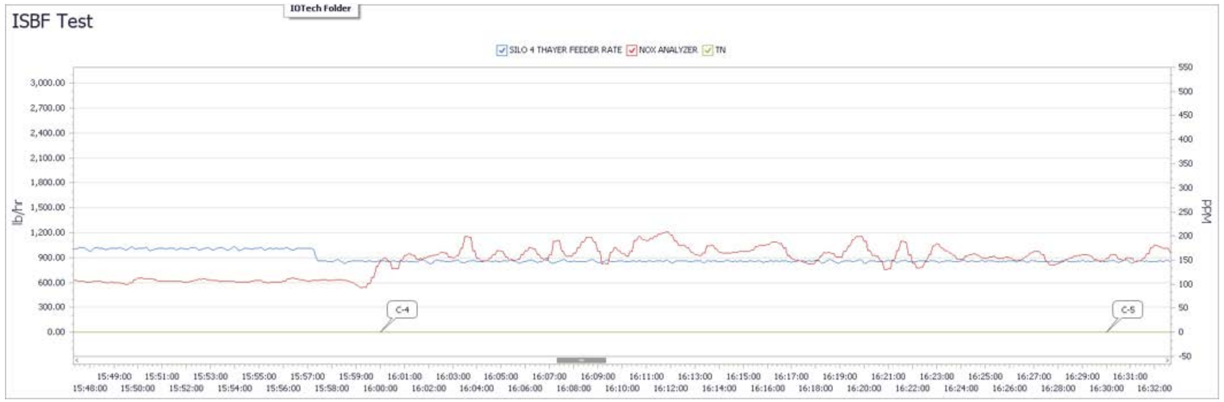


Combustion Tests (Low Feed rate Operation)

