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

(Award No. DE-FE00031547)

2019 Annual Project Review Meeting for Crosscutting Research

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Acknowledgement – DOE NETL
Sydni Credle – DOE NETL Project Manager

4/9/19

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**

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.

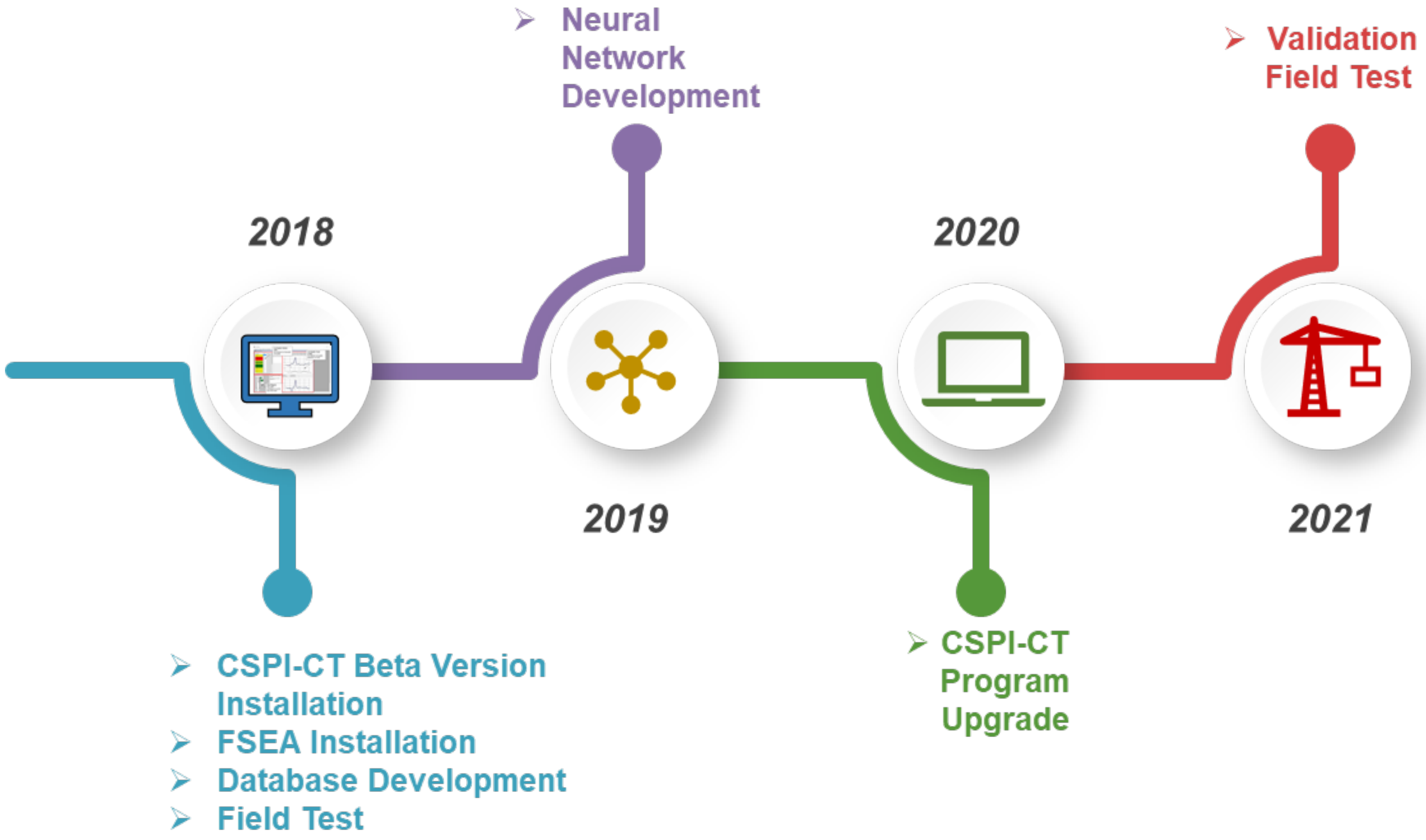
Project Information

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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Project Background

Microbeam’s Fireside Performance Indices

High temperature fouling (silicate) – Platens and high temperature convective pass

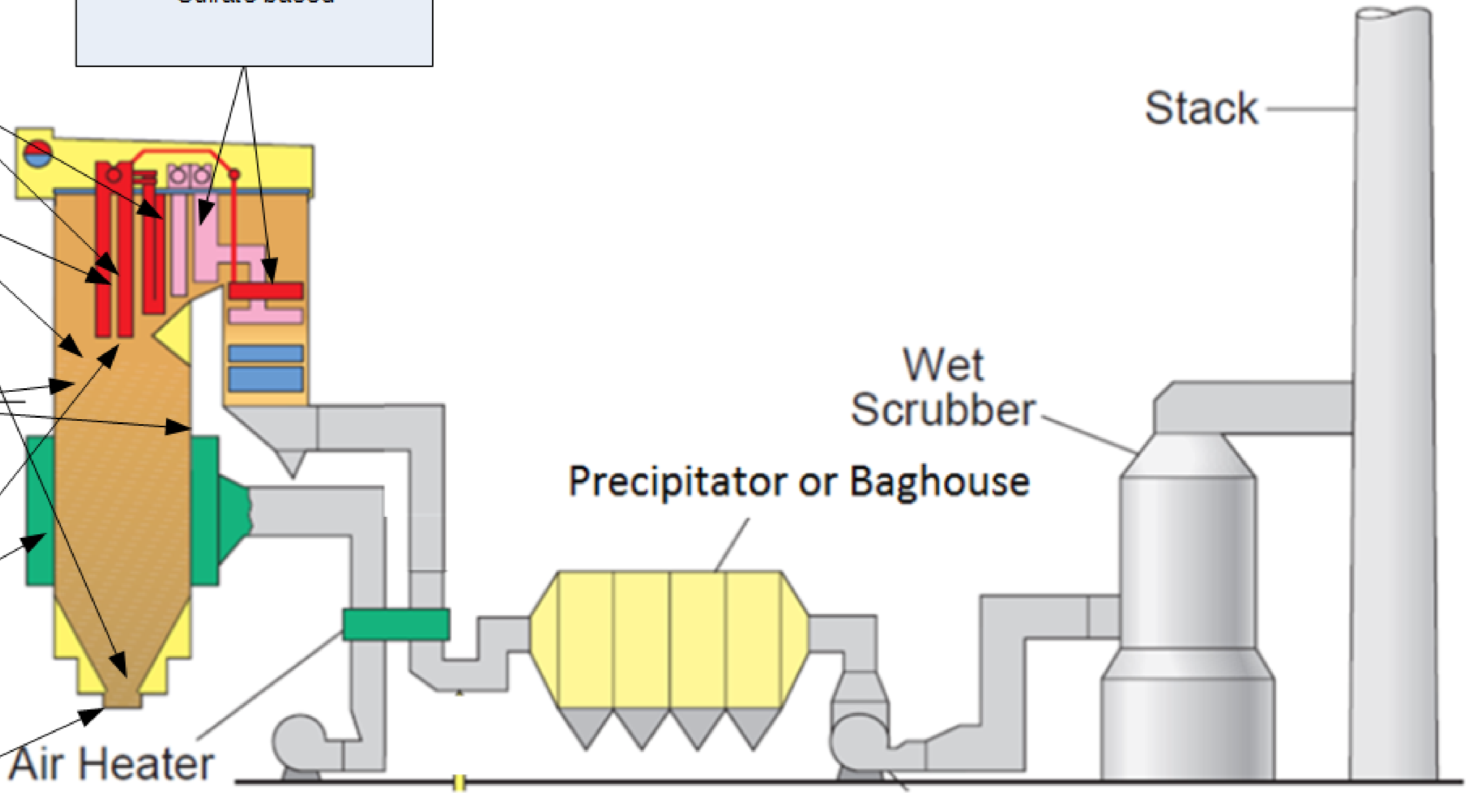
Low temperature fouling – Sulfate based

Deposit Strength – Wall slagging, high temperature fouling (silicate), and slag removal

Wall slagging – Accumulation potential on the boiler walls

Wear –
Abrasion wear – fuel handling
Erosion wear – heat transfer surfaces

Slag flow – slag discharge systems – cyclone-fired boilers and wet bottom systems



