IMPROVING COAL-FIRED PLANT PERFORMANCE THROUGH INTEGRATED PREDICTIVE AND CONDITION BASED MONITORING TOOLS

(Award No. DE-FE00031547)

2021 Annual Project Review Meeting

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MICROBEAM TECHNOLOGIES, INC.

Presentation Overview

- **Project Information**
  - Project Team
  - Project Goal and Objectives
- **Background**
  - Microbeam's Fireside Performance Indices
  - Microbeam's Combustion System Performance Indices (CSPI) Program
- **Accomplishments**
  - CoalTracker Algorithm Development and Testing
  - Combustion System Performance Indices Algorithm Development and Testing
- **Opportunities for Plant Improvement and Cost Savings**
- **Next Steps**

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Project Team

- Technical Team:
  - Microbeam Technologies Inc.
  - University of North Dakota
    - Institute of Energy Studies (IES)
  - Rochester Institute of Technology
    - Department of Software Engineering
- Funding Support:
  - U.S. Department of Energy, National Energy Technology Laboratory
  - Otter Tail Power's Coyote Station
  - North American Coal Company
  - Great River Energy
- Project Support:
  - Energy Technologies Inc.

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UND INSTITUTE FOR ENERGY STUDIES THE UNIVERSITY OF NORTH DAKOTA

R·I·T

OTTER TAIL POWER COMPANY

NORTH AMERICAN COAL CORPORATION

Energy Technologies Inc.

GREAT RIVER ENERGY

MICROBEAM TECHNOLOGIES, INC.

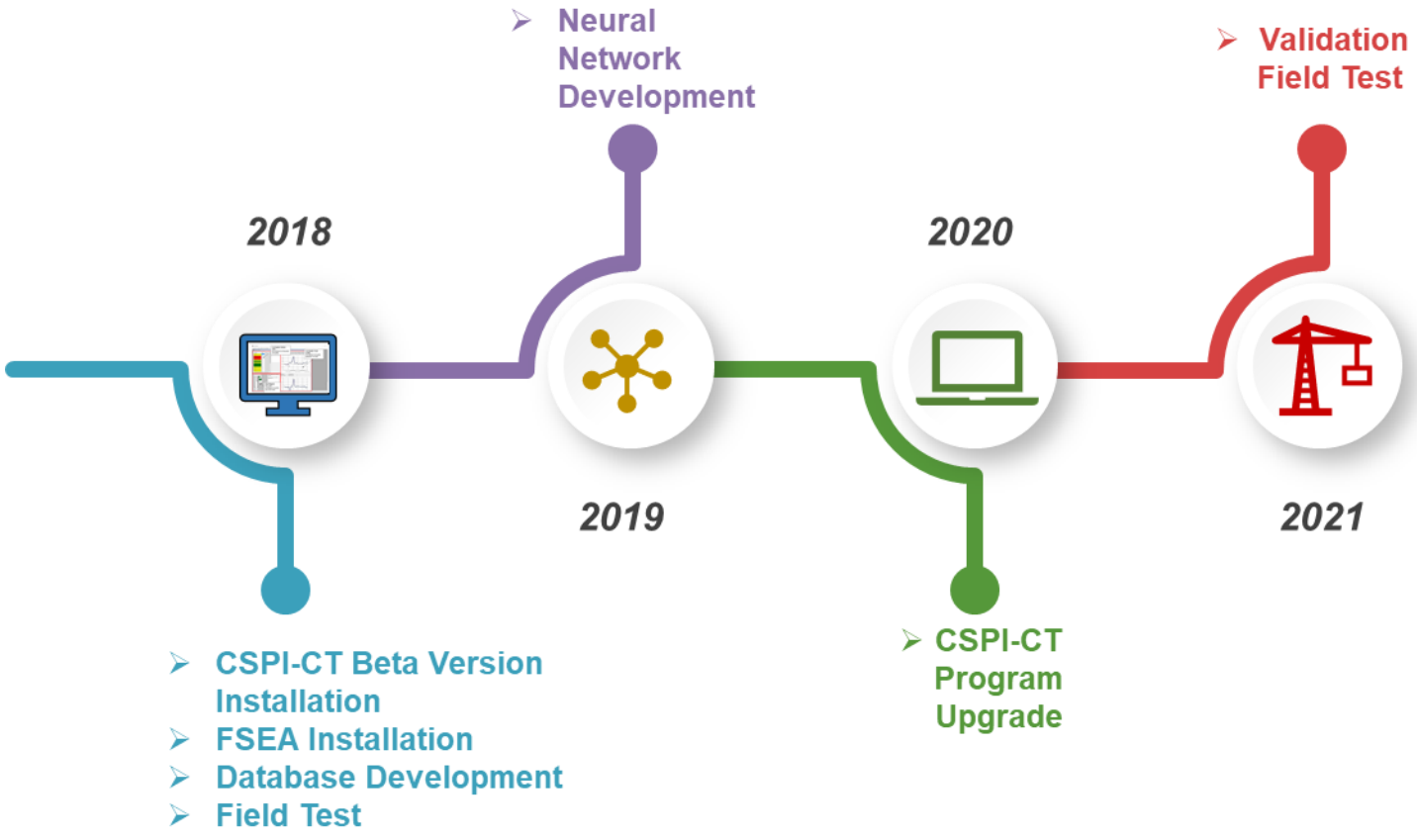
Project Information

Goal

Demonstrate at a full-scale coal-fired power plant the ability to improve boiler performance and reliability through the integrated use of condition-based monitoring (CBM) and predictions of the impacts of coal quality on boiler operations.

Project Period

January 1, 2018 – December 31, 2021 (4 Years)



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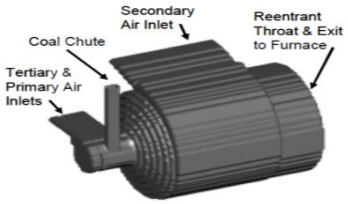
Testing Sites

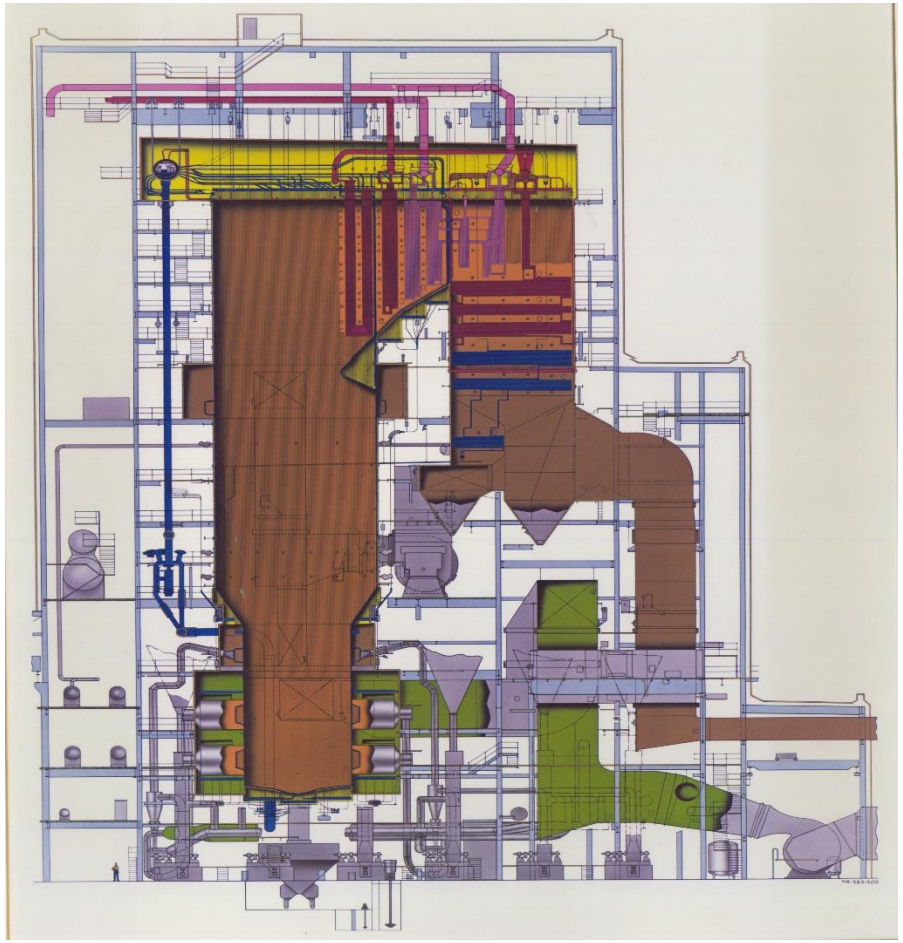


Primary site: Otter Tail Power's Coyote Station

- Cyclone Fired Boiler
- MW – 450
- Fuel – ND Lignite
- Daily fuel delivery – 7000 - 12000 tons of coal – 2.5 million tons of lignite annual consumption – Mine mouth plant

Secondary Site: Great River Energy's Coal Creek Station

- Pulverized Tangential Boiler
- MW – 550 (2 Units)
- Fuel – ND Lignite
- Annual fuel delivery – 7.5 - 8 million tons of coal – Mine mouth plant



