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

(Award No. DE-FE00031547)

2020 Annual Project Review Meeting

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Acknowledgement – DOE NETL
Robie Lewis – DOE NETL Project Manager

11/6/20

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Presentation Overview

- **Project Information**
  - Project Team
  - Project Background
  - Project Goal and Objectives
- **Accomplishments**
  - Full Stream Elemental Analyzer Calibration
  - CoalTracker Algorithm Development and Testing
  - Neural Network Training and Testing
  - Combustion System Performance Indices Algorithm Development and Testing
- **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®

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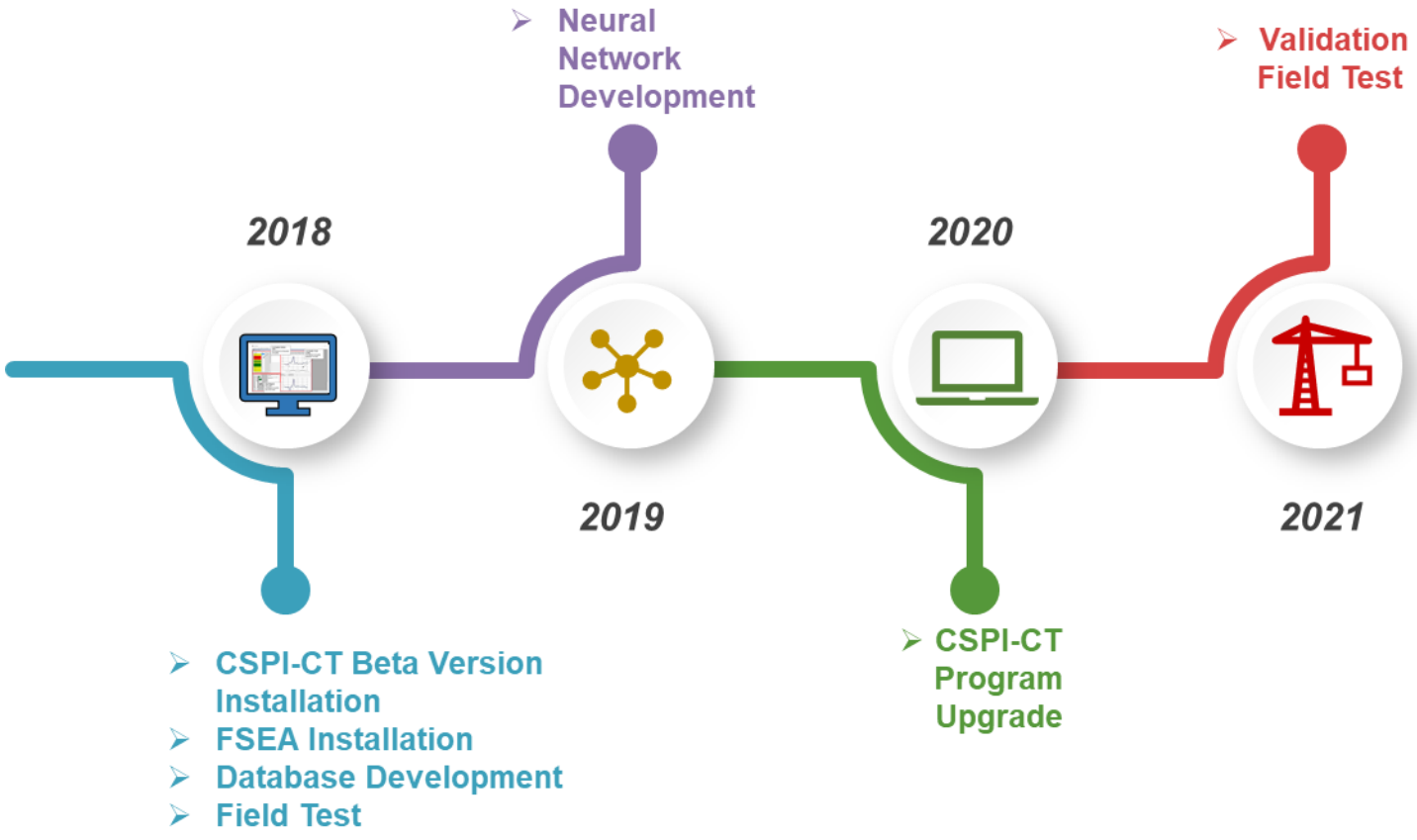
Project Information