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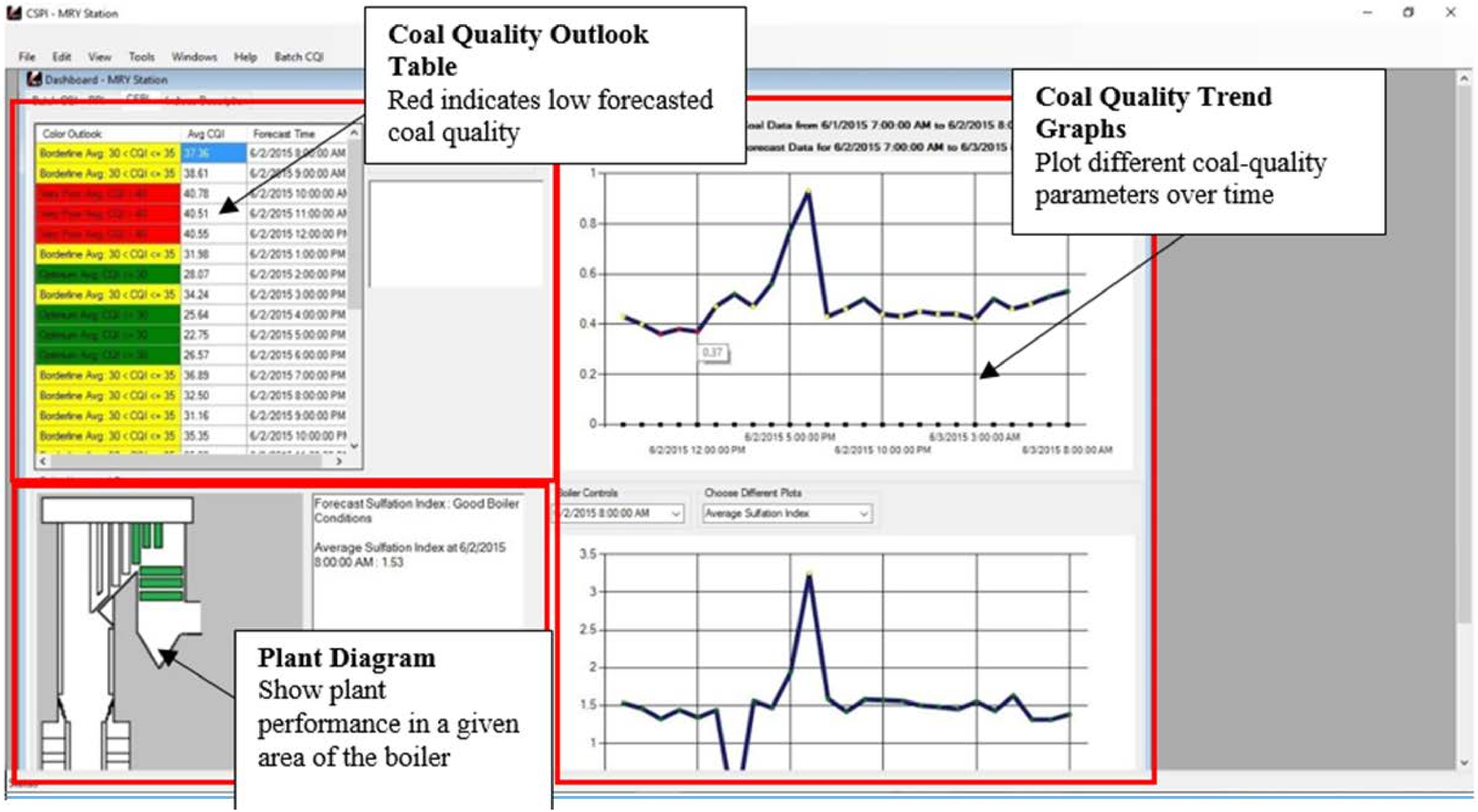
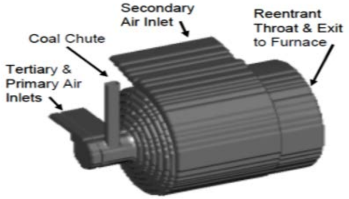
Project Background

Microbeam's Combustion System Performance Indices Program User Interface



Testing Sites

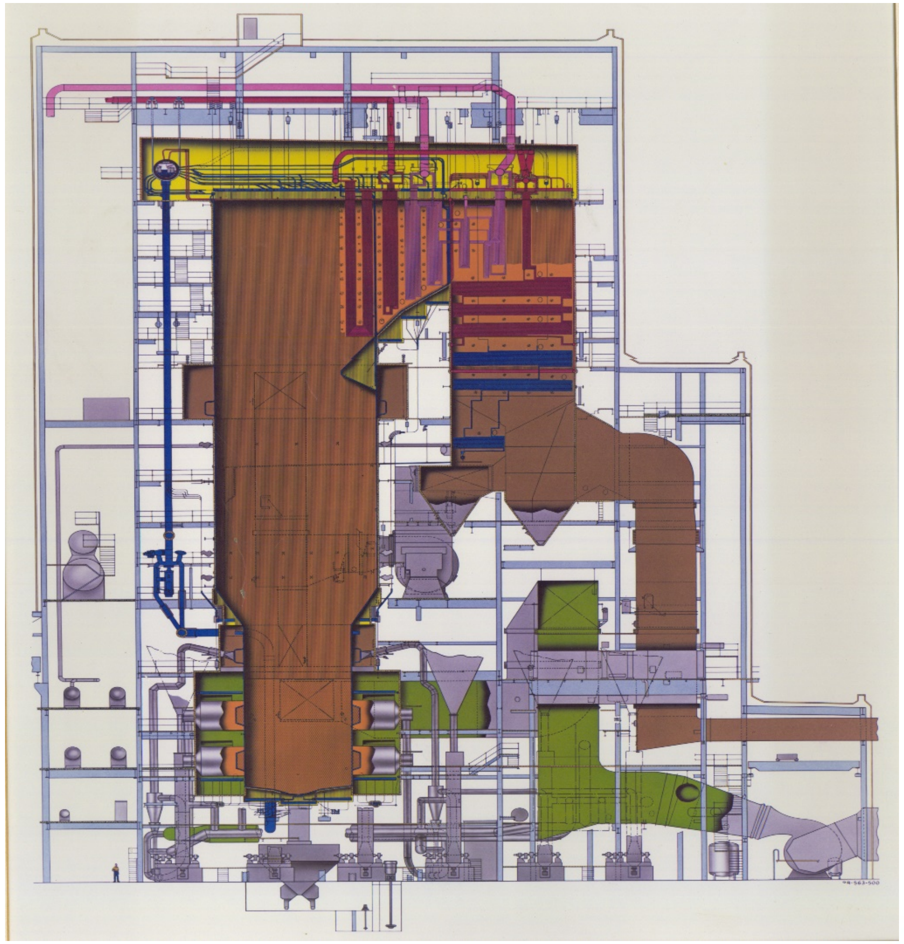


Primary site: Otter Tail Power's Coyote Station

- 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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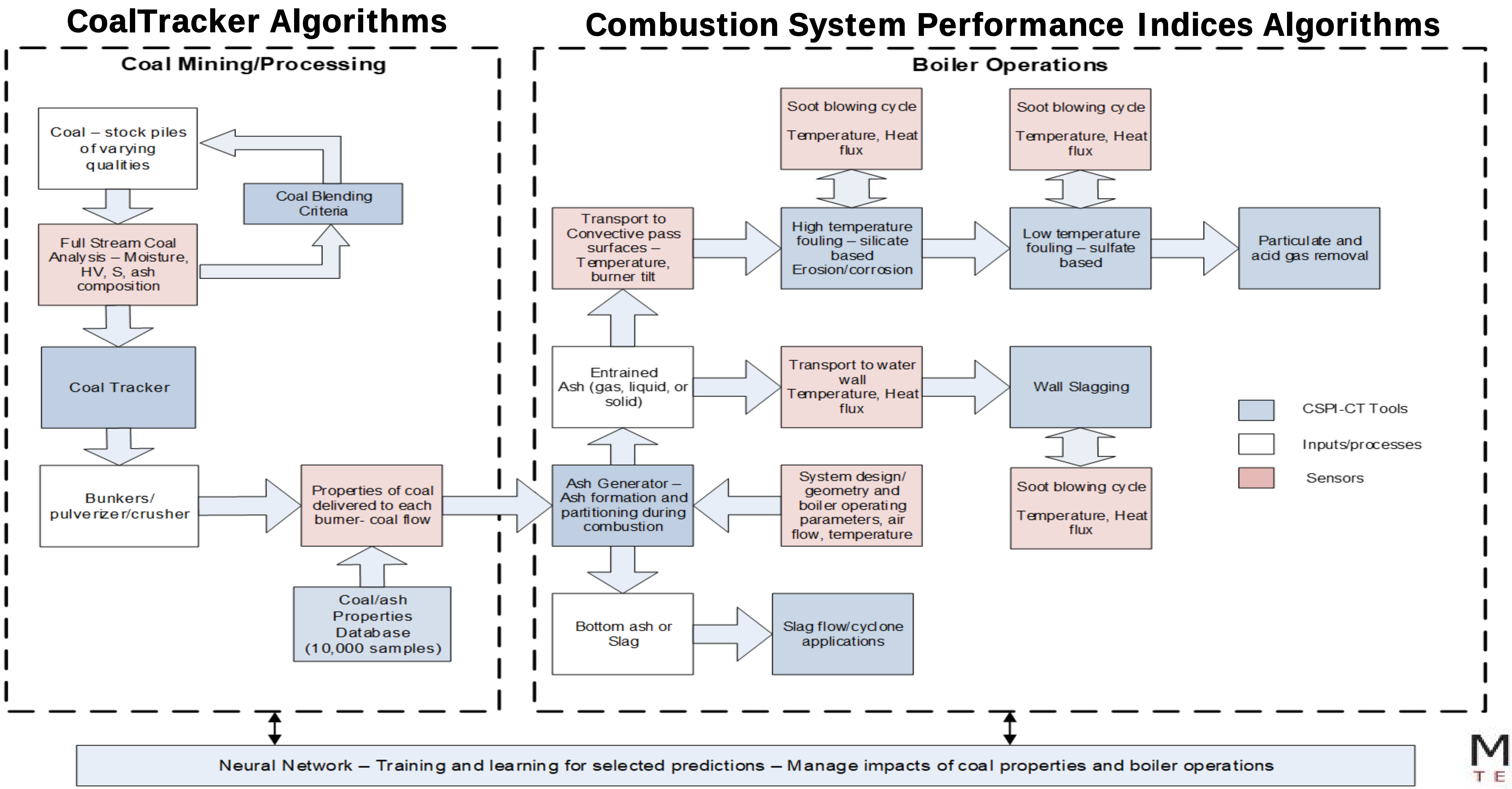
Project Overview



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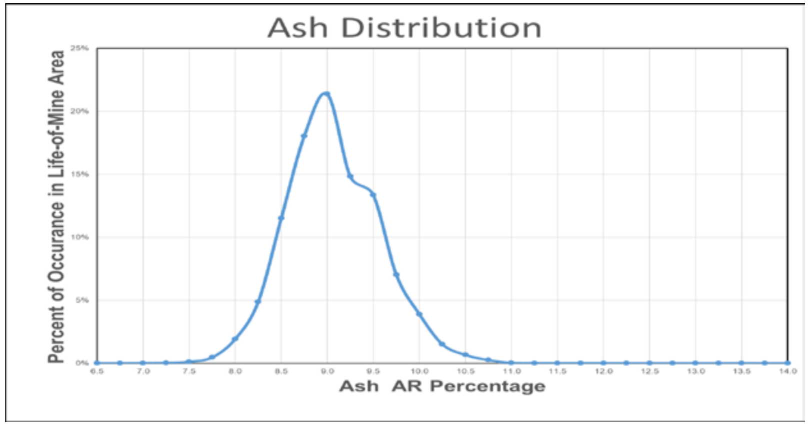
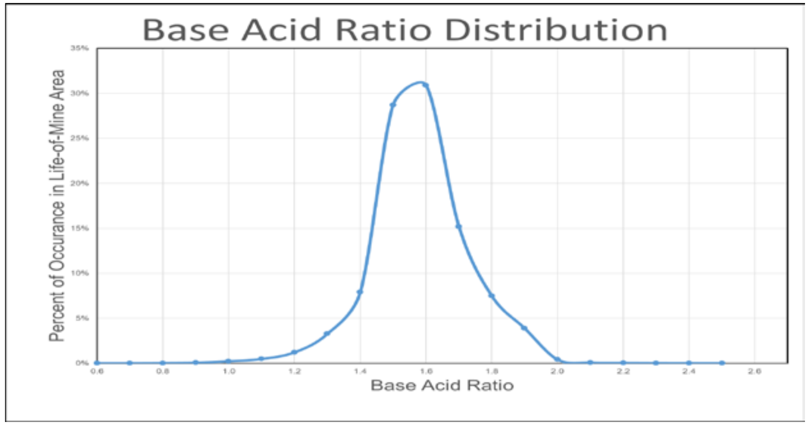
Accomplishments