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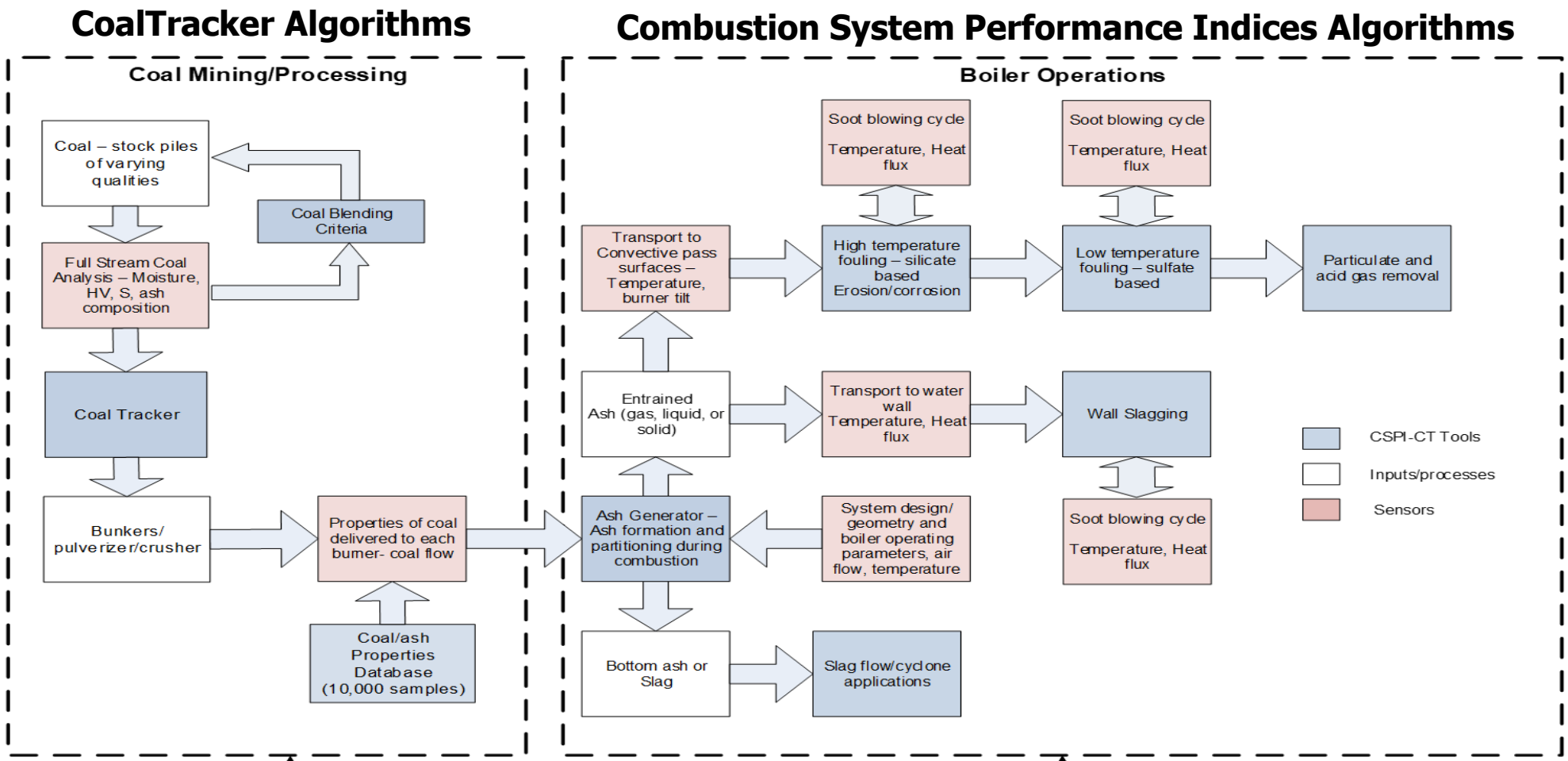
Project Overview



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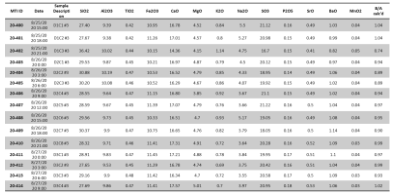
Accomplishments

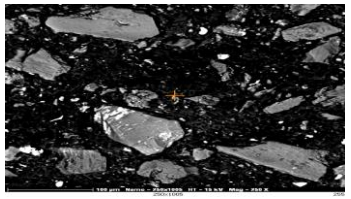
- **Database Development**
  - Coal properties, burner performance, and overall plant performance
  - > 4 years, >200 parameters, >390 million datapoints
- **Neural Network Training**
  - Burner performance, heat transfer (SSH) performance, plant performance (heat rate)
  - Demonstrated impacts of fuel quality on predictions
- **Combustion System Performance Indices Algorithm Development and Testing**
  - Upgraded version of Combustion System Performance Indices (CSPI) installed at plant
  - CoalTracker used to predict adverse fuel events
  - Operator training completed: operators use CSPI daily to manage fuel properties
  - Estimated cost savings of >$6 million in 2020

Fuel Properties and Plant Operational Database Development

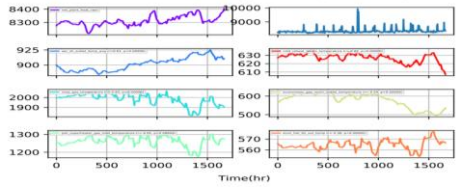
Coal Ash Analysis



Scanning Electron Microscopy Analysis

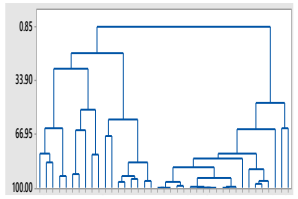


Plant Operational Data

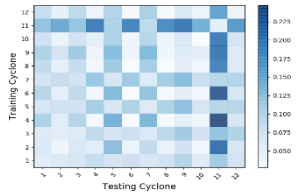


Statistical Analysis & Neural Network Training and Testing

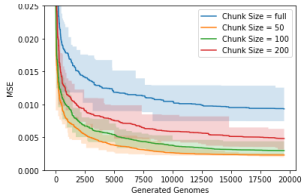
Statistical Analysis



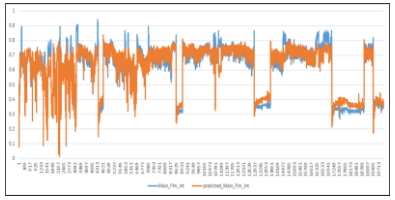
Trait Similarity



NN Training



Power Plant Operational Data Predictions



CoalTracker Program

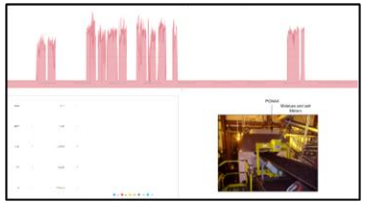
Tracks Coal From Point of Delivery to Burners

As-Delivered Fuel → Coal Storage → Silo → Burner

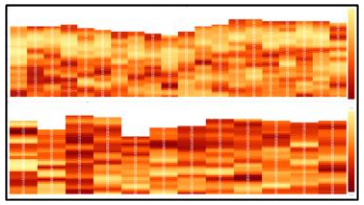
Date	Time	Delivered Coal/Belt 1 Ash Content Level	Live Storage Ash Content Level	Belt 7 Ash Content Level	Silo Ash Content Level	Cyclones Ash Content Level
Nov 13	5:00 AM	Medium	Medium	Medium	Medium	Medium
Nov 14	6:30 AM	High	Medium	Medium	Medium	Medium
Nov 14	11:00 AM	High	Med/High	Medium	Medium	Medium
Nov 14	4:00 PM	High	Med/High	High	Medium	Medium
Nov 14	5:00 PM	High	Med/High	Med/High	Med/High	Medium
Nov 14	11:20 PM	High	Med/High	High	High	High
Nov 15	8:10 AM	Medium	Med/High	High	High	High
Nov 15	8:15 AM	Medium	Med/High	Medium	High/Med	High
Nov 15	3:30 PM	Medium	Medium	Medium	Medium	Medium

Combustion System Performance Indices (CSPI) – CoalTracker (CT) Platform

As Delivered Fuel Quality

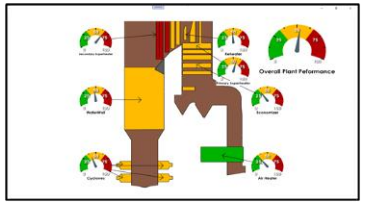


Fuel Quality Predictions in Live Storage and Silos

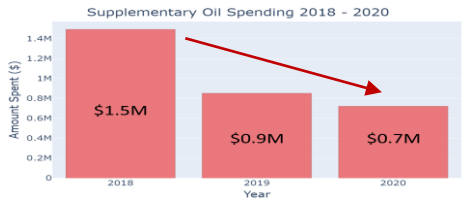


Boiler Slagging and Fouling Indices Prediction

Boiler Diagnostics



Examples of Cost Benefits to Power Plant – Reduction in Supplementary Fuel Oil Spending



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CoalTracker Algorithms Development and Testing

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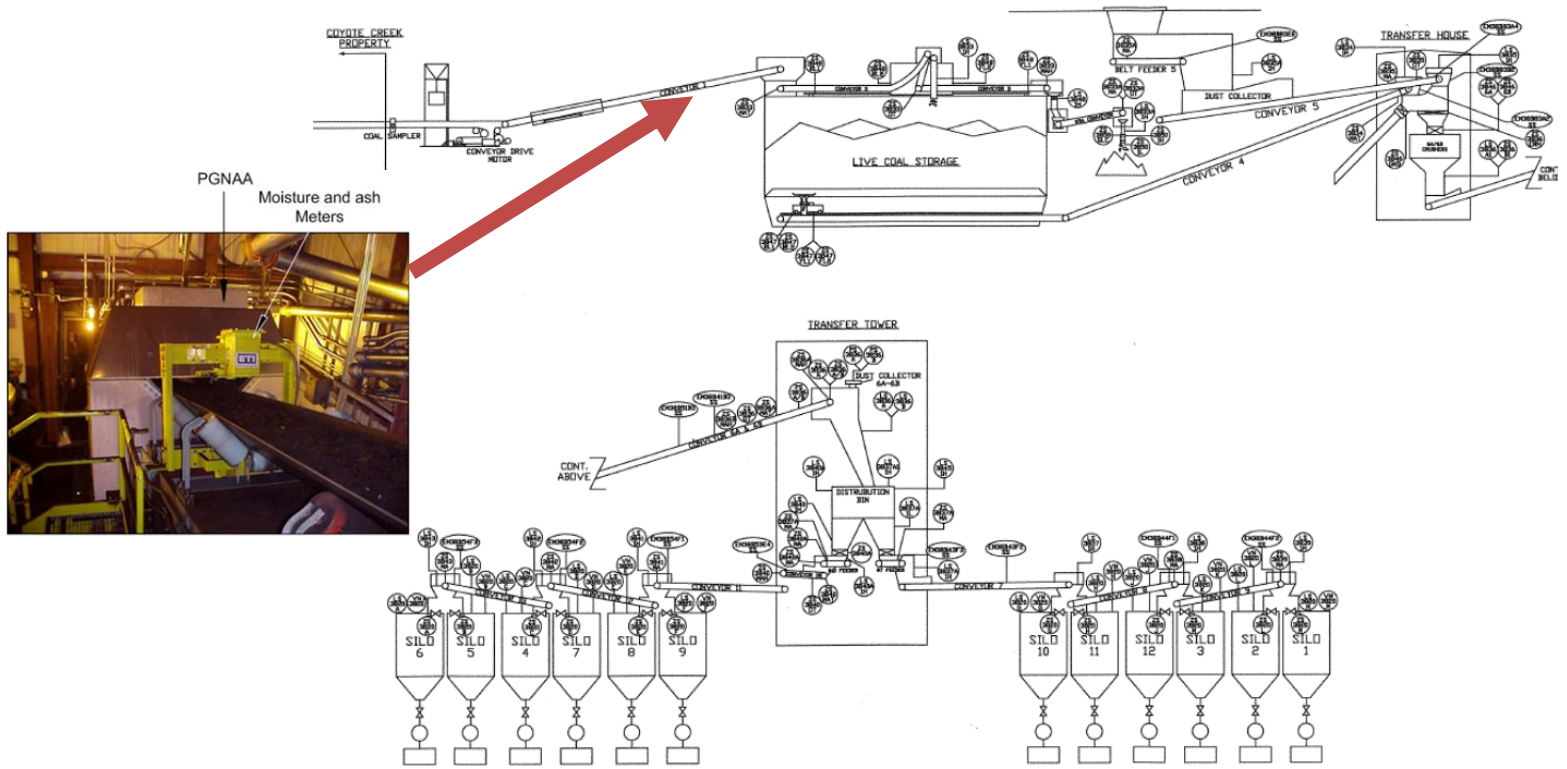
Full Stream Elemental Analyzer (FSEA) Installation July 2018



Before Installation – Coal analysis results from one composite sample representing 7000 – 12000 tons of coal available **after 3 days of firing**.