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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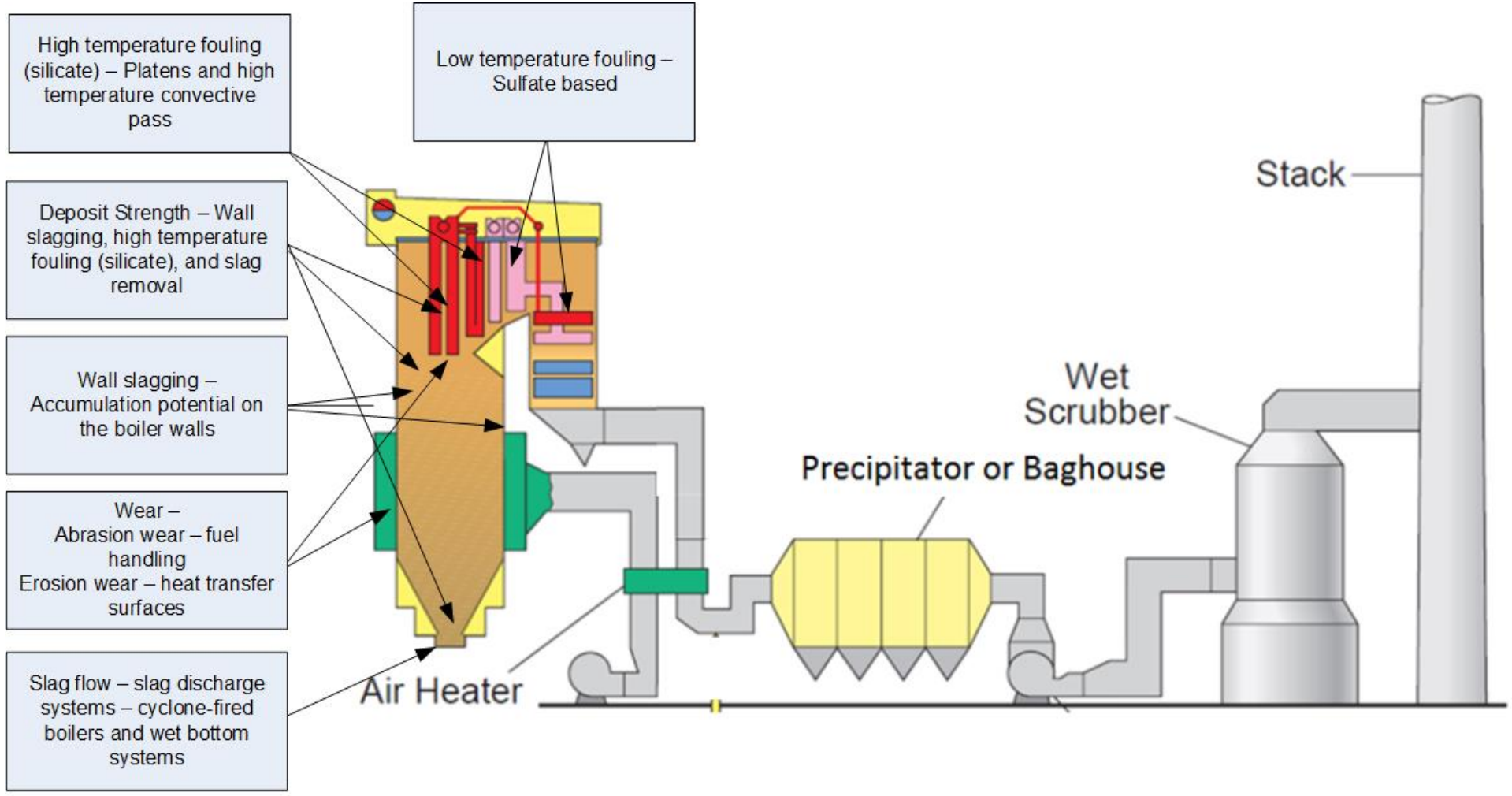
Project Background