- **CoalTracker Algorithm Development and Testing**
  - Analyzer installation (Coal properties)
  - Database development (Coal properties)
  - Coal Tracking applications
- **Combustion System Performance Indices Algorithm Development and Testing**
  - Access to plant operating/conditions monitoring (Plant operation and performance)
  - Beta version of Combustion System Performance Indices (CSPI) installed at plant
  - Database development (Powerplant Parameters)
  - Neural network training (Plant performance)

Database Development – Neural network and Machine Learning Applications for Improving Plant Performance

Database	Database consists of	Data Points / No. of Samples
Life of Mine Dataset	Life of Mine coal properties – Ash, BTU, ash composition	16000 Data points
As-fired Fuel Properties Dataset	As-fired Fuel properties – Ash, BTU, ash composition	500 samples
FSEA Data	FSEA Output - Fuel properties	Minute-by-minute data for 9 months
Plant Parameter Data	Plant Operating Parameters	Operating data for 25 months - Over 54,000 data points for each month





$$B/A = \frac{Fe2O3 + CaO + MgO + K2O + Na2O}{SiO2 + Al2O3 + TiO2}$$

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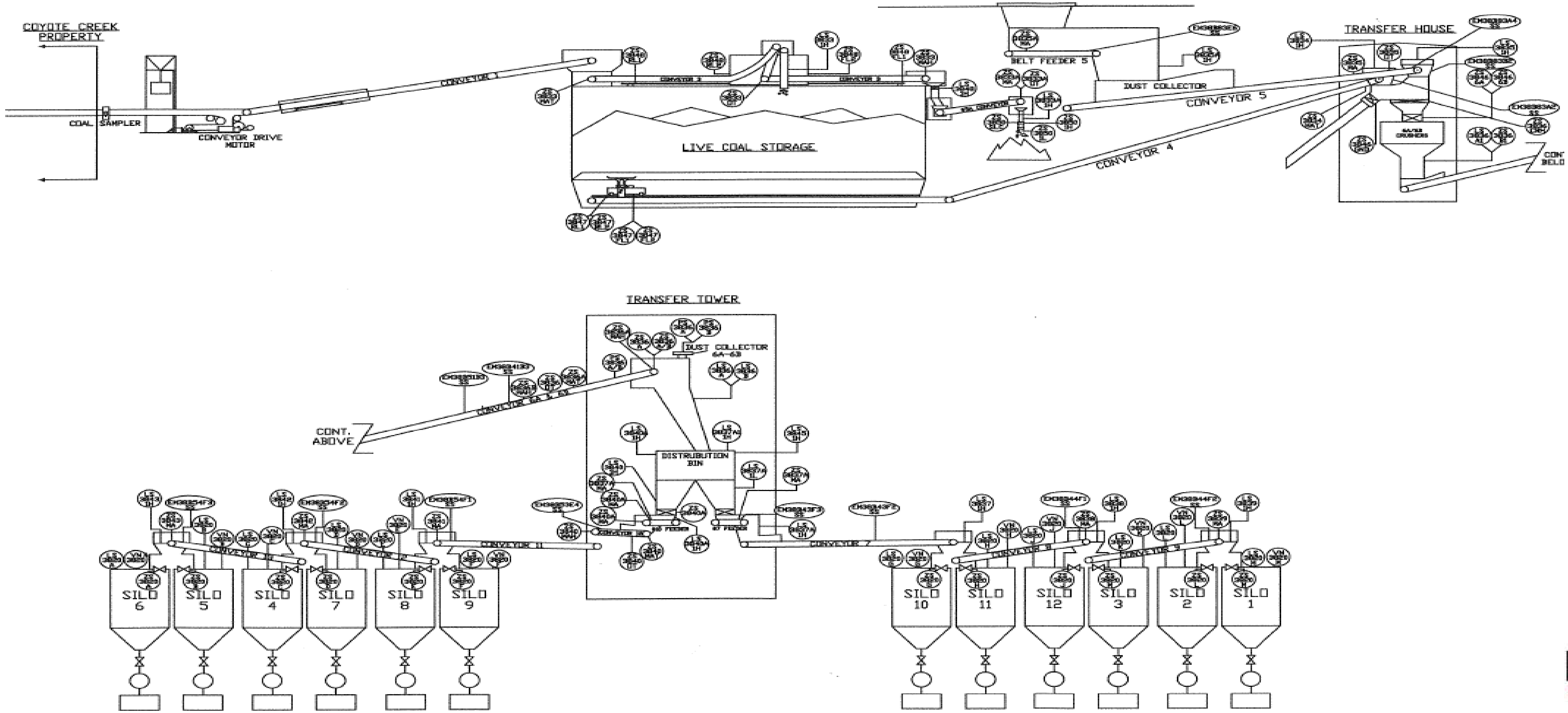
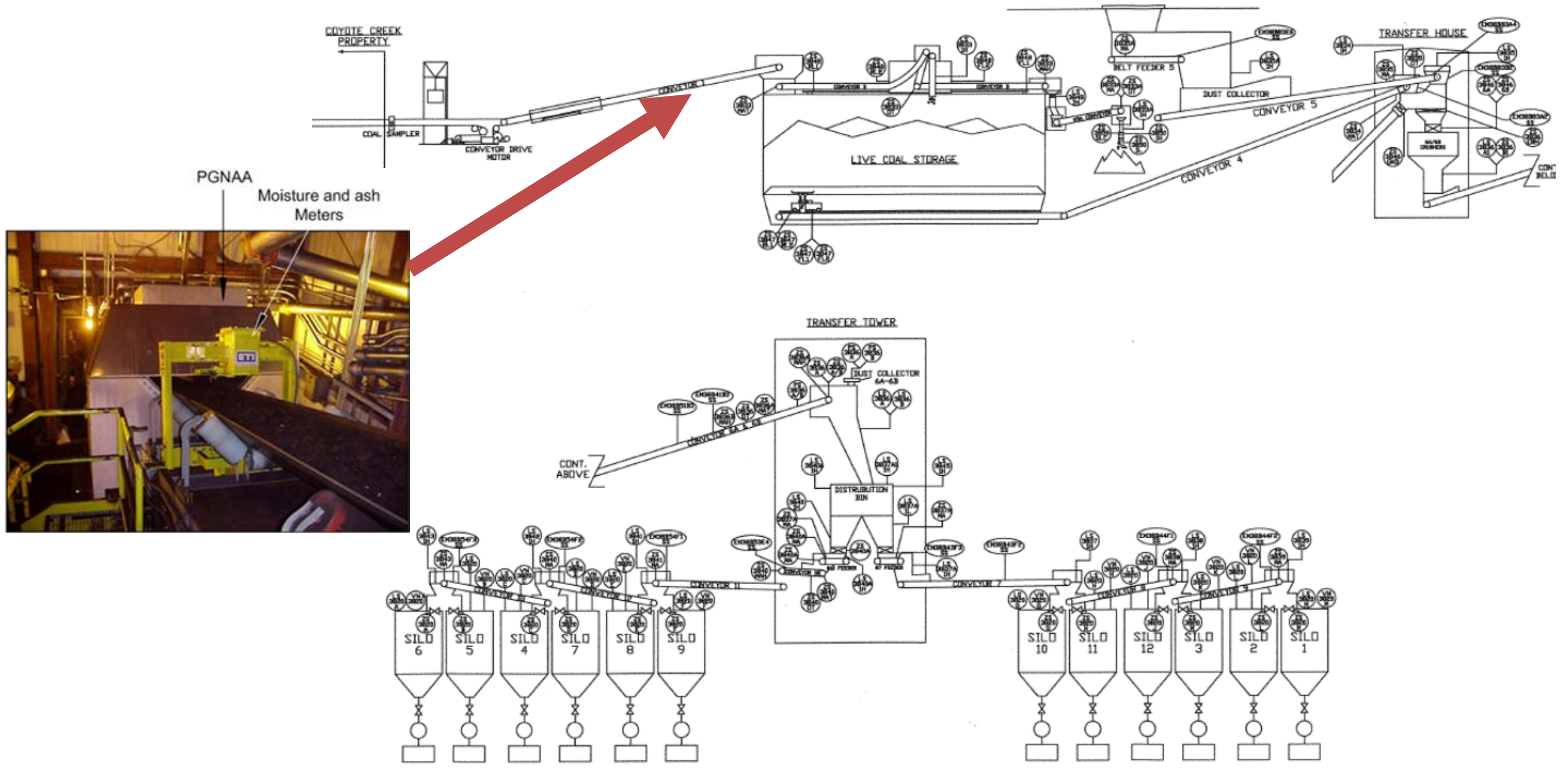
CoalTracker Algorithms Development and Testing