FSEA Impact – Coal properties are reported **every minute** for every 90-120 tons of as-delivered fuel **before firing**.
Flexibility of coal blending and storage.

Coal Properties from FSEA – Ash, Moisture, Heating Value, S, C, and inorganic constituents based on prompt gamma neutron activation, microwave, and dual gamma attenuation.

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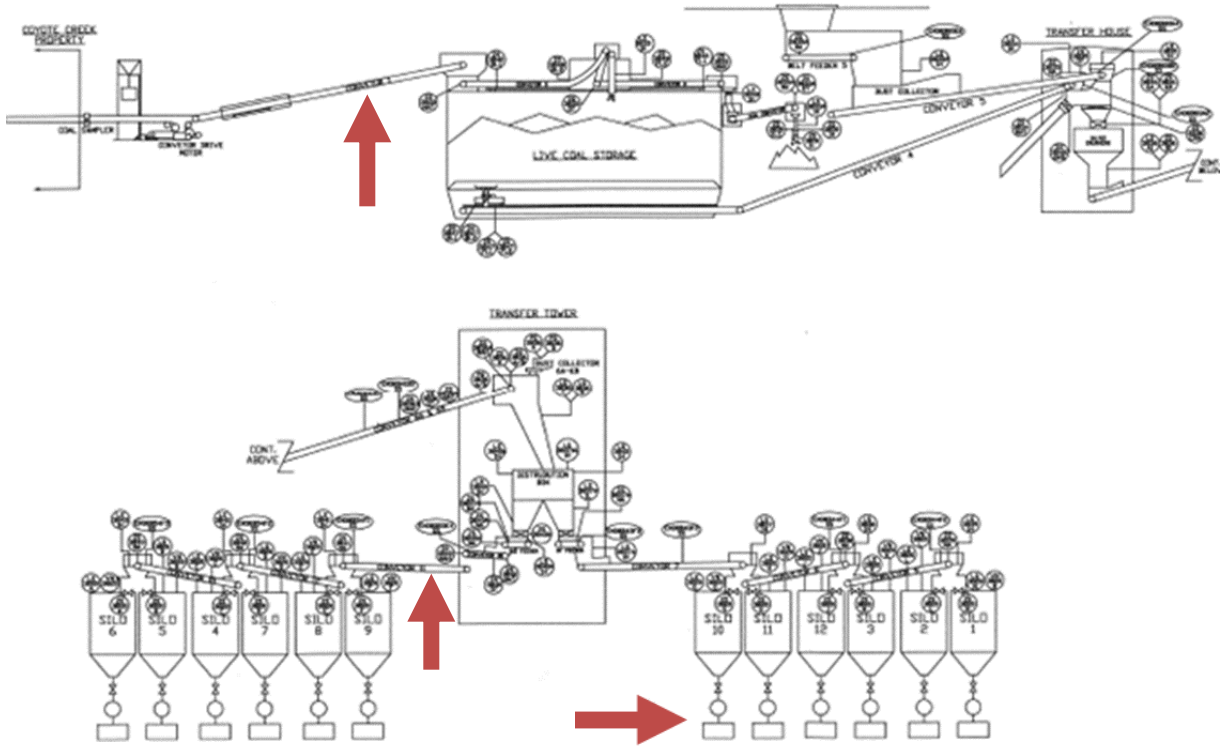
Field Testing

Coal from the mine → Belt 1 /FSEA → Live Storage → Transfer Tower → Belt 7/10 → Silos → Cyclones/ Boiler

- Collect and analyze coal samples
  - Continued characterization of FSEA performance
  - Obtain detailed data for CoalTracker
- Track power plant performance during the field test
- Use CSPI-CT beta version to predict plant performance
- Validate plant performance with real-time data



Total Number of Coal Samples Collected during the field test -> 149

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CoalTracker Output

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CSPI-CT Plant Performance Parameter Database Development

Databases	Hours of Operation	Datapoints
A	1691	91092
B	390	19761
C	337	18251
D	601	31587
E	611	28508
F	1294	69549
G	1525	82130
H	354	19167
I	83	4536
J	29	1620
K	905	48653
L	1428	77055
M	59	3239
N	154	8315
O	371	20033
P	168	9125
Q	169	9350
R	1739	95476

Databases	Hours of Operation	Datapoints
S	164	9072
T	365	20124
U	1899	88107
V	1060	58299
W	1217	66986
X	187	10337
Y	338	18529
Z	1688	91794
AA	1048	56702
AB	247	13637
AC	353	19768
AD	158	8848
AE	588	32928
AF	28	1568
AG	12	672
AH	1527	85512
AI	34	1904
AJ	608	34048

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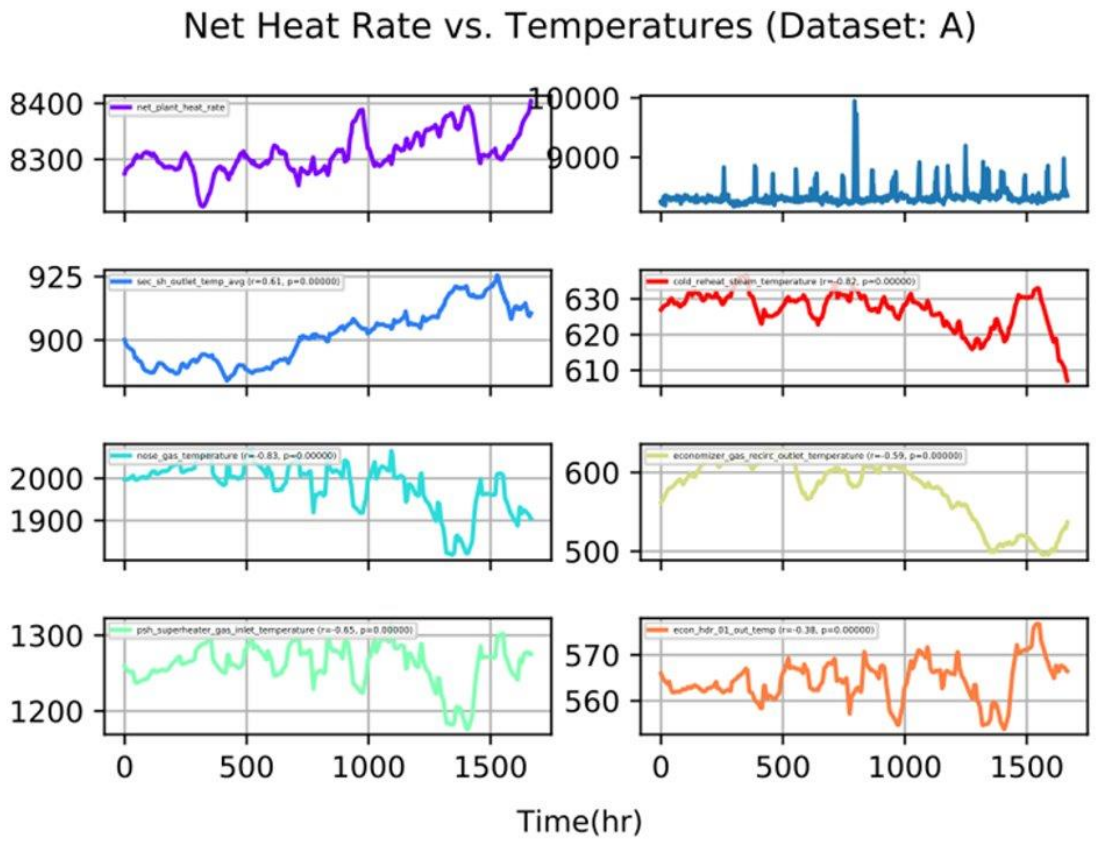
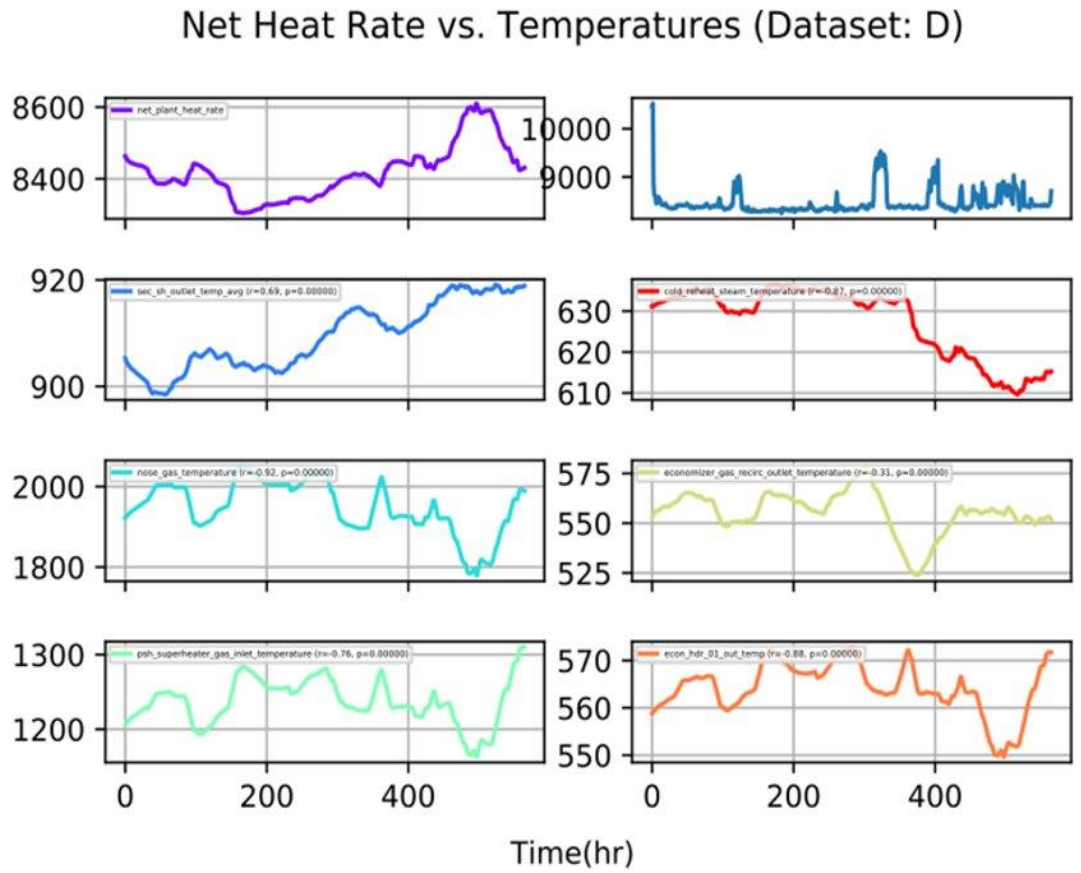
Data Analysis and Statistical Analysis