Microbeam's Fireside Performance Indices



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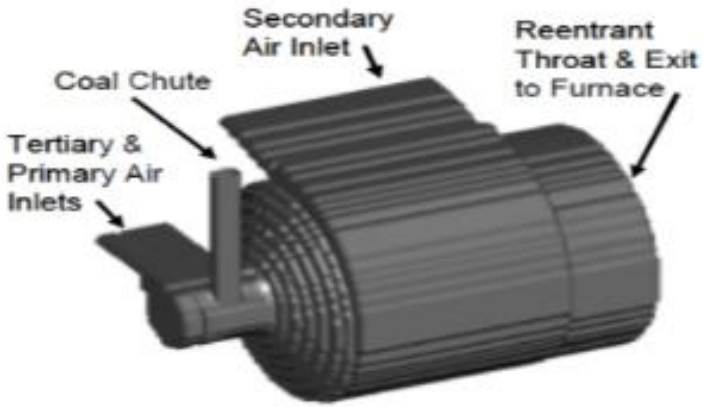
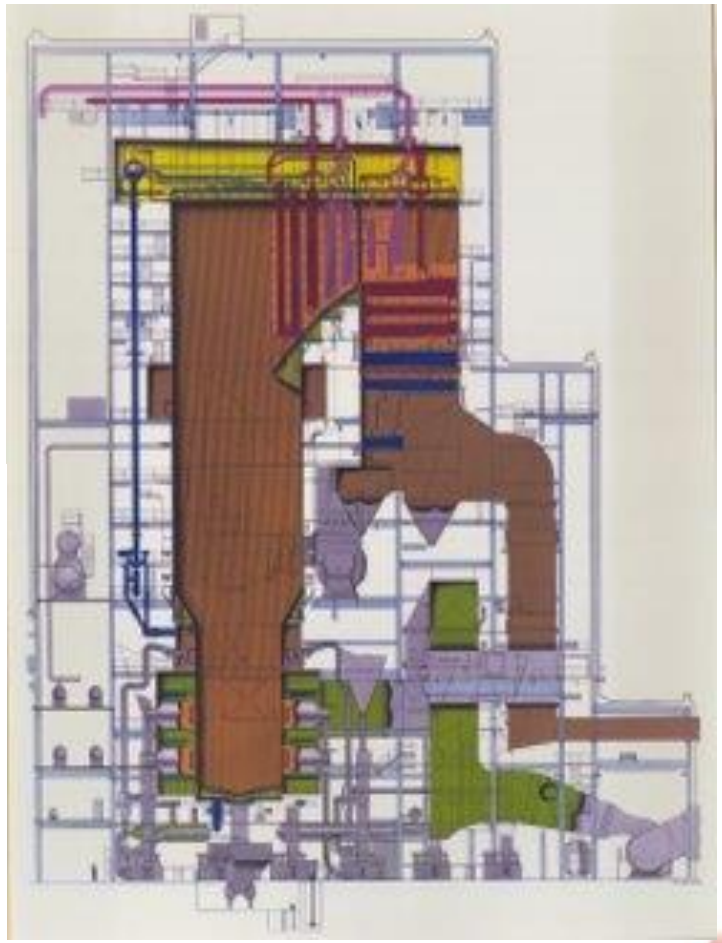
Testing Site

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





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Accomplishments

- **CoalTracker Algorithm Testing**
  - Database development (coal properties) and data analysis
  - CoalTracker algorithm development and validation testing
- **Combustion System Performance Indices Algorithm Development and Testing**
  - Database development (powerplant parameters) and data analysis
  - Neural network training (plant performance) and testing
  - Neural network development (fuel properties + plant performance) and testing
  - Cyclone coal quality index (CCQI) and superheater coal quality index (SCQI) development
  - Upgraded Combustion System Performance Indices (CSPI) installed at the plant in the control room
  - Modifications to CSPI-CT program based on feedback from plant operators and engineers