Coal Handling System

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



Full Stream Elemental Analyzer (FSEA) Installation July 2018



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

<u>FSEA Impact</u> – 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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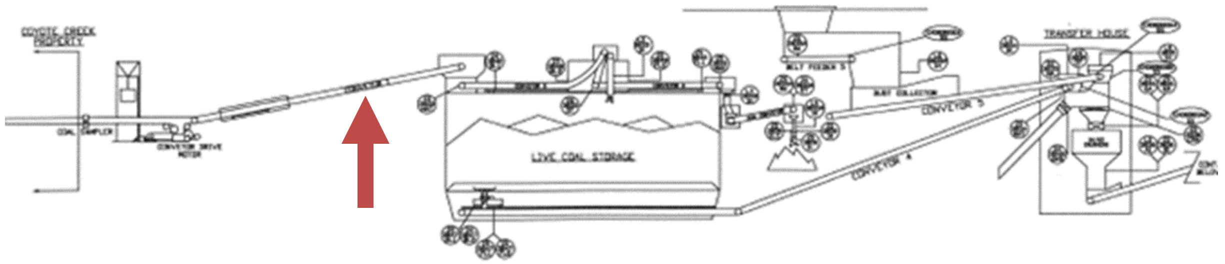
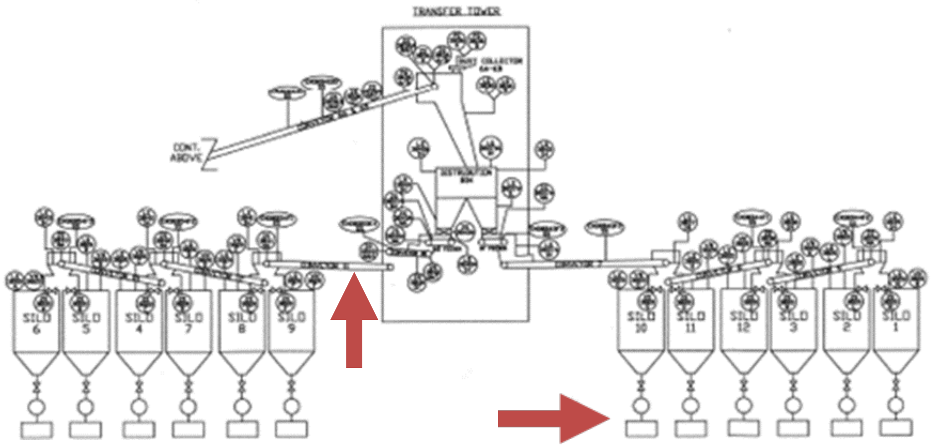
Field Testing

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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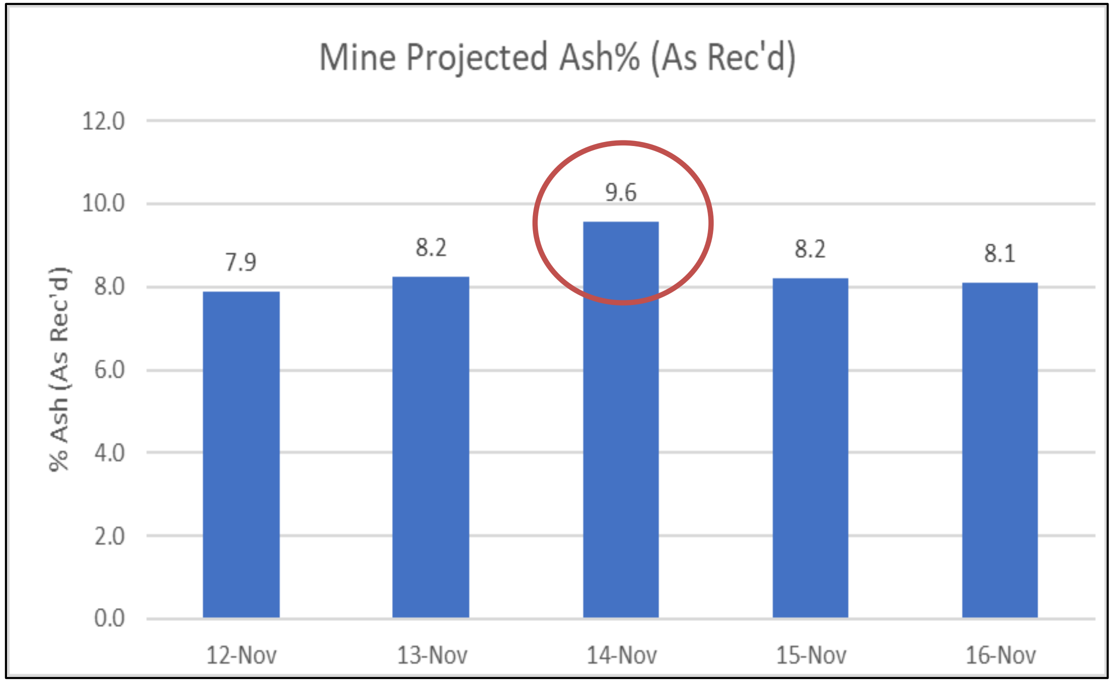
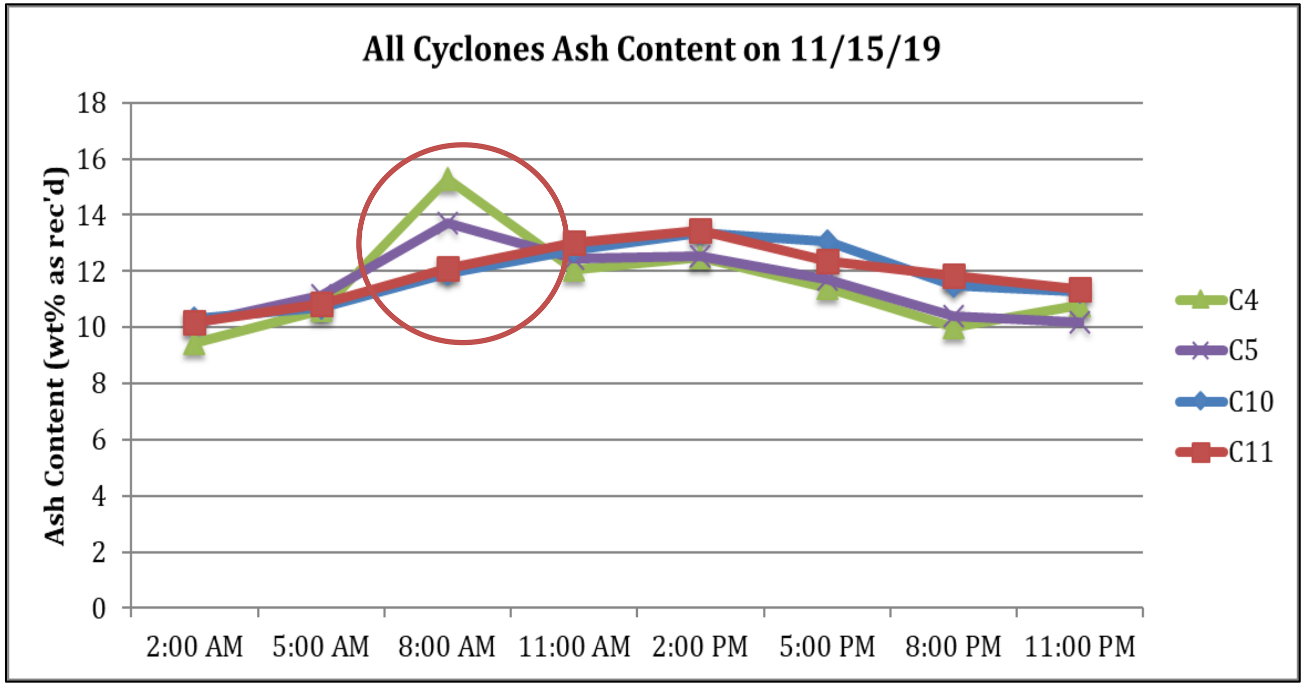
Tracking Coal through the System

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

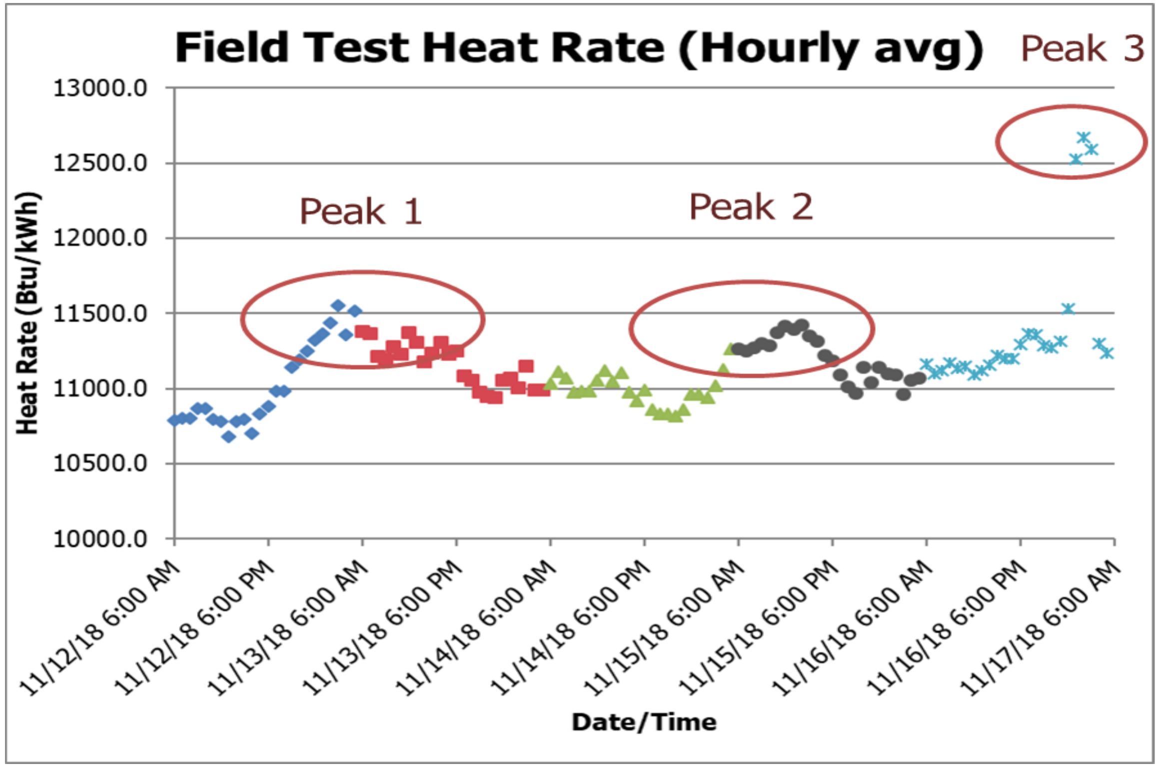




Heat Rate

(Assumption – 12 to 24 hour time lag between coal delivery point and burner)

- Peak 1 & 2 – higher heat rate – due to coal compositional changes
- Peak 3 – Drop in load – boiler cleanup



Field Test Conclusion - Coal analysis results are consistent with preliminary CoalTracker algorithm calculations.