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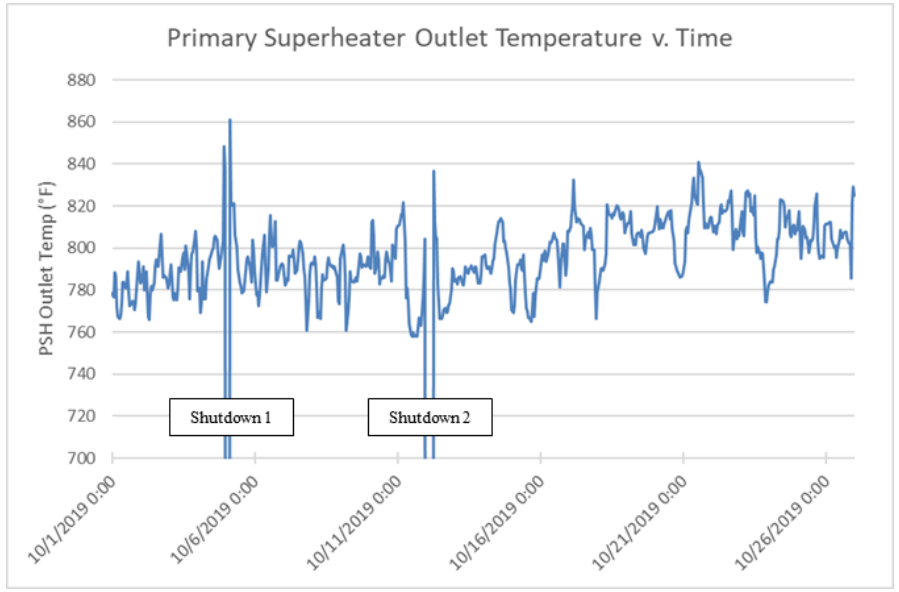
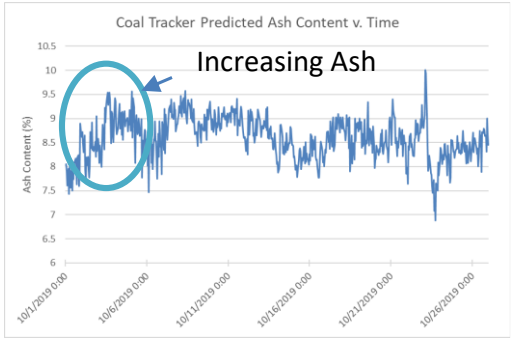
Ash Deposition

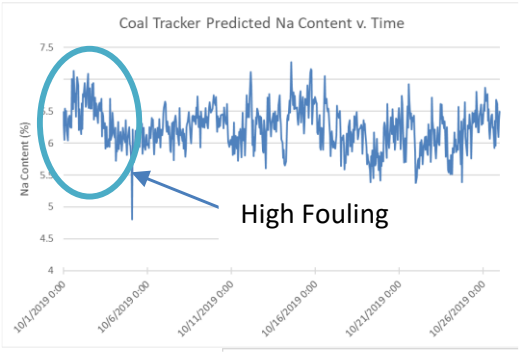
Forced outages - Diagnosing problems

Shutdown

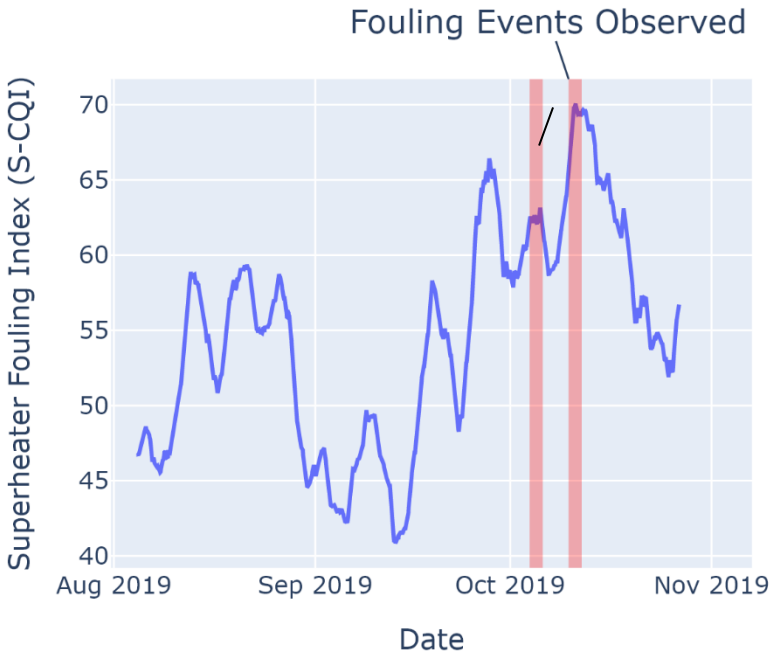


As-Fired Coal Properties





On-line Predictions



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Neural Network Development Overview

- Neuro-Evolution for Time Series Data Prediction
- Methods (see next slide):
  - NEAT-based (EXALT, EXAMM)
  - Ant Colony-based (ASNE, ANTS, CANTS)
  - Transfer learning (N-ASTL)
- Operating Parameters:
  - Main Flame Intensity at 12 cyclone burners
  - Steam outlet temperature, SSH
  - Net Plant Heat Rate
- Results:
  - EXAMM vs. Traditional RNNs
  - Deep Recurrent Connections
  - Further out predictions (past the next time step)
  - Coal Tracker Integration
  - Time Shifting Coal Tracker Parameters
  - Transfer Learning
  - Production RNN Generation
  - Time-lagged Correlation Visualization

Approach to Conducting Statistical and Neural Network Modeling of Boiler Operations

3. Secondary superheater (SSH) performance
- Conditions monitored – Inlet and outlet temperature, cleanliness factor, attemp sprays, tube failure

Factors that impact
– Operating parameters - boiler load, coal flow, air flow, air flow split between cyclone and OFA, soot blowing in SSH, gas flow rate
- Coal properties – ash content, moisture, heating value, ash composition, sodium level

CQMS – Erosion, high temperature fouling, strength development, Peak impact pressure-deposit removal

2. Waterwall Performance
- Conditions monitored – boiler nose temperature, SSH attemperation sprays, cleanliness fact[illegible]ecovery)

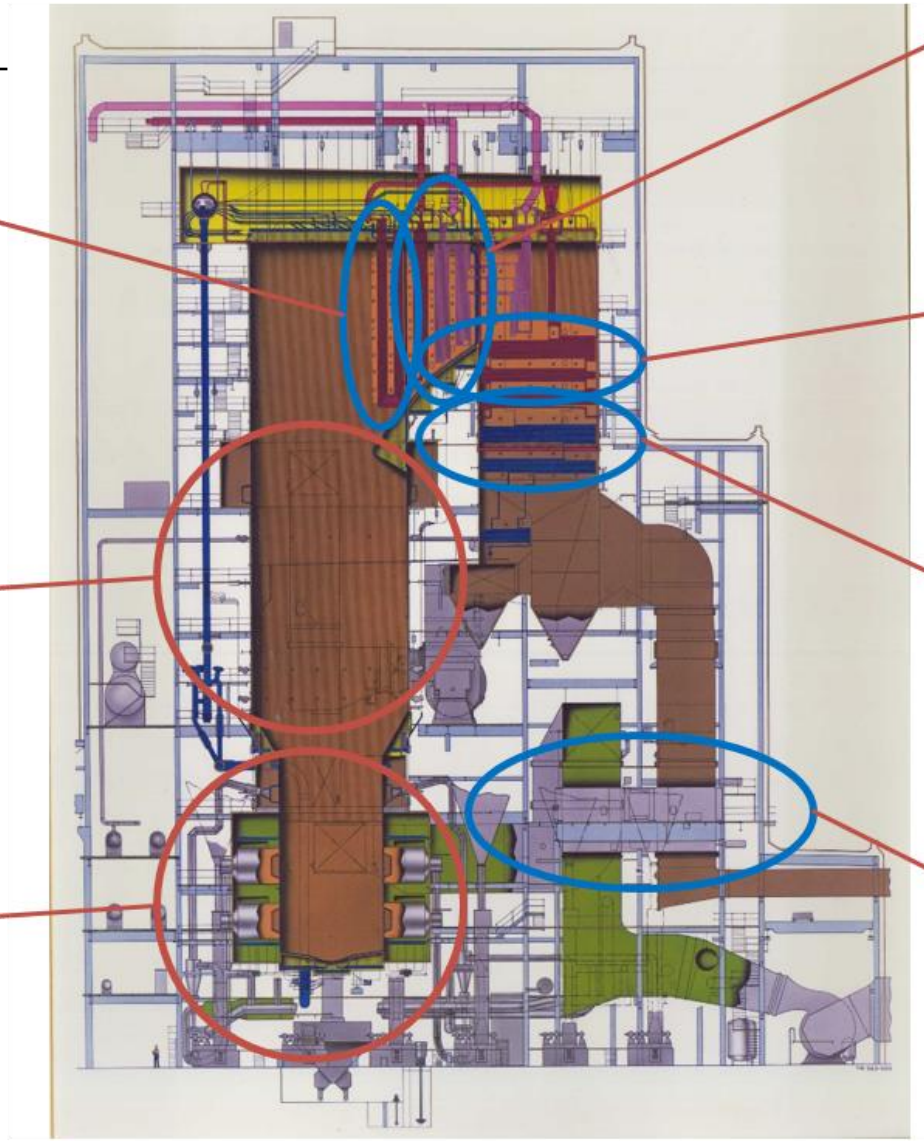
Fac[illegible]
– Op[illegible]ters - boiler load, coal flow, air flow, air flow split between cyclone, OFA, soot blowing
- Coal properties – ash content, moisture, heating value, ash composition, S (pyrite), clays

CQMS – Wall Slagging, deposit strength

1. Cyclone burner performance
- Conditions monitored – oil flow, flame intensity

Factors that impact
– Operating parameters - boiler load, coal flow, air flow, air flow split [illegible]
air [illegible]
- Coal properties – ash content, moisture, heating value, ash composition, base/acid

CQMS – slag flow



4. Reheat Superheater (RSH)
- Conditions monitored – Inlet and outlet temperature, Cleanliness factor, attemp sprays

Factors that impact
– Operating parameters - boiler load, coal flow, air flow, air flow split between cyclone and OFA, soot blowing in RSH
- Coal properties – ash content, moisture, heating value, ash composition, sodium level