Combustion Air Distribution

- Fine versus Extra Fine

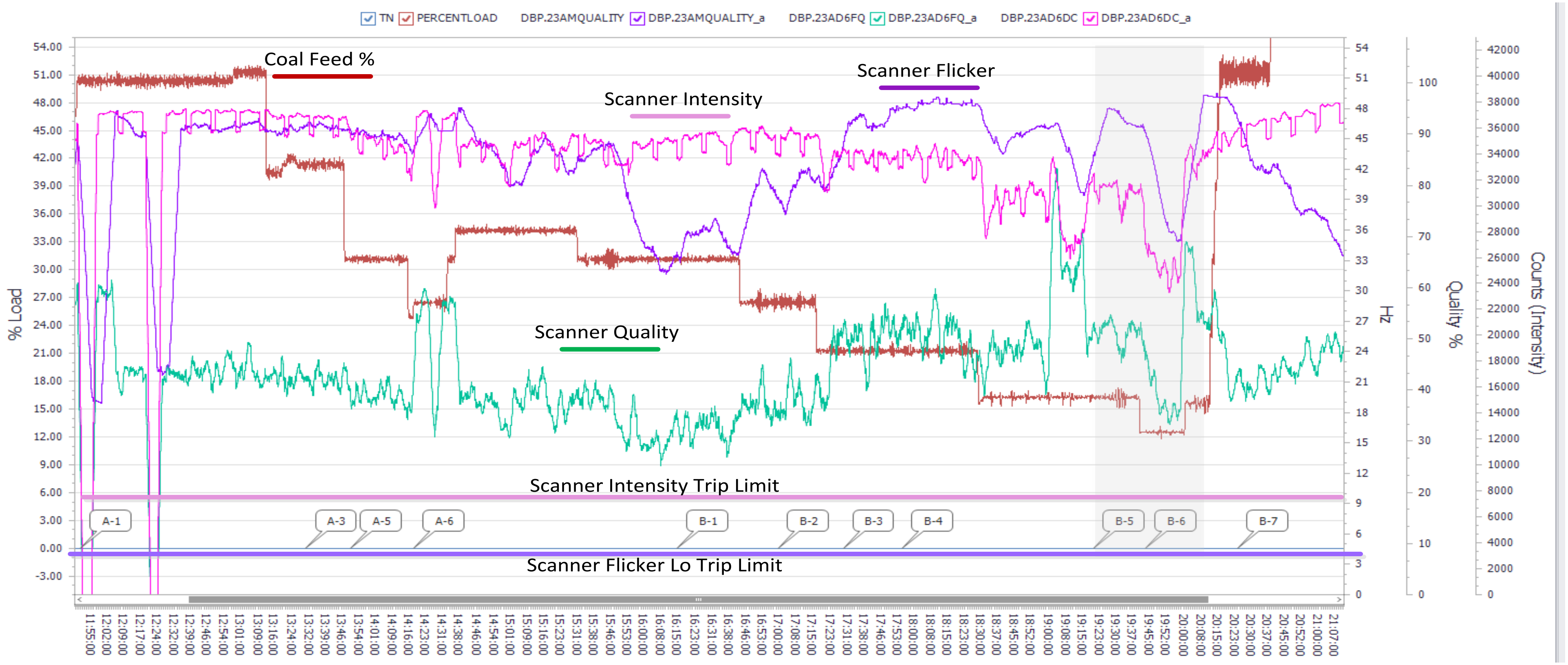




Low Load Boiler Operation
Combustion Tests (Low Feed rate Operation)

Flame Scanner as Stability Sensor

- Flame scanner Flicker frequency indirectly indicates flame attachment distance – not stability.



Low Load Boiler Operation
Combustion Tests – Coal Distribution

Test Results		
Low Feed Rates	Successful down to 15% (disclaimer - *specific to test*)	• Fuel + Aux air dampers closed • Minimum Primary Air (60fps) • Extra fine coal promote early ignition/lower NOx
Coal Velocity	Good results tracking but investigating absolute value	• Correct issue at low flows – software update
Flame Scanners	No issues detecting flame at low loads Analytics required to assess flame stability	• Investigating best features for flame stability (Phase II)
Combustion Camera	Excellent flame images	• Tremendous potential as global stability monitor
Flue gas Grid	Good NO results, CO/O2 readings were high	• Investigating high readings

**Example field data to emphasize typical pipe-to-pipe coal distribution.*

Agenda for Project Presentation

Agenda

Introduction

Plant Low Load Dynamic Simulation Study

Low Load Pulverizer Tests

Low Load Combustion Tests

Phase II Discussion

Wrap Up

Phase II Field Test Summary - Discussion

Objectives

- DOE – Improve the performance and economics of existing coal fueled plants to enable continued operation on coal
- GE – Validate the pulverizer / burner control system to extend the minimum load operating point in a safe and reliable manner on an existing full-scale utility boiler.

Scope

- Conduct detailed engineering, installation, commissioning, testing on the entire coal-fired combustion system on an existing full-scale utility boiler

Schedule

- 21 months starting January 2019

Budget Estimate

- 2.7 MUSD: 2.1 MUSD DOE / 0.2 MUSD GE / 0.4 MUSD SC Cross

Objectives

Validate the pulverizer / burner control system to extend the minimum load operating point in a safe and reliable manner on an existing full-scale utility

1. Prepare for spring host site outage at Santee Cooper Cross Generation Station Unit 4
2. Install extended low load system on Cross pulverizer / combustion system
3. Long term field test of extended low load system to obtain field data to validate combustion system performance at low load boiler operation

Tasks

Task 1 Project Management and Reporting

- Ongoing project management and reporting to GE and DOE management
- Presentations to the NETL and at a National Conference

Task 5 – Host Site Preparation and Field Test

Subtask 5.1 Host Site Outage Engineering and Preparation

- Specify, design, and procure the components of the extended low load system for the host site pulverizer and combustion systems

Subtask 5.2 Host Site Outage Installation

- Onsite support to host plant during control system installation / tie-ins

Subtask 5.3 Long Term Field Test

- Monitor operational improvements with field test data analysis
- Inspect and complete post-test data analysis and reporting