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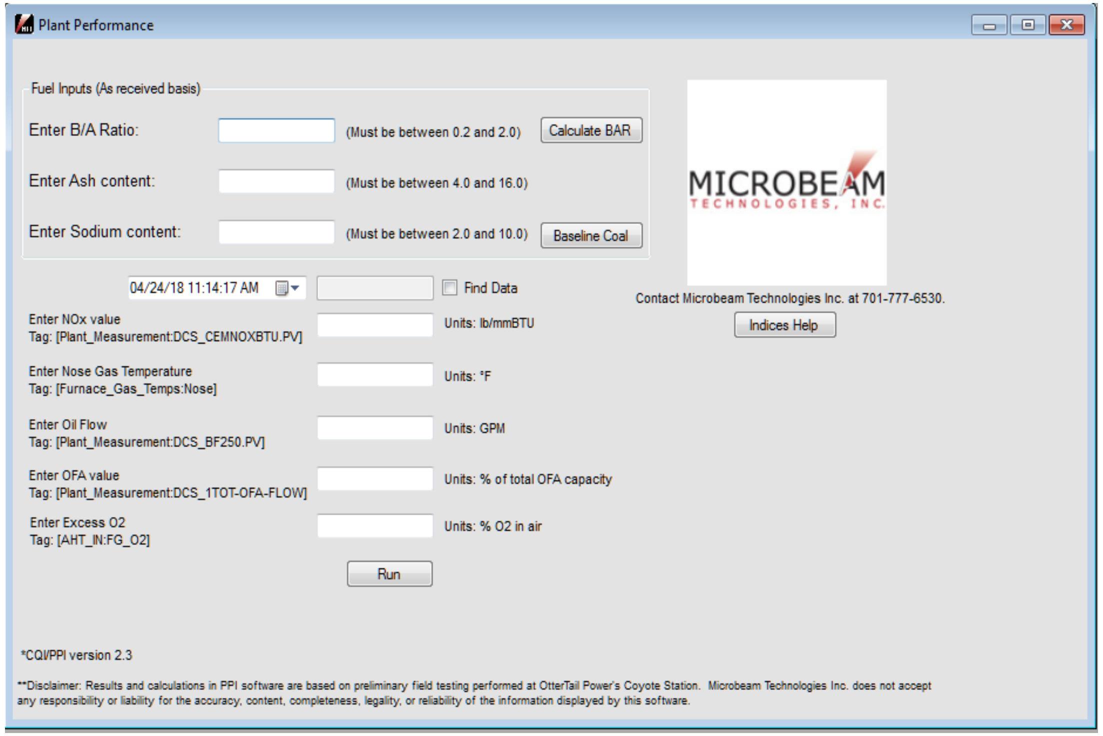
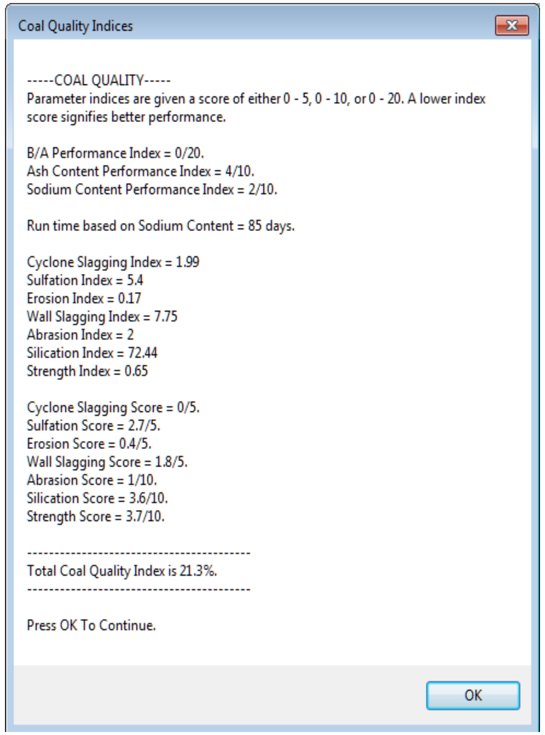
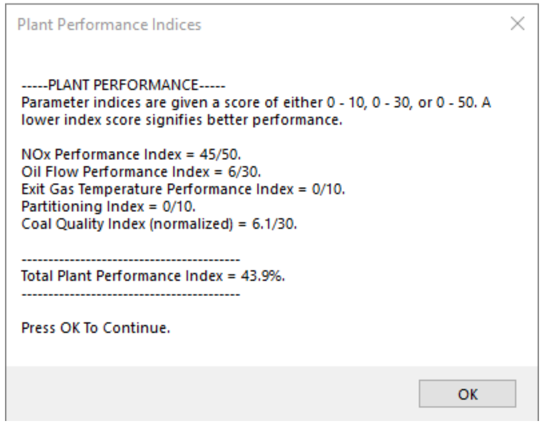
Combustion System Performance Indices (CSPI) Program

Milestone : CSPI-CT Program's Beta Version On-Site Installation

- CSPI-CT program’s beta version was installed at Coyote station on April 25, 2018.







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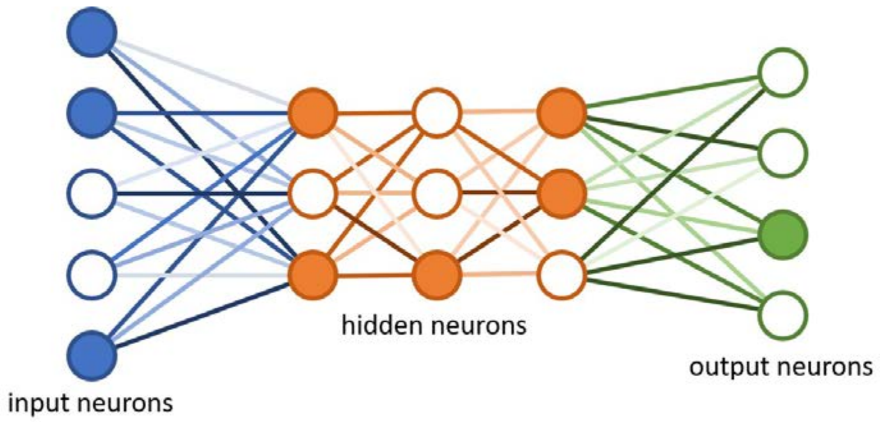
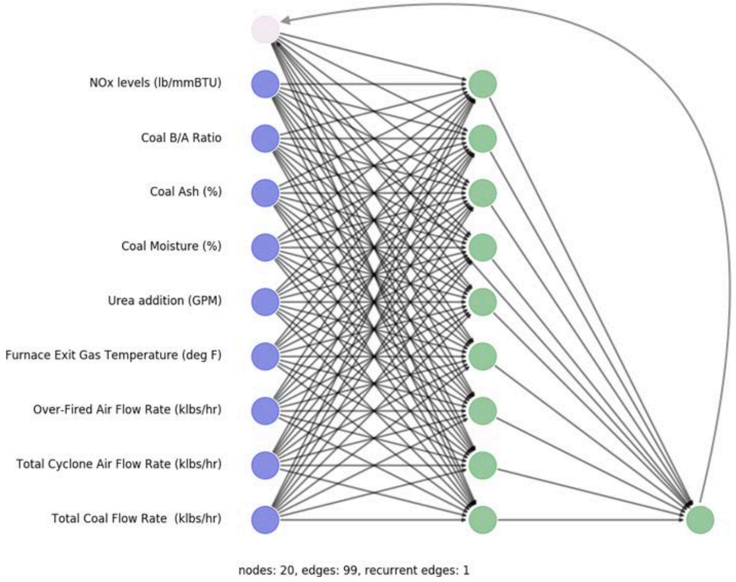
Augmenting CSPI Program

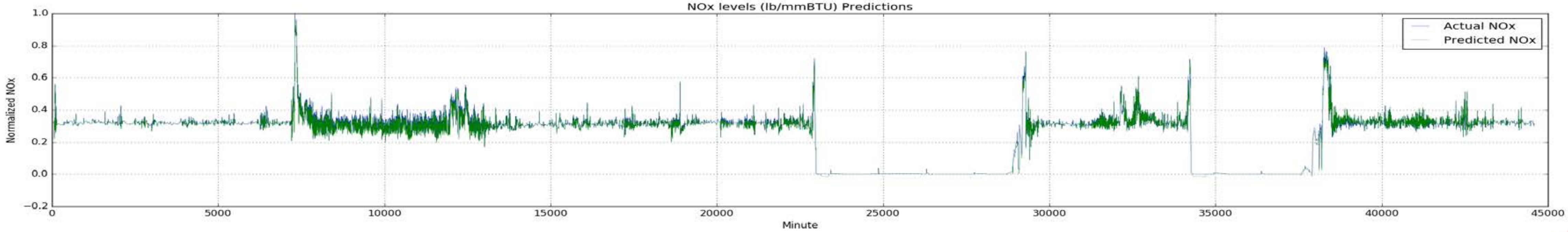
Neural Networks

Why Neural Networks?

- Because they are generic methods which can represent any function.
- They can be trained to be powerful predictors for time series data.