CQMS – low temperature fouling (sulfate based), temperature dependence

5. Primary superheater (PSH) performance
- Conditions monitored – Inlet and outlet temperature, Cleanliness factor, attemp sprays

Fac[illegible]
– Op[illegible]ters - boiler load, coal flow, air flow, air flow split between cyclone and OFA, sootblowing in PSH
- Coal properties – ash content, moisture, heating value, ash composition, sodium

CQMS – low temperature fouling (sulfate based), temperature dependence

6. Economizer performance
- Conditions monitored – Inlet and outlet temperature, Cleanliness fact[illegible]

Fac[illegible]
– Op[illegible]ters - boiler load, coal flow, air flow, air flow split between cyclone and OFA, sootblowing in Econ
- Coal properties – ash content, moisture, heating value, ash composition

CQMS – low temperature fouling (sulfate based), temperature dependence

7. Air heater performance
- Conditions monitored – Air inlet an[illegible]
Cl[illegible]
Fact[illegible]
– Operating parameters - boiler load, coal flow, air flow, air flow split between cyclone and OFA - -
- Coal properties – ash content, moisture, heating value, ash composition, sodium, halogens

Database

Statistics

Neural Networks

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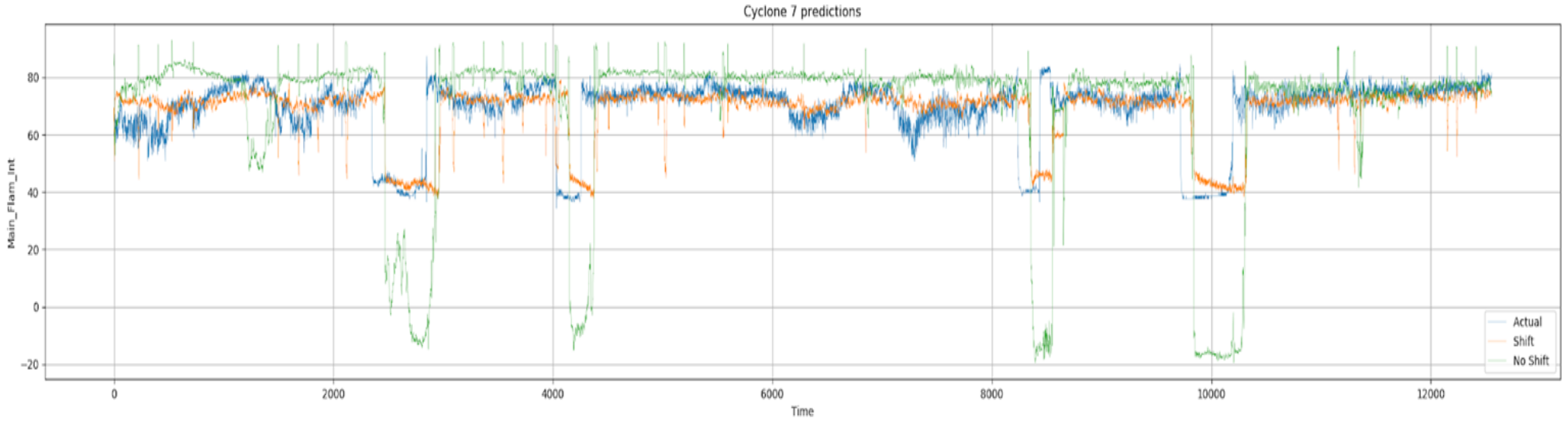
Improving Prediction with Shifted Parameters

- Microbeam's coal tracker's program can predict the fuel properties up to 8 hours in the future.
- When we train the binaries, we can use those fuel properties ahead of time to improve the training and testing accuracy.
- Fuel properties parameters: Base_Acid_Ratio Ash_Content Na_Content Fe_Content BTU Ash_Flow Na_Flow Fe_Flow.
- Time offset: 120 mins



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Improving Predictions with Smaller Input Sub-file Size

- Input sub-files with different size (25, 50, 100 datapoints per file) are tested on EXAMM
- RNNs update the weights of the models with gradients calculated from errors obtained from smaller batches of data
- Sub-file size = 50 performs the best

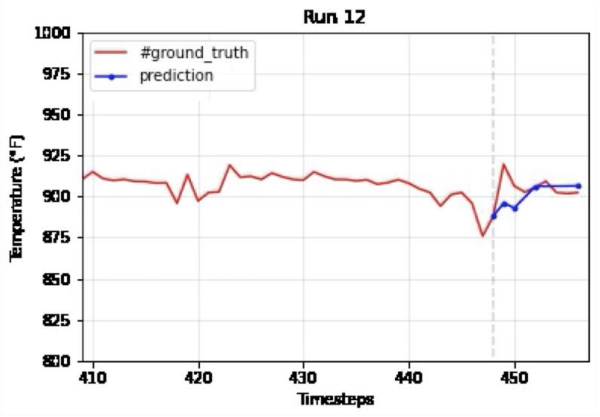

Figure 1: Predictions for a model trained on files of 100 records

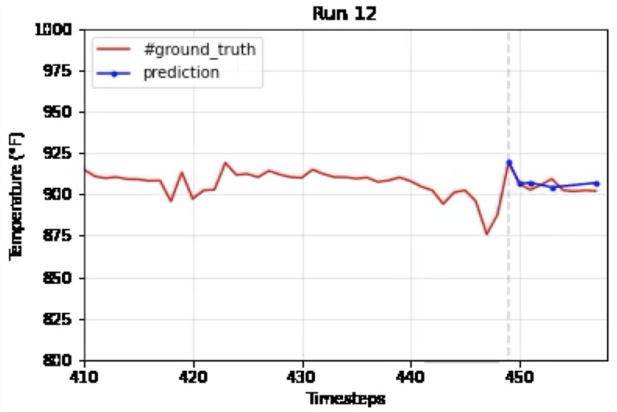

Figure 2: Predictions for a model trained on files of 50 records

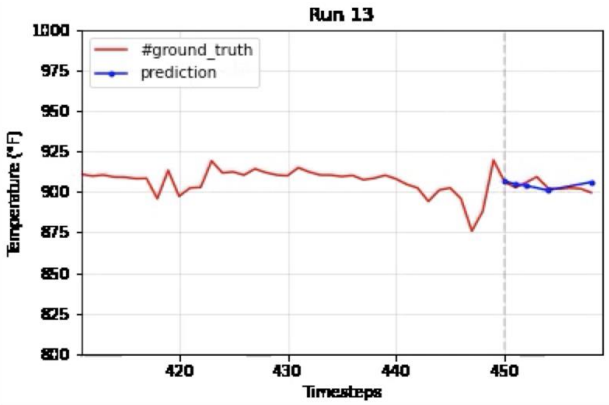

Figure 3: Predictions for a model trained on files of 25 records

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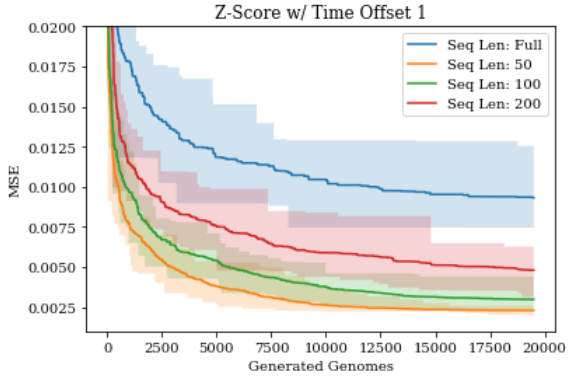
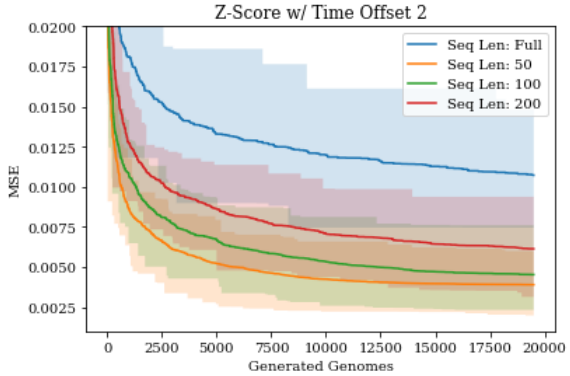
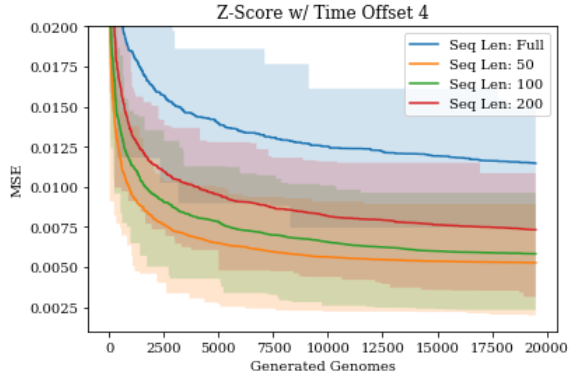
Neural Network Training and Testing