Task 1
Project Management and Reporting

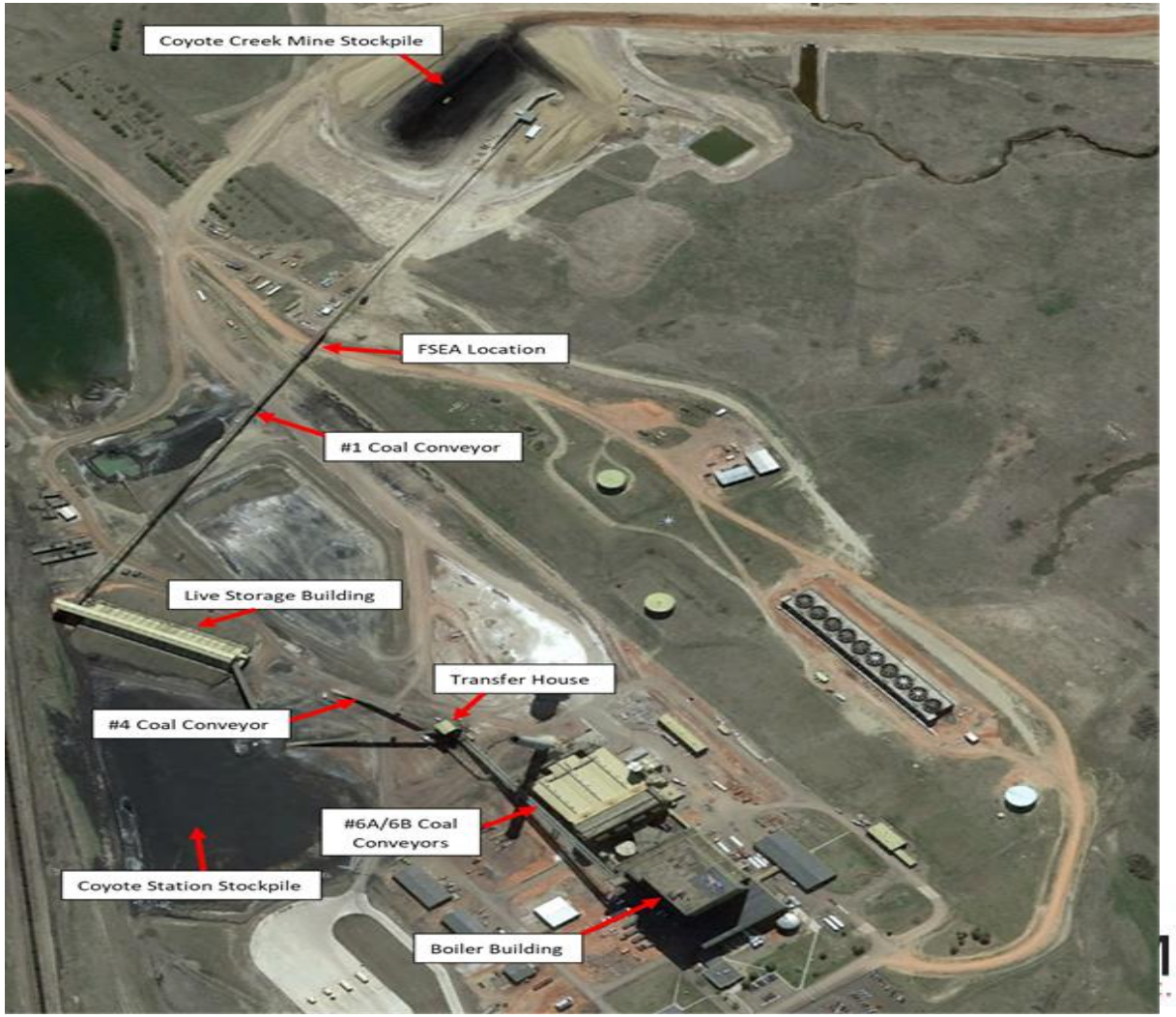
- Kick-off Meeting – February 6, 2020
- Project Management Plan – January 30, 2018
- Quarterly Reports – QR11 submitted on October 28, 2020
- Database Summary Report - submitted on February 29, 2020
- CSPI-CT Summary Report – due on March 31, 2021
- Field Test Report
- Validation Report
- Final Technical Report

Task 1 - Project Management and Reporting Milestones

Budget Period	Task Number	Description	Planned Completion End of month	Actual Completion Date	Verification Method
1	1	Update PMP	1/30/18	1/30/18	PMP File
1	1	Kick-off meeting	2/15/18	2/06/18	Kick-off slides
1	2	CSPI-CT program	4/30/18	4/25/18	Quarterly Report
1	2	PGNAA Installation and CSPI-CT Program Shakedown Testing	6/30/19	6/30/19	Quarterly Report
1	3	Plant Parameter Database Development	3/31/19	3/31/19	Quarterly Report
1	3	Statistical Correlation Development	5/31/19	5/31/19	Quarterly Report
1	3	Neural Network Development	12/31/19	12/31/19	Quarterly Report
2	3	Database Summary Report	2/29/20	2/29/20	Report File
2	4	CSPI Program Upgrade	12/31/20		Quarterly Report
2	4	Summary Report Upgraded CSPI-CT	3/31/21		Report File
2	5	Field Test	5/31/21		Quarterly Report
2	5	Field Test Report	9/30/21		Report File
2	6	Validation Report	12/31/21		Report File
2	1	Final Report	12/31/21		Report File