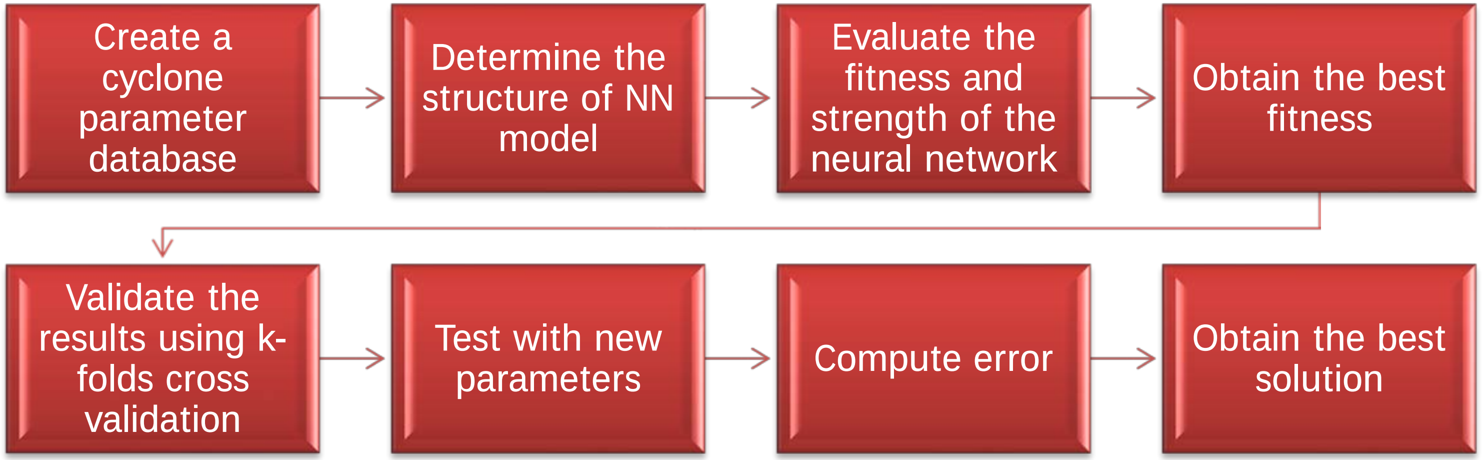


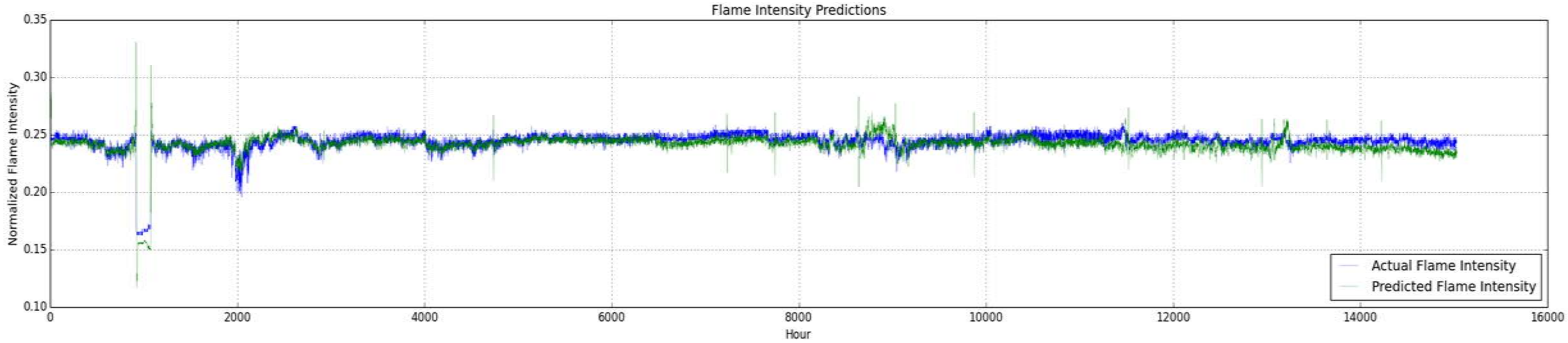
Evolutionary Algorithms Developed under this Project

- **Evolutionary eXploration of Augmenting LSTM Topologies (EXALT)**
  - Progressively evolves larger recurrent neural networks (RNNs) to perform time series data prediction.
  - Can select which input parameters have the best predictive ability and eliminate confuser parameters.
  - Can be executed in parallel over a large number of cores on high performance computing clusters.
  - Evolved RNNs exported to binary files for use within Microbeam's software.
- **Evolutionary eXploration of Augmenting Memory Models (EXAMM)**
  - Based on EXALT, except with a library of memory cells. Nodes can be LSTM, GRU, MGU, or Delta-RNNs.
  - Can be executed in parallel.
  - Mutations have further refinements from EXALT.

Neural Networks for Cyclone Database

- Input parameters –
  - 6 months of operating data
  - 12 operational parameters
  - 12 independent cyclones
- Predicted parameters – flame intensity and oil flow
- K fold cross validation with 2 files per fold and 10 repeats per fold – 1320 runs – 14,200 CPU hours





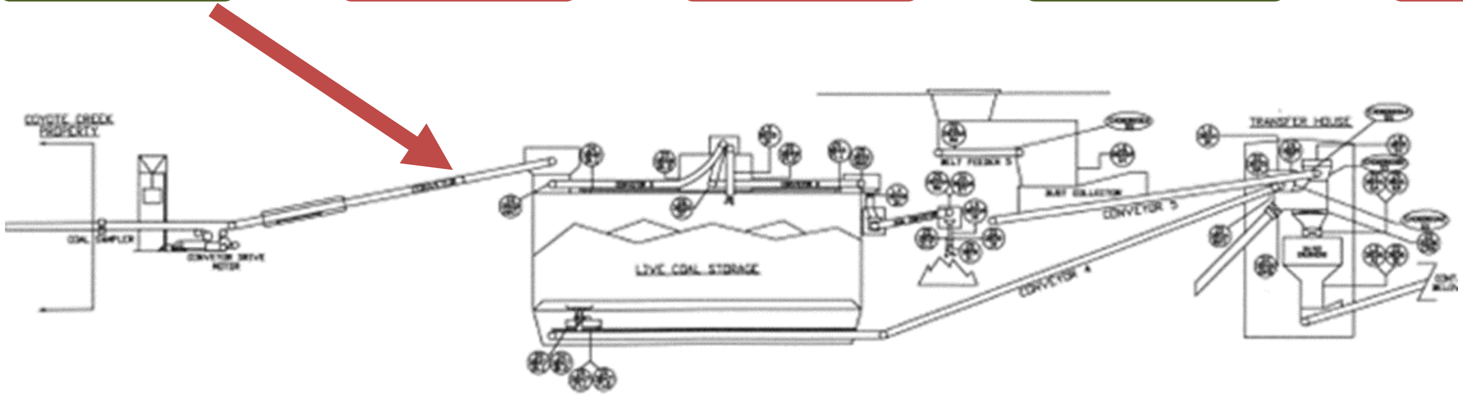
Example of Application

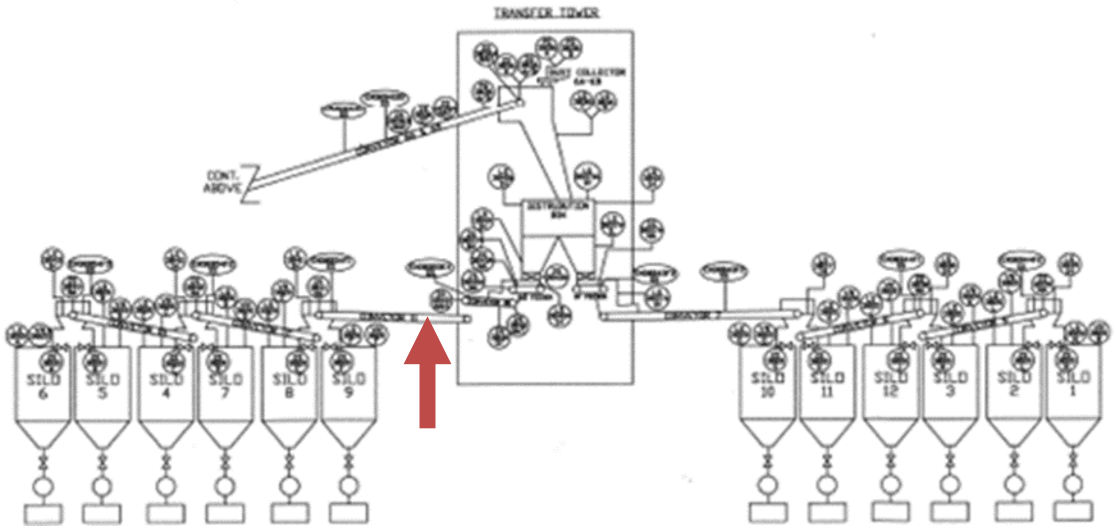
Cyclone Slagging Issues - Jan 2019

- Power plant faced slagging problems starting Jan 30, 2019 through Feb 2, 2019.
- Plant operators changed Over Fired Air setpoint to add more air through cyclones. (NO_x - 0.49 – Very high)
- 40000 gallons of oil was added to maintain the slag flow.