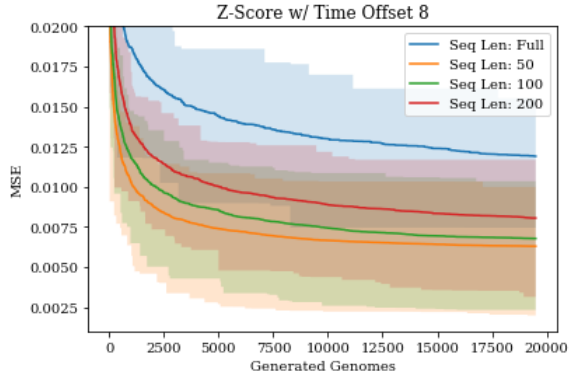
Net Plant Heat Rate and Flame Intensity

Net Plant Heat Rate

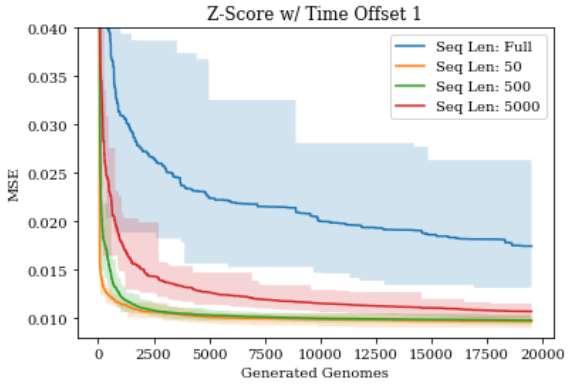


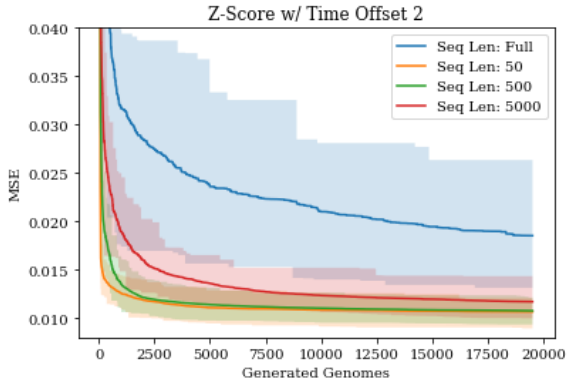


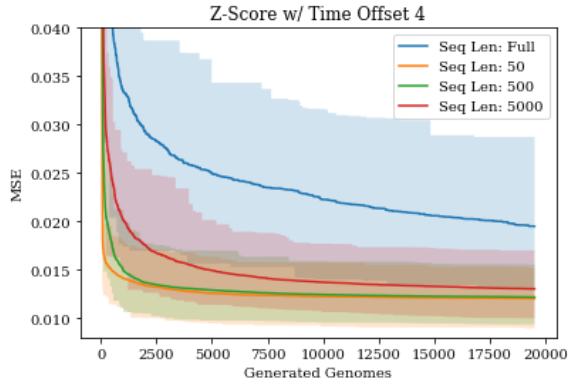


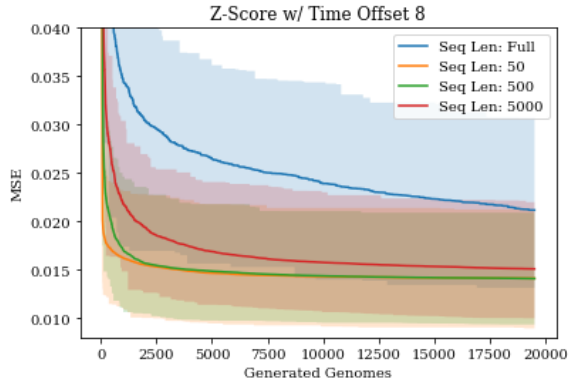


Flame Intensity









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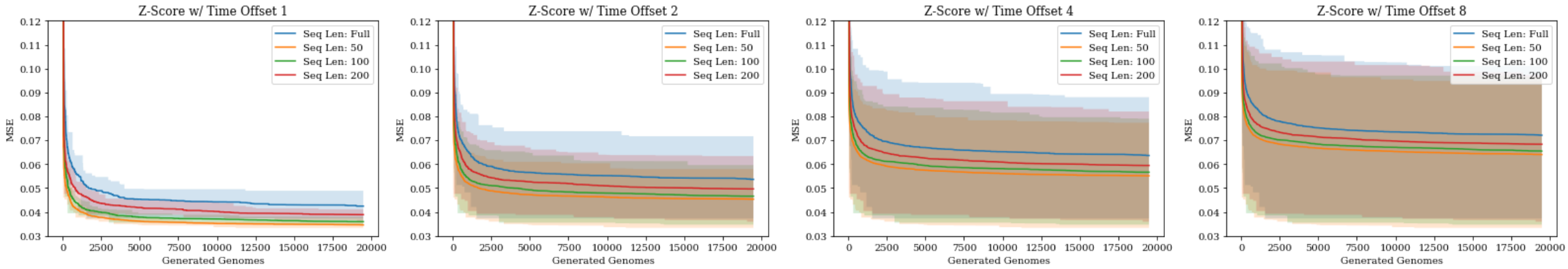
Neural Network Training and Testing

Secondary Superheater Outlet Steam Temp



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Combustion System Performance Indices (CSPI) Program Upgradation

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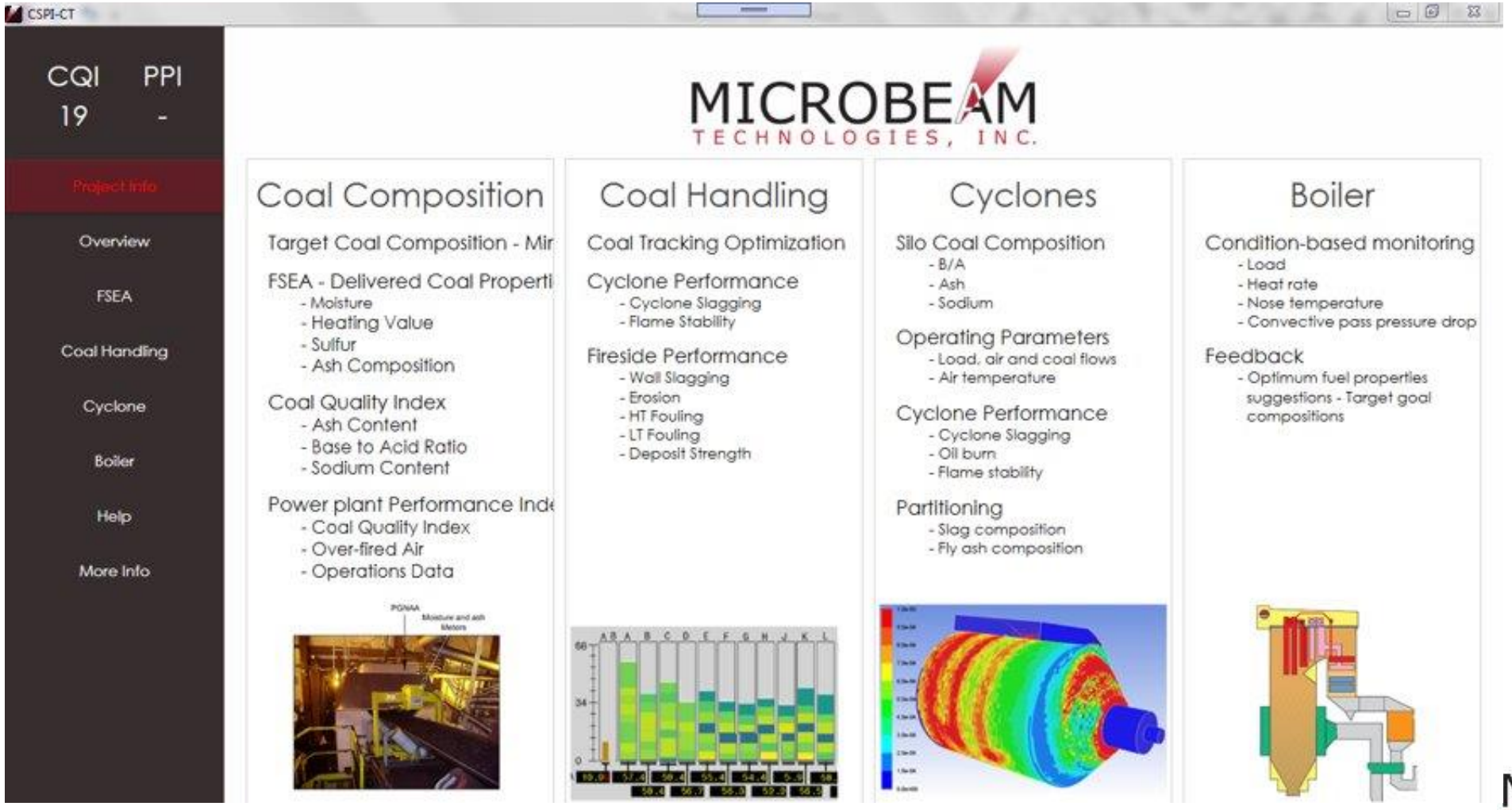
CSPI-CT



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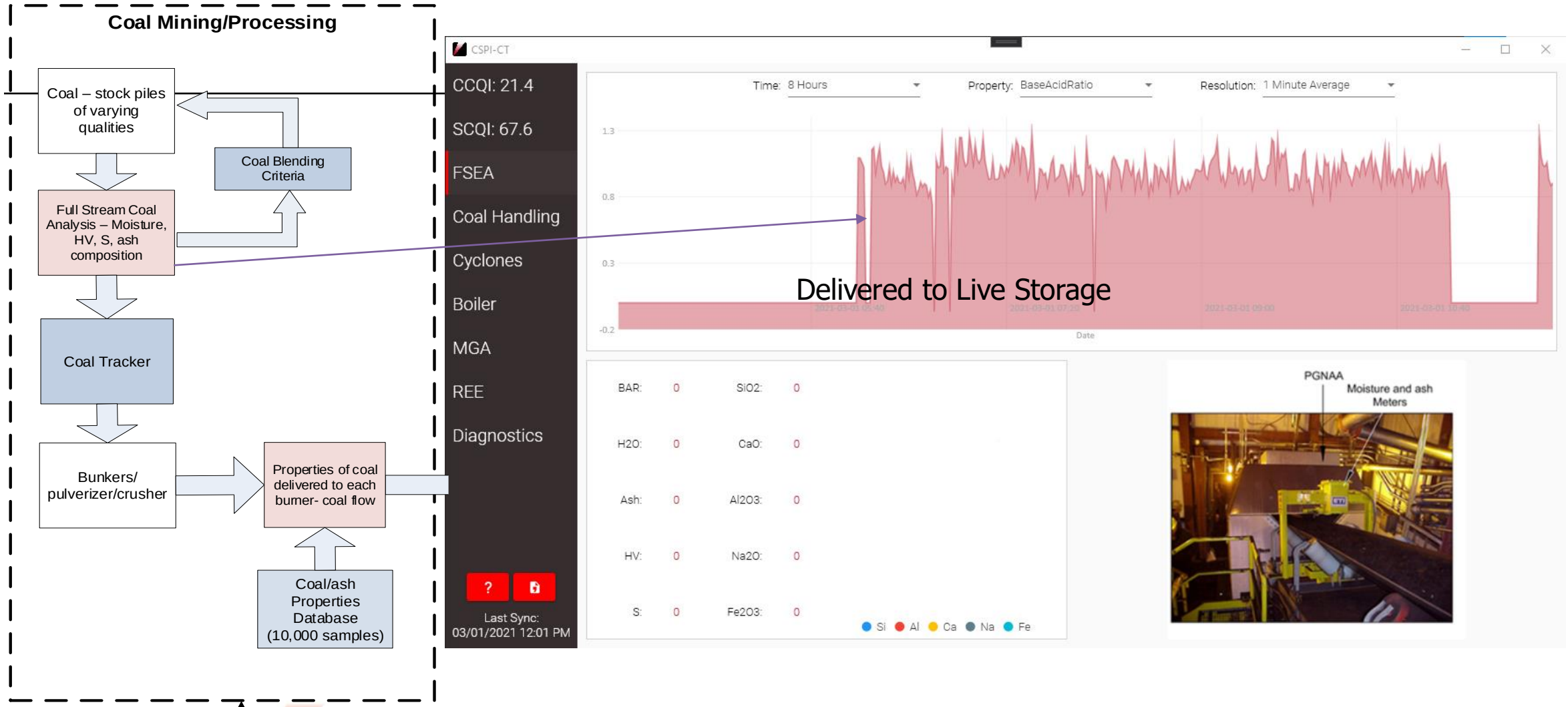
As-Received Fuel Properties