Santee Cooper – Cross Generating Station

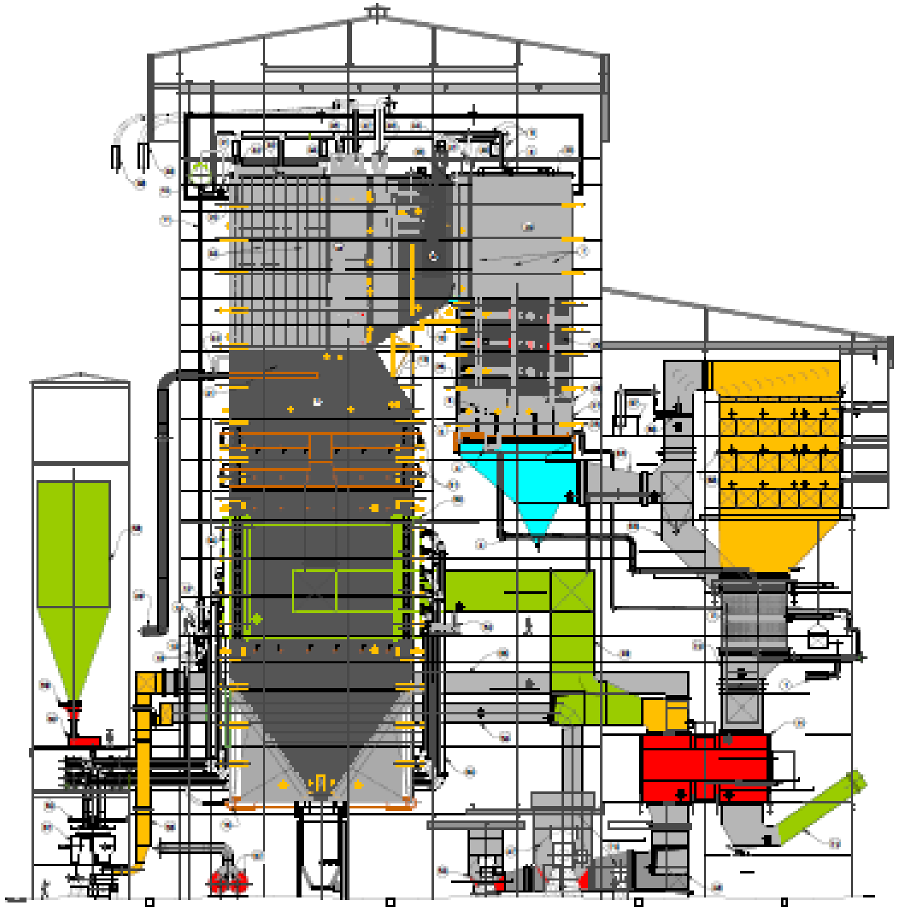
santee cooper®

Located in Pineville, SC approximately 25 miles northwest of Charleston, SC on Lake Moultrie and next to Lake Marion

Santee Cooper Corporate is located in Moncks Corner, SC about 15 miles south of Cross Station

Cross Unit 4

- Commissioned 2009
- 640 MWe subcritical 1055F / 1055F
- Tangential firing system



Phase II Field Test Program

Objectives

- Install and test the pulverizer / burner control system on an existing full-scale utility boiler
- Extend the minimum load operating point in a safe and reliable manner

Scope

- Detailed engineering, installation, commissioning, testing on the entire coal-fired combustion system

Benefits

- Establish a reference for high turndown
- Validate for other plants, T-Fired and wall-fired, use turndown to improve dispatchability

Phase II Field Test Program
Pulverizer and Burner Control System

NATIONAL ENERGY TECHNOLOGY LABORATORY

Sensor	Description
Flame Scanners	1) Flame detectors designed for high turndown and advanced status reporting to Burner Management System (BMS) 2) Flame detectors for inferring fuel-air imbalances.
Secondary Air Damper Controls	1) Individual DCS control of each air damper to respond to the fuel-air imbalances measured by the Flame scanners and flow sensors.
Pulverizer Sensors	1) Coal Flow Sensors for measuring pipe to pipe coal distribution, air velocity, and air temperature. 2) Inlet coal moisture and output humidity to infer coal fineness. 3) Spillage sensor for ensuring normal operation when operating at low feed rates and low air flow levels.
Pulverizer Controls	Change air flow curves to regulate primary air transport velocity at low load. Use Spillage, Air Velocity, and Humidity sensor as feedback for air control.
Flue Gas CO / O_2 / Temperature	Flue gas analysis grid for monitoring combustion and temperature pattern.
Furnace Outlet Temperature	Furnace outlet temperature grid to better tune models and predict slagging conditions.
Fireball Monitoring	2D Temperature calibrated camera to measure fireball stability, fireball features and position, and feedback for secondary air distribution biases.
Edge Analytics	Analytics for deriving flame stability, fireball stability, O2 setpoint, air distribution biases, etc. from the installed sensor mix.