Task 2
CSPI-CT and Sensor Installation and Shakedown

- Subtask 2.1: CSPI-CT Program's Beta Version On-Site Installation
  - PGNAA Installation
- Subtask 2.2: CSPI-CT Program's Beta Version Testing and Validation
- Subtask 2.3: Sensor Integration and Testing



CoalTracker Algorithms Development and Testing

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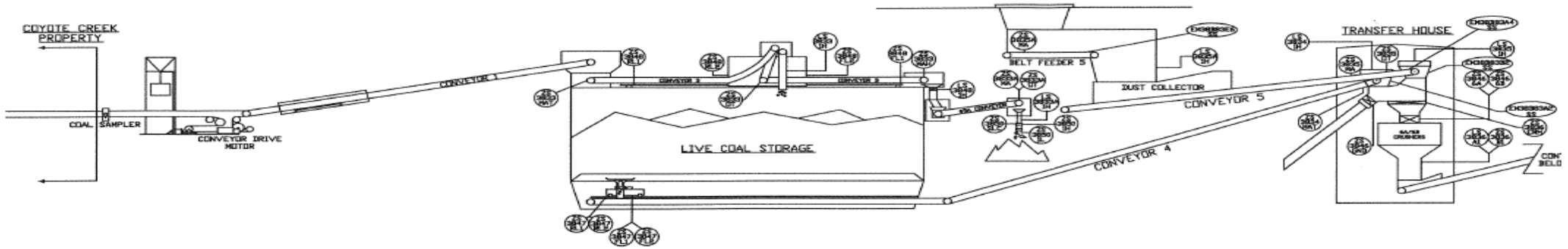