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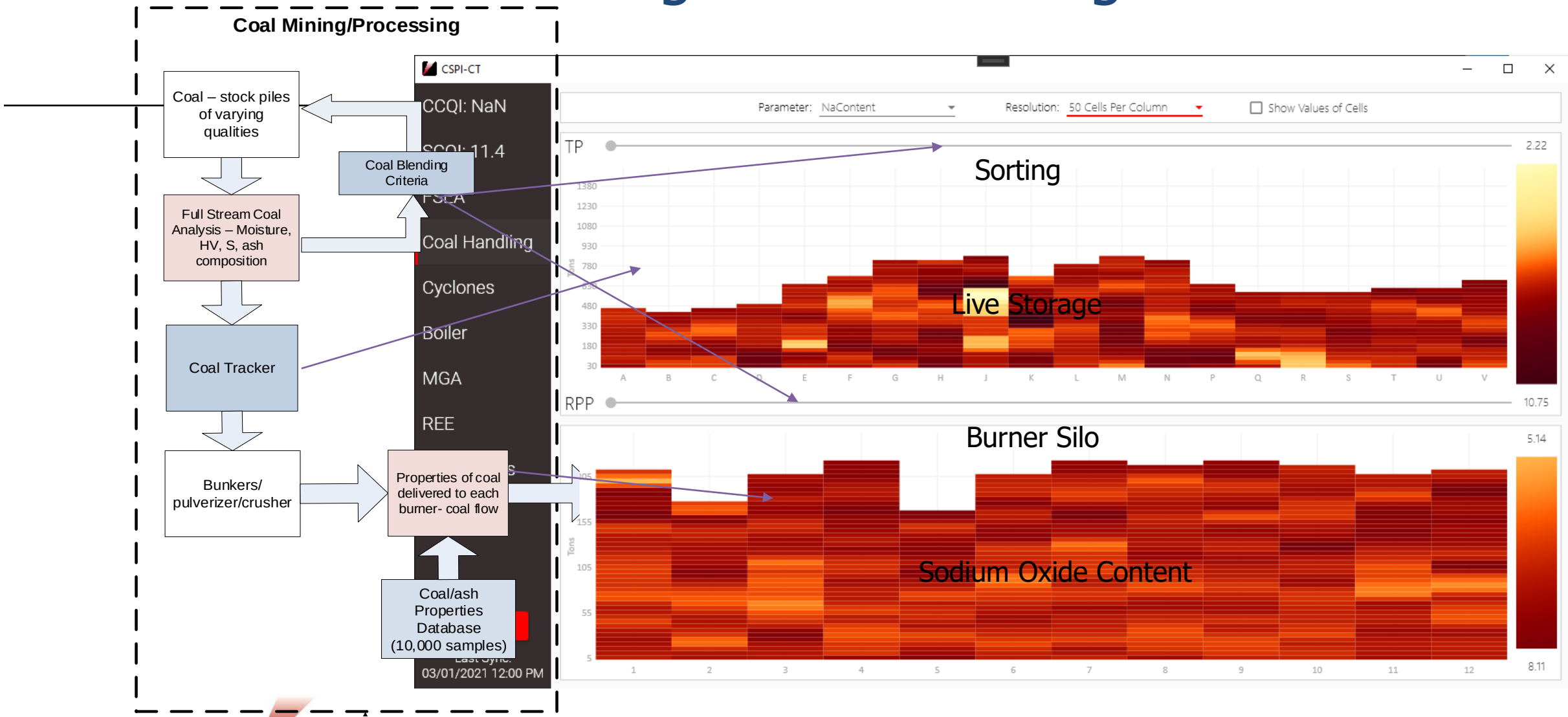
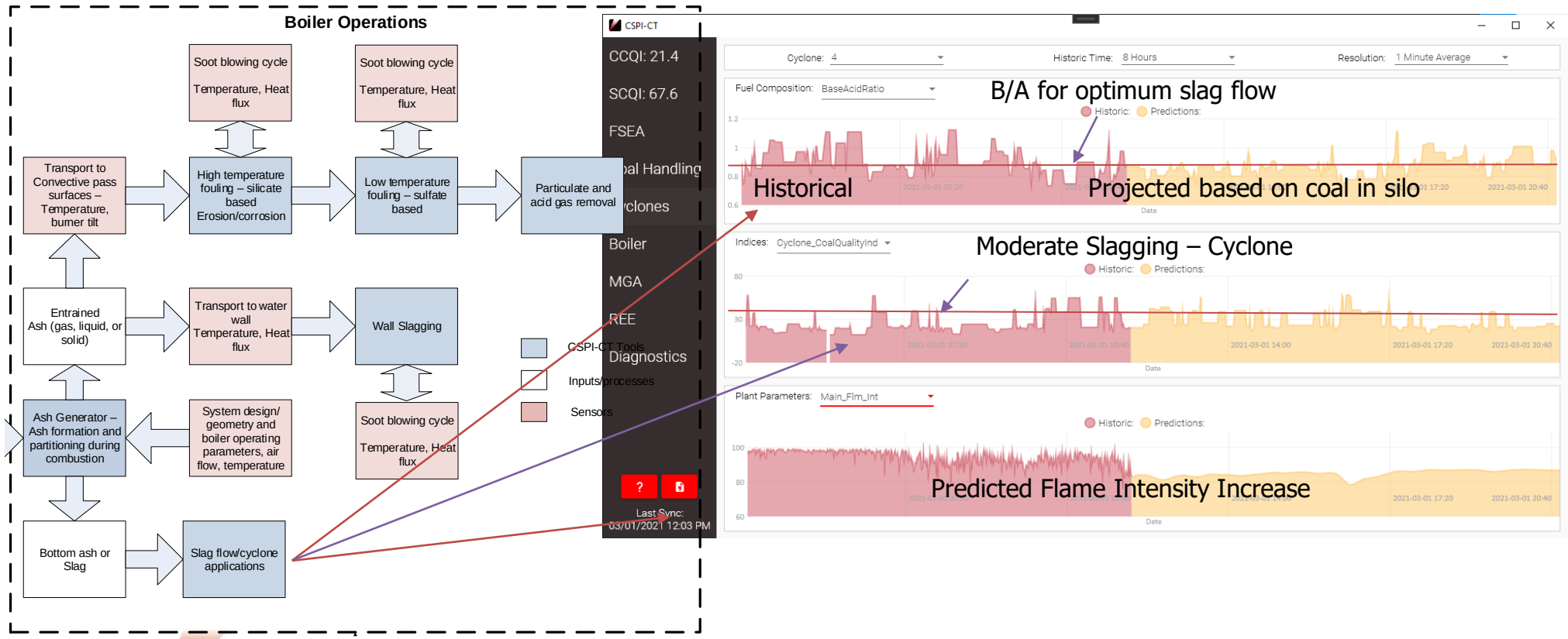
Coal Mining and Processing



Boiler Operations – Cyclone Performance



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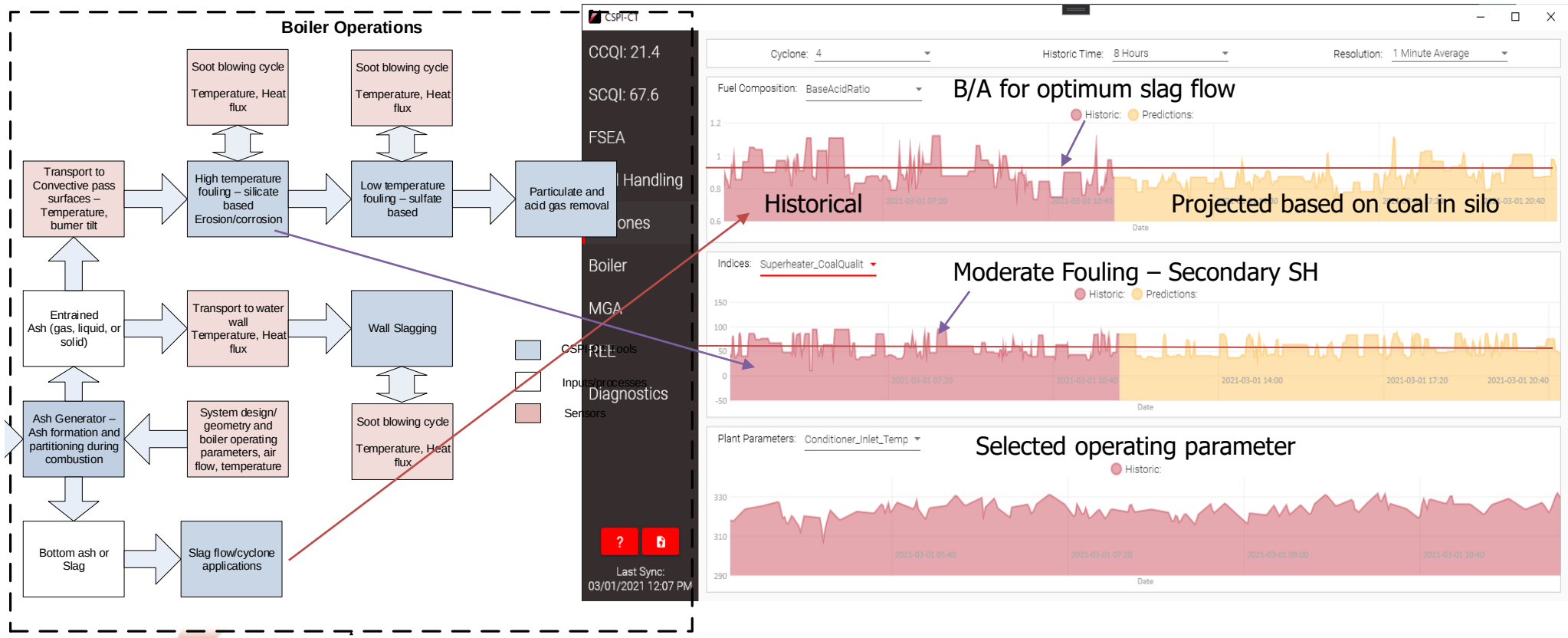
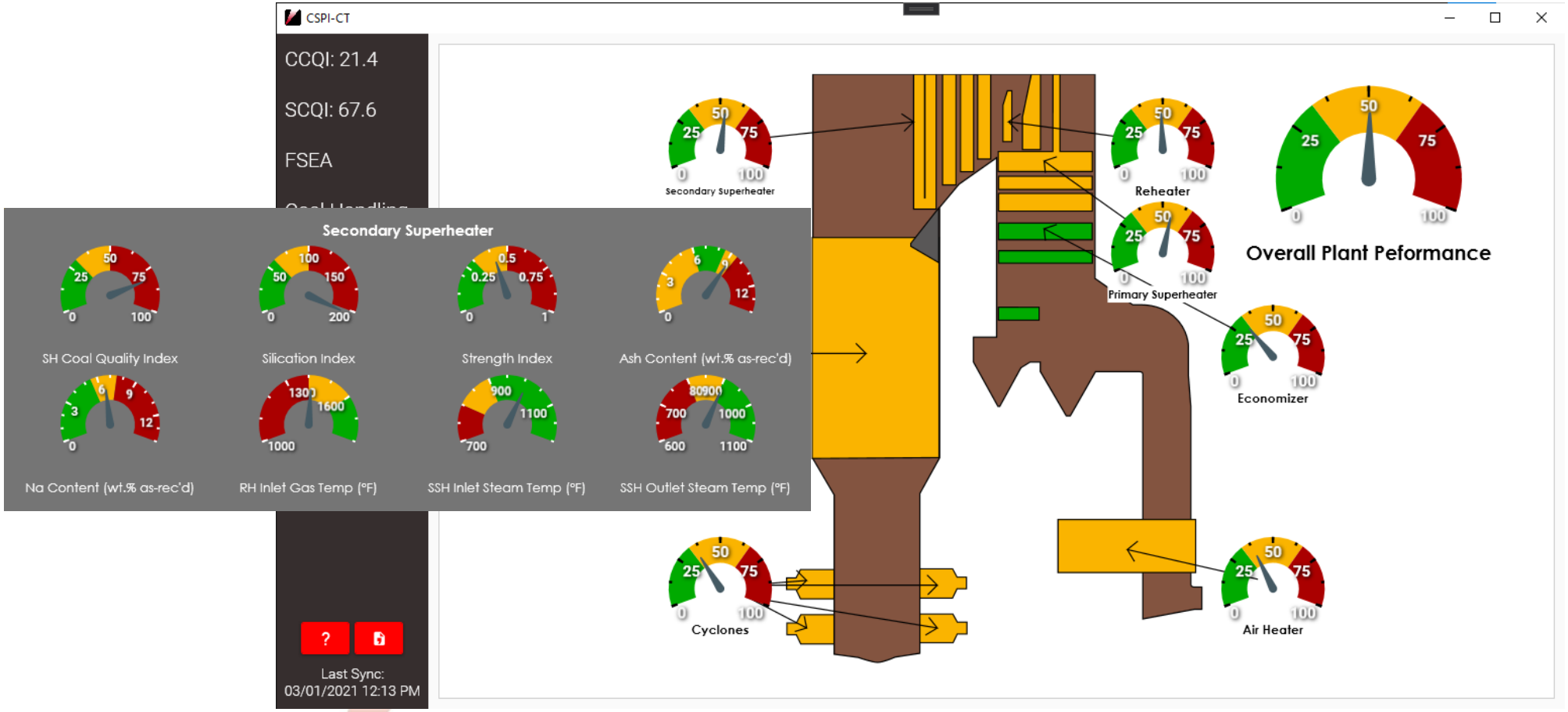
Boiler Operations – Cyclone and High Temperature Fouling