FSEA Data/Coal Sample Collection Locations - Slagging Event

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





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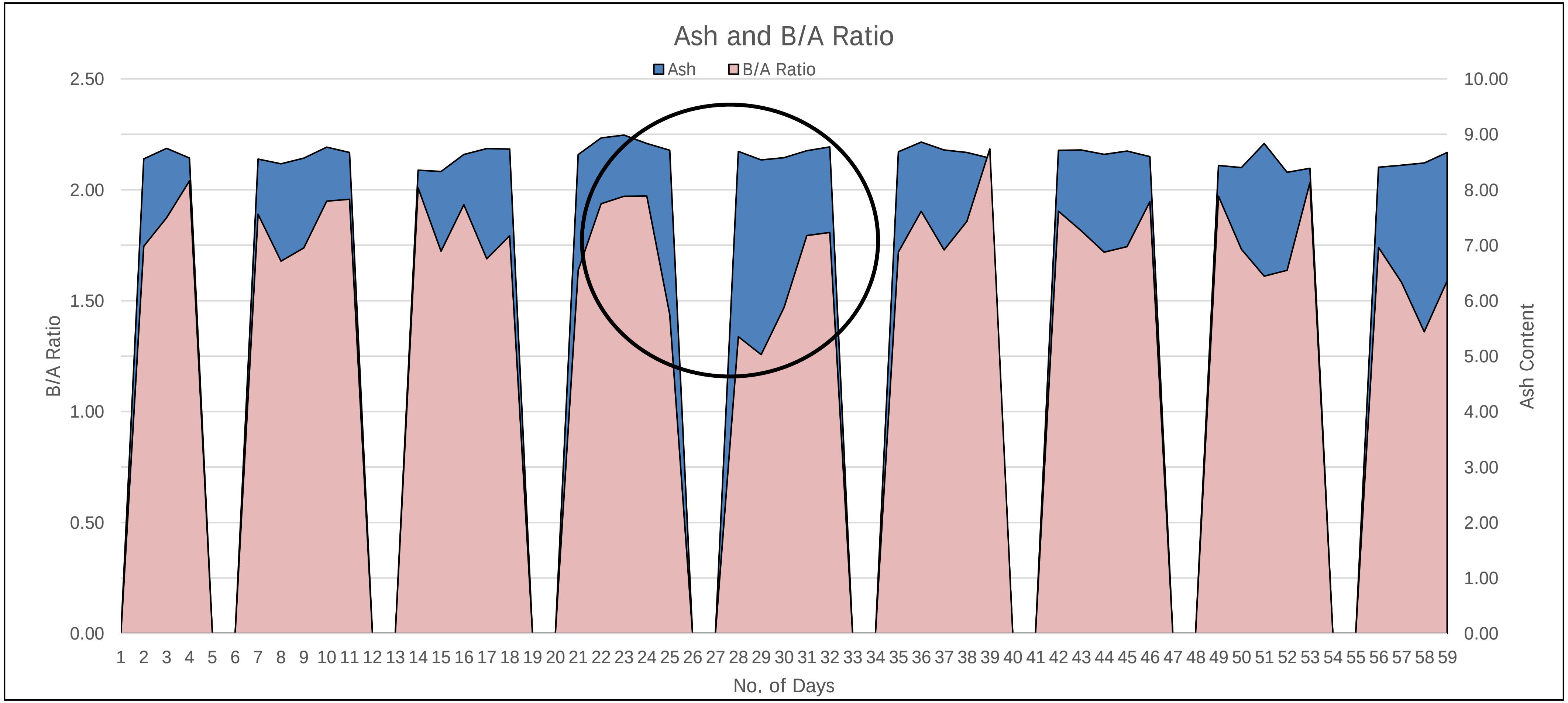
FSEA Data
B/A Ratio
Jan-Feb 2019



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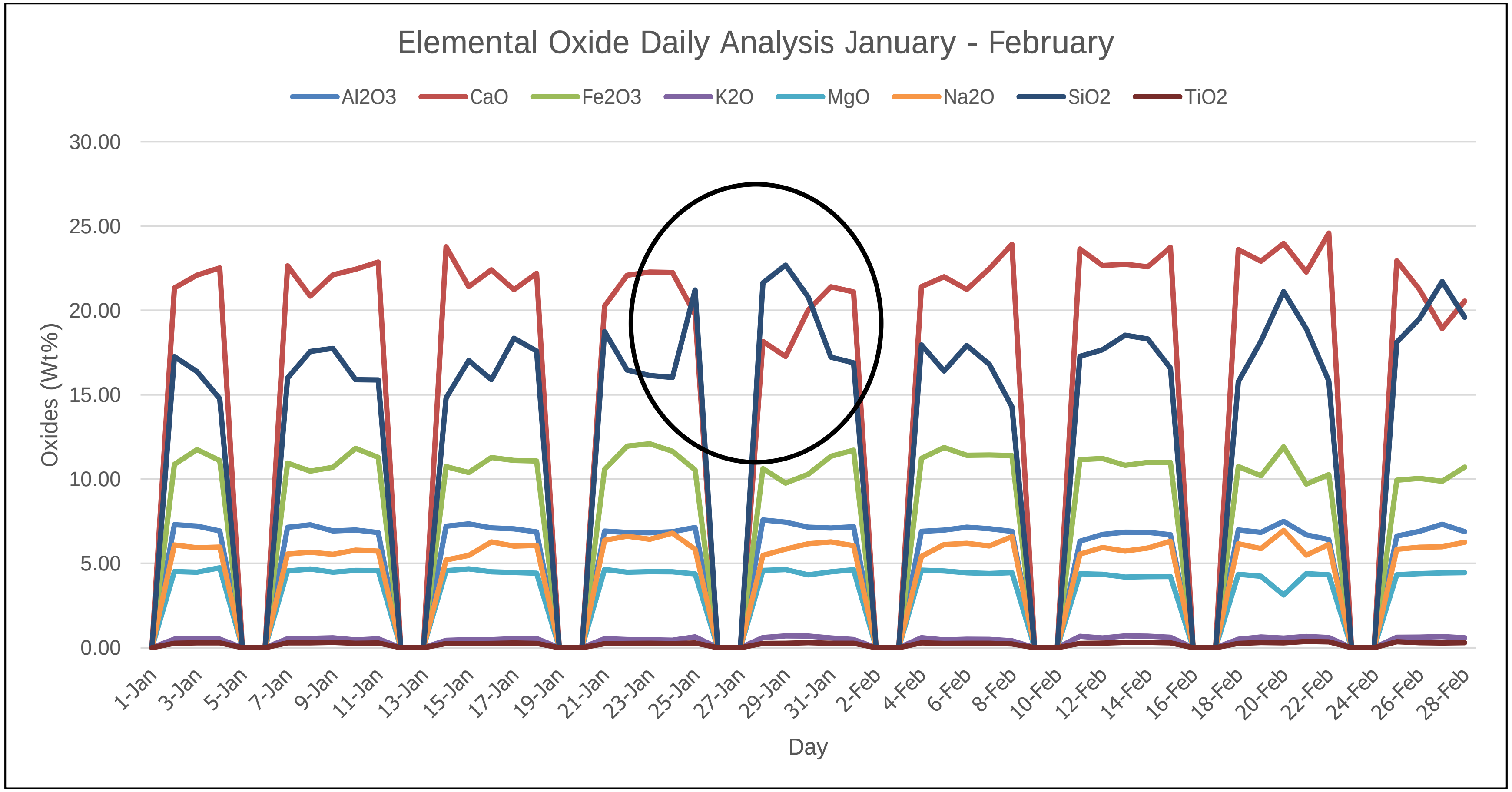
FSEA Data
Jan-Feb 2019



Sharp increase in Si and drop in Ca

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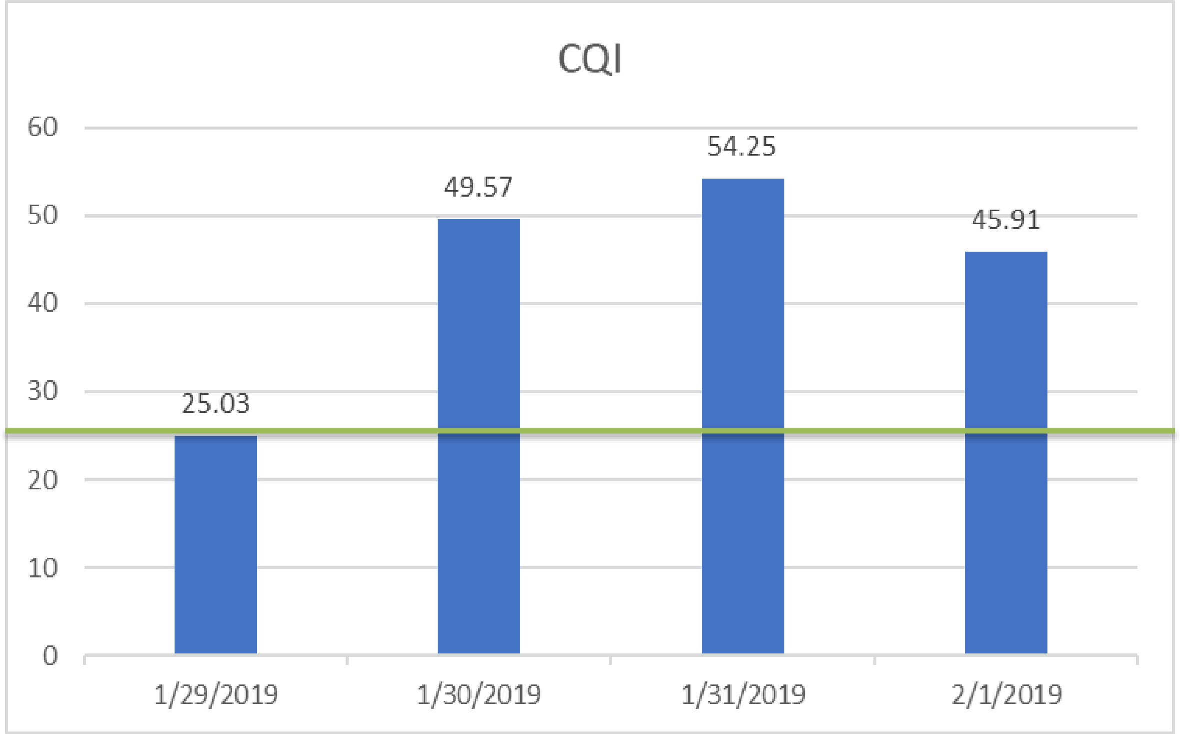
Microbeam's Coal Quality Index Predictions

- Samples collected from Belt 7 were subjected to proximate, ultimate, ash composition and Computer controlled scanning electron microscopy (CCSEM) mineral grain analysis.
- Changes in mineral composition were observed which in turn affected the slag flow in cyclones.