Phase II Field Test Program
Pulverizer and Burner Control System

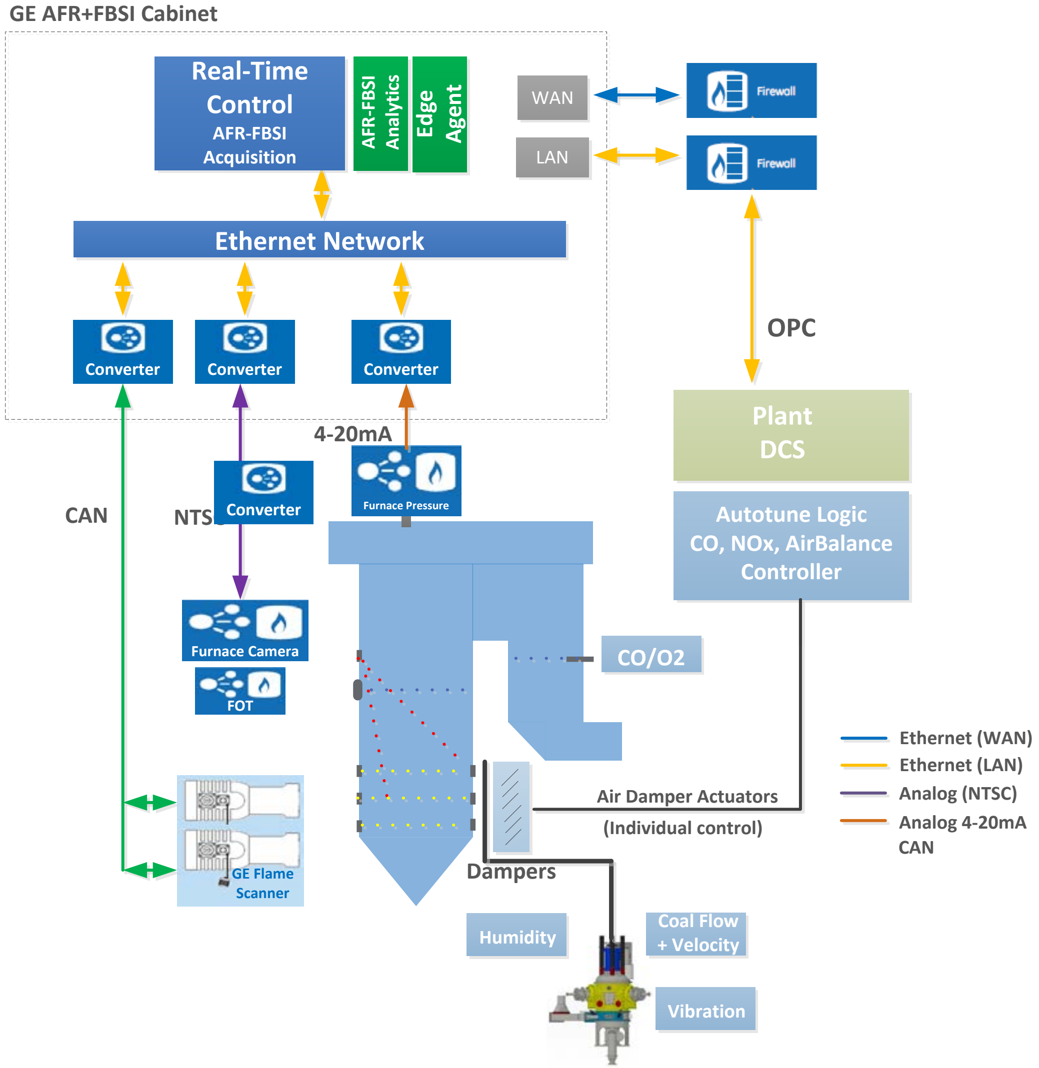
Key Components

Digital Boiler⁺: Advanced boiler optimization system:

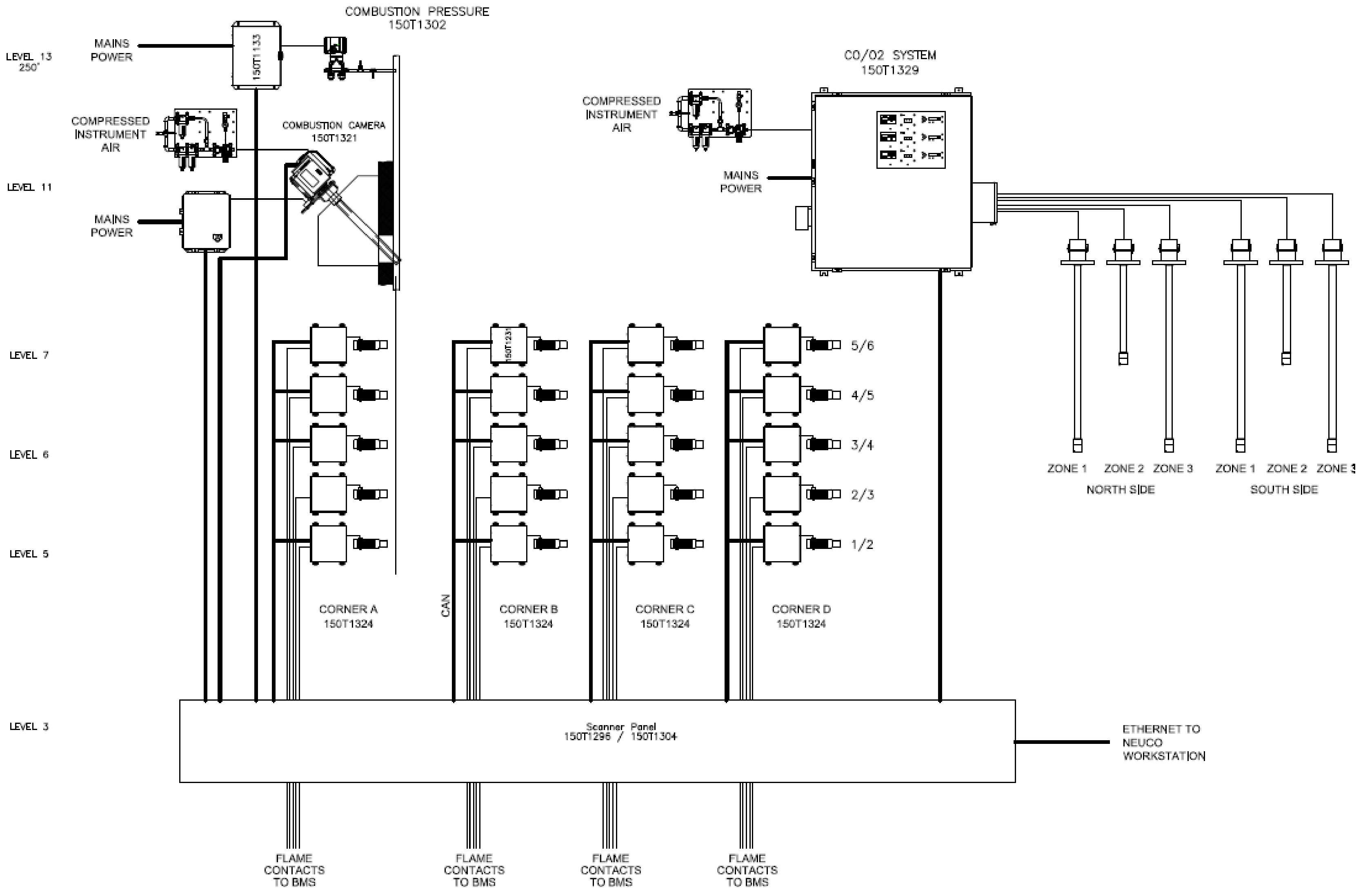
1. Low Load Stability mode… ensures stability of the combustion process during low load operation.

Safe operation

- Insights into local and global furnace conditions that are derived from standard instruments using advanced analytics.
- Decoupled and individually controlled secondary air dampers



Phase II Field Test Program
Combustion + Burner Control System



Thank you!