CSPI-CT Boiler Diagnostics



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Opportunities for Plant Improvement and Cost Savings

- Installation of FSEA
  - Decreased cost of analysis
  - Opportunity to blend coal
  - Opportunity to optimize plant operating conditions to match coal properties
- Improved heat rate – coal property impacts
- Decrease oil firing through optimizing fuel properties
  - No significant oil burn event since installation and use of the technology
- Decrease fireside ash deposition- reduce number of scheduled and forced outages (maintenance costs)
- Preliminary cost savings estimated*

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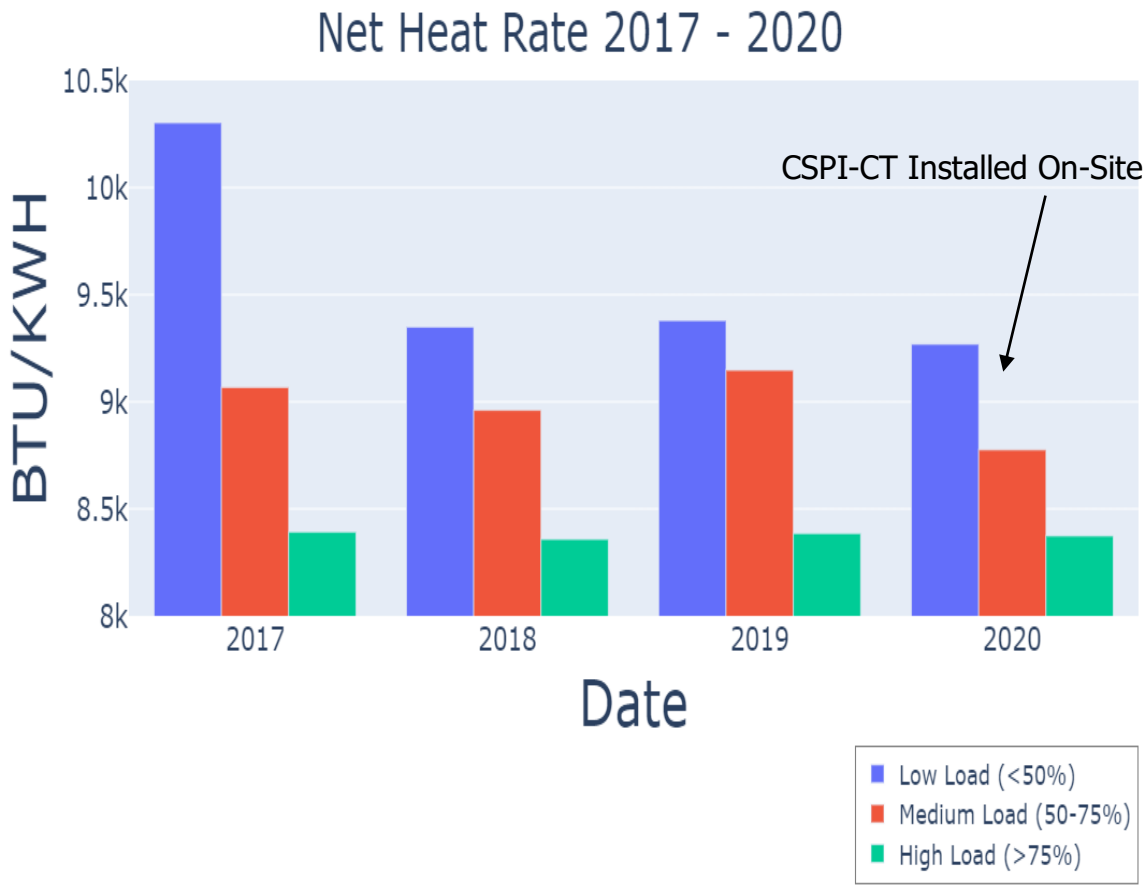
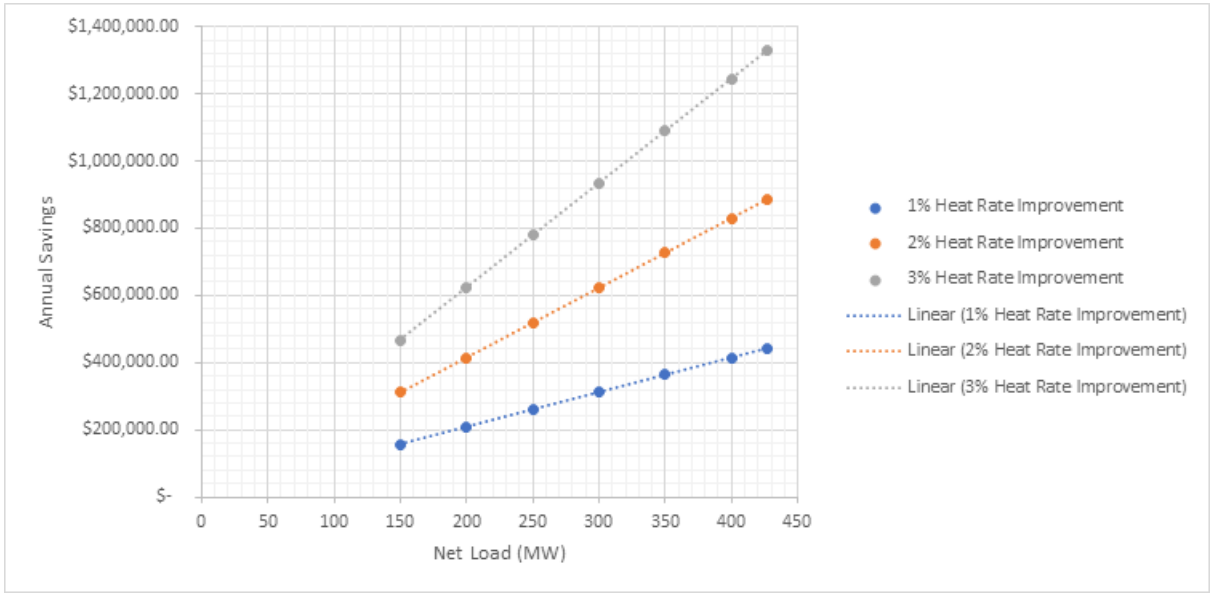
**All cost saving results are estimations and subject to certain assumptions. In particular, it is difficult to determine causes of derates without more detailed documentation from the plant itself, and all revenue data is an estimation based on hourly pricing and MW output without factoring in unplanned shutdowns due to tube leaks, pump failures etc.*

Heat Rate Savings – CSPI-CT Installation





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Condition Based Monitoring (CBM) Project Progress Summary

- 25 Databases - 23429 hours of operational data
- Life of Mine Database - 16,000 data points
- As-delivered fuel properties database – 3,000,000 data points
- As-fired fuel properties database - 500 coal short prox results
- Conducted a field test – collected 149 coal samples
- Conducted over 30 project meetings and spent over 1200 hours analyzing data
- Published 9 papers and 1 book chapter
- Currently working on updating indices with modified correlations

- Implemented 4 Novel Algorithms (EXALT, EXAMM, EXONA, CANTS)
- Trained 42 million RNNs
- NN Flame Intensity predictions
- Predicting 8 hours in the future – Net Plant Heat Rate
- Installed CSPI-CT full-featured version on-site
- Developed CoalTracker model to track fuel
- Developed phenomenological, statistical and neural network based predictive algorithms
- Developed Graphical User Interface (GUI) for CSPI-CT

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Next Steps

- **Validation Field Test**
  - Planned for May 2021
  - Field test report due on May 31, 2021
- **Combustion System Performance Indices Algorithm Development and Testing**
  - Conduct neural network training for additional boiler parameters
  - Improve indices predictions based on field test data
  - Augment indices with neural network derived relationships
  - Installation and testing of a neural network based CSPI-CT
- **Operator and Plant Personnel Training**
  - Follow-up training (initial training Dec. 2020)

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Questions

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