Good fuel quality – CQI < 30

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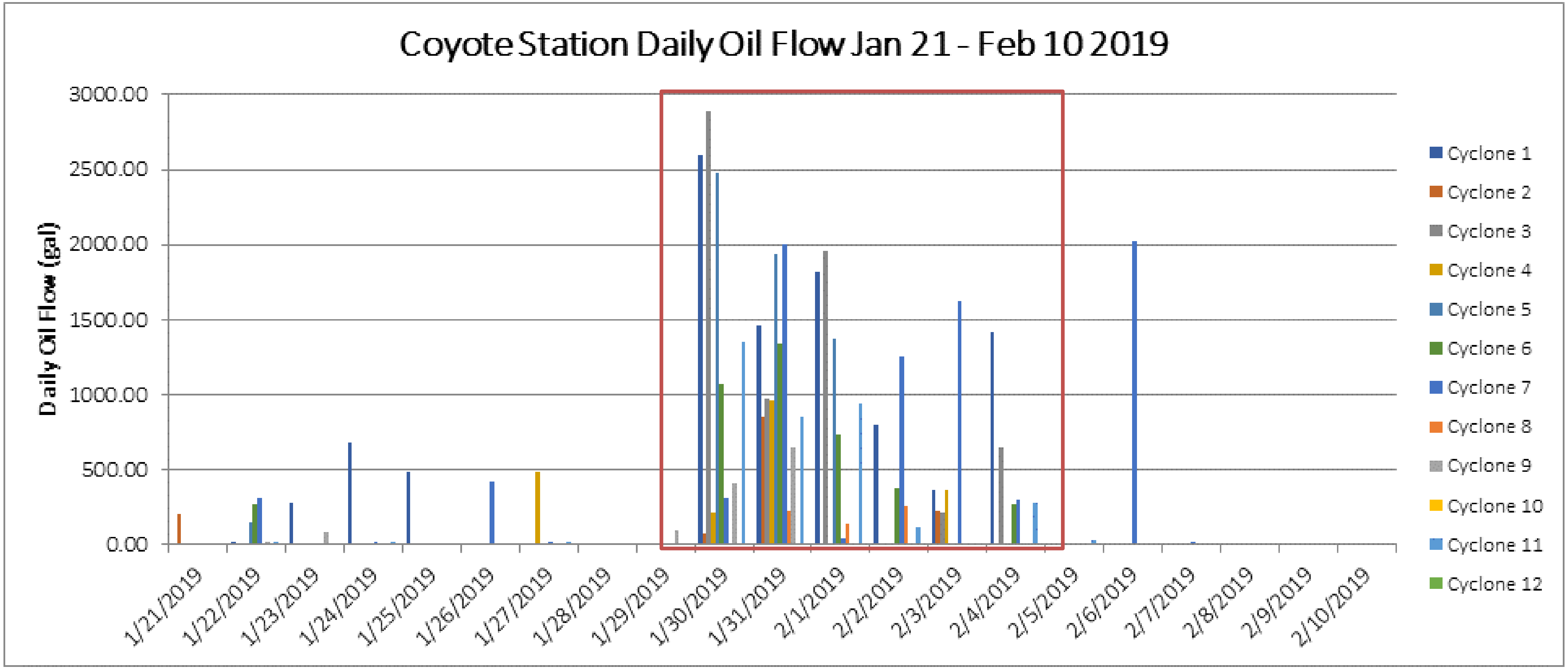
Oil Flow in Cyclones



Total 40,000 gallons of oil was added during this week ~ Cost - $100,000

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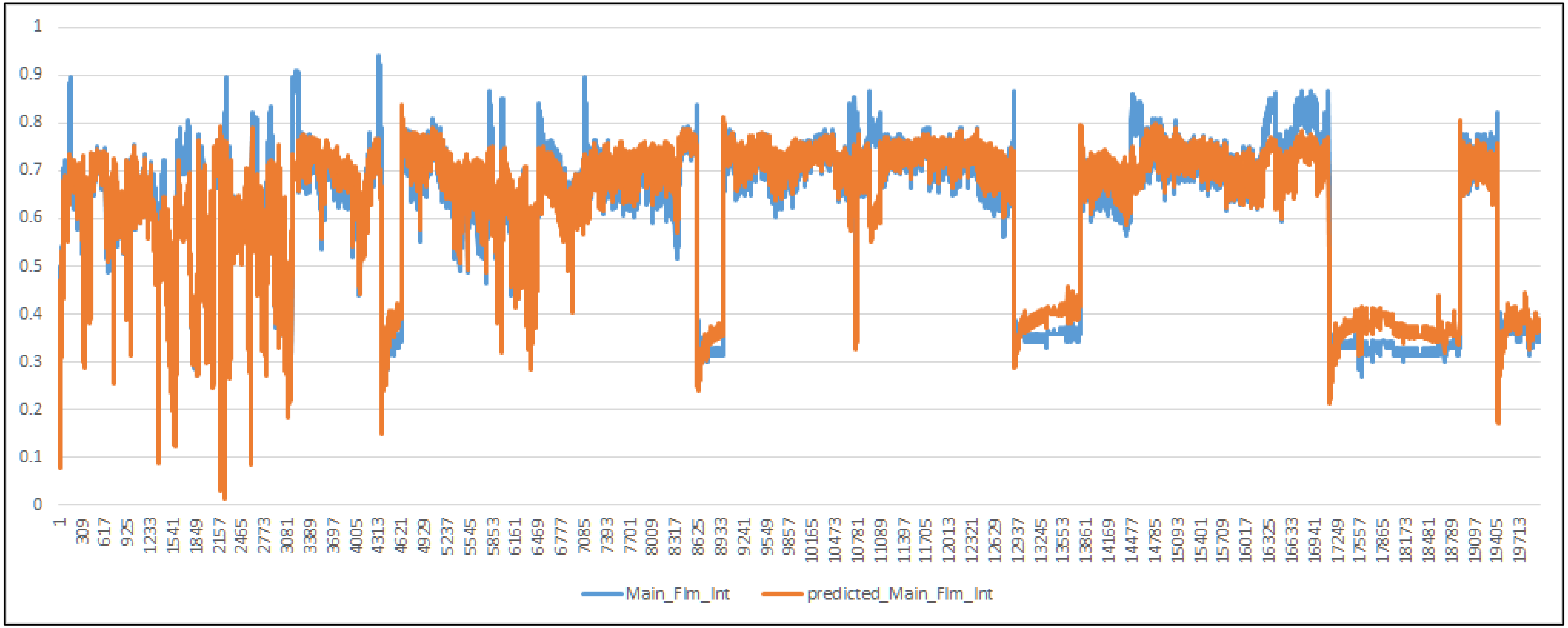
Neural Network Predictions

Predicted vs Actual flame intensity during the cyclone slagging issues

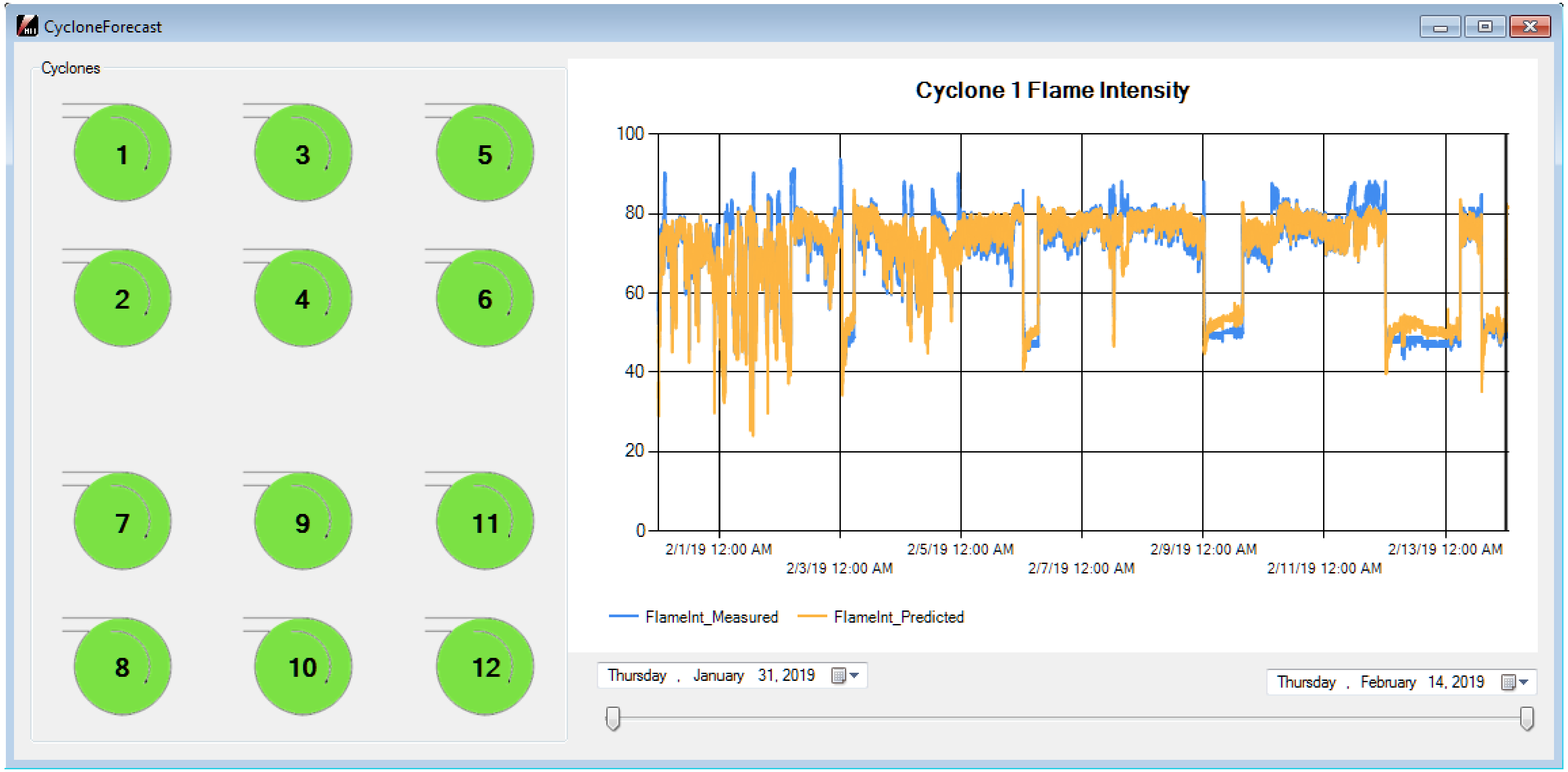


X axis: Jan. 31 - Feb. 13 2019 (Cyclone Slagging Issues)

Y Axis: normalized flame intensity

%Error: 4.09%

CSPI-CT User Interface
(Feb 1, 2019 – Feb 14, 2019)



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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
- Decrease fireside ash deposition- reduce number of scheduled and forced outages (maintenance costs)

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Next Steps

- **CoalTracker Algorithm Development and Testing**
  - CCSEM mineral analysis on field test samples
  - Improve CoalTracker predictions based on field test and slagging event data
- **Combustion System Performance Indices Algorithm Development and Testing**
  - Conduct neural network analysis on waterwall, superheater and economizer database
  - 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**

Questions?

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