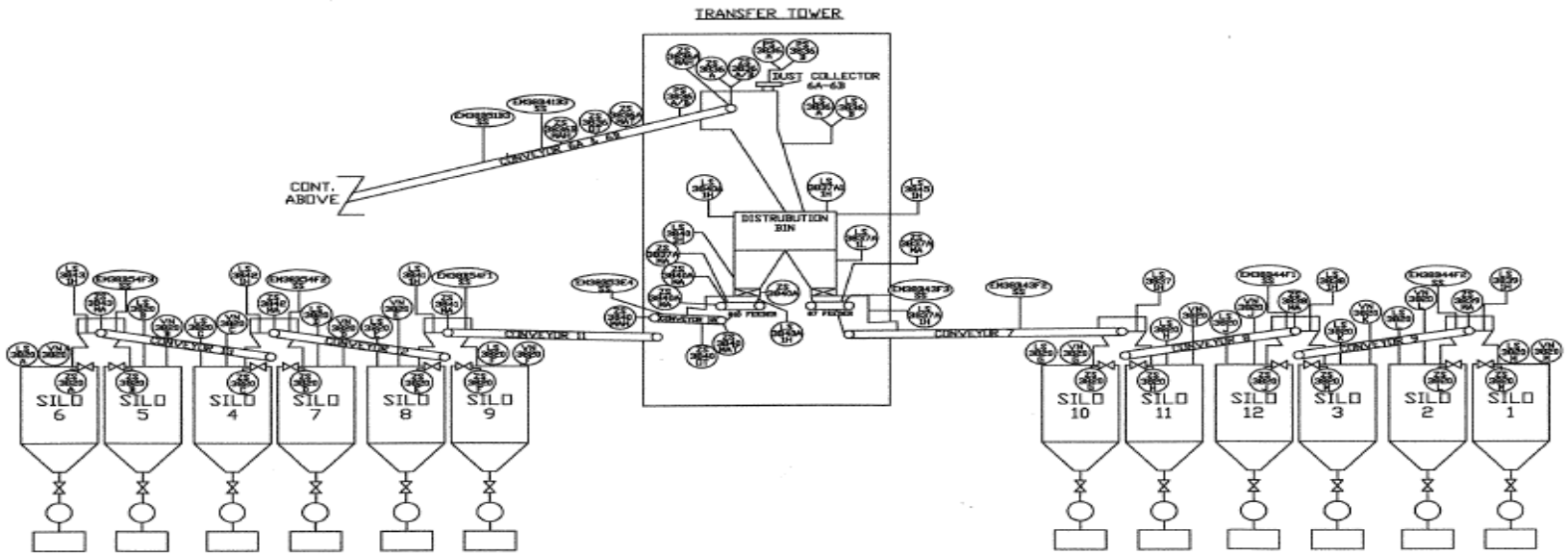
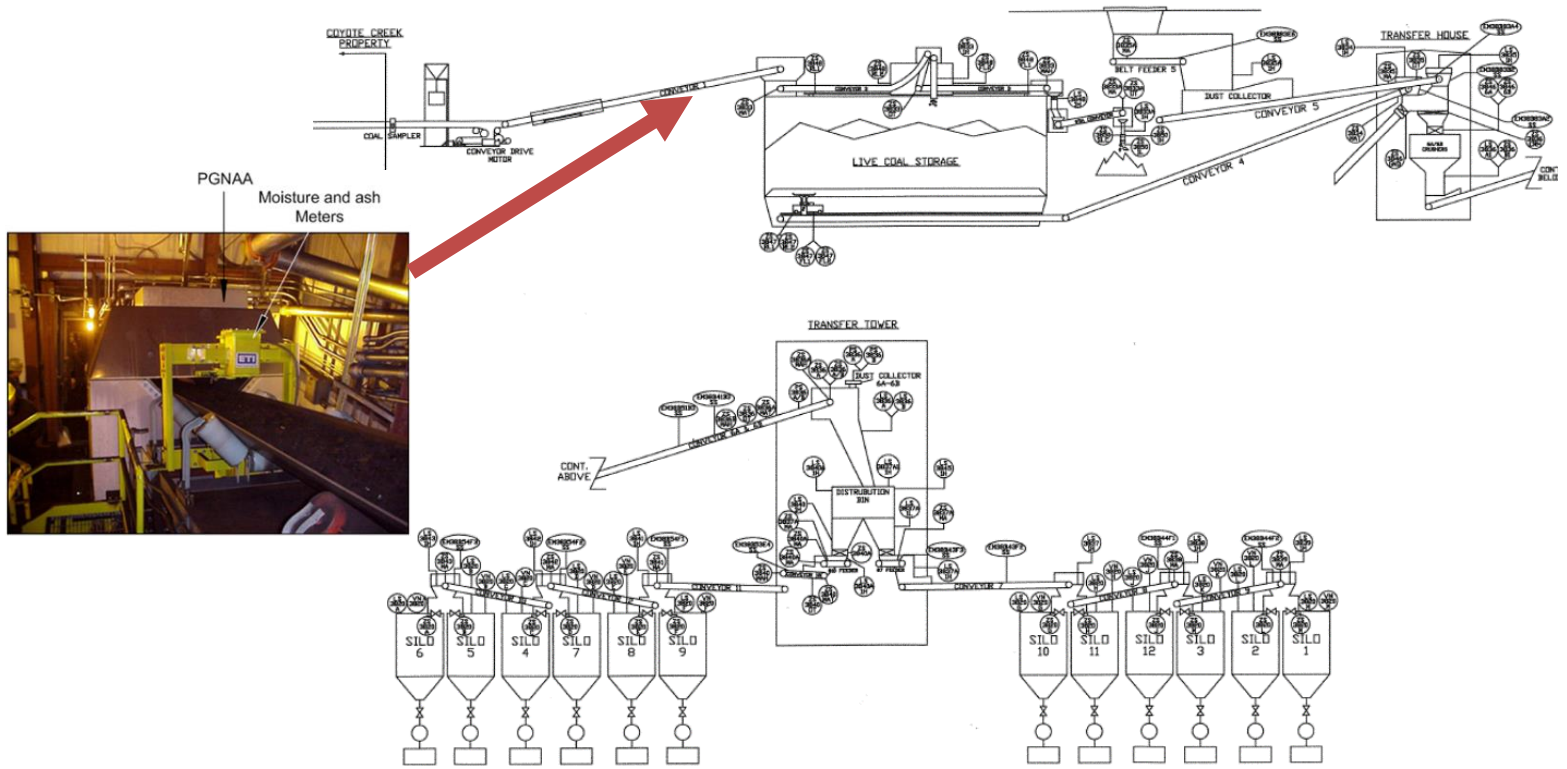
Coal Handling System

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





Full Stream Elemental Analyzer (FSEA) Installation July 2018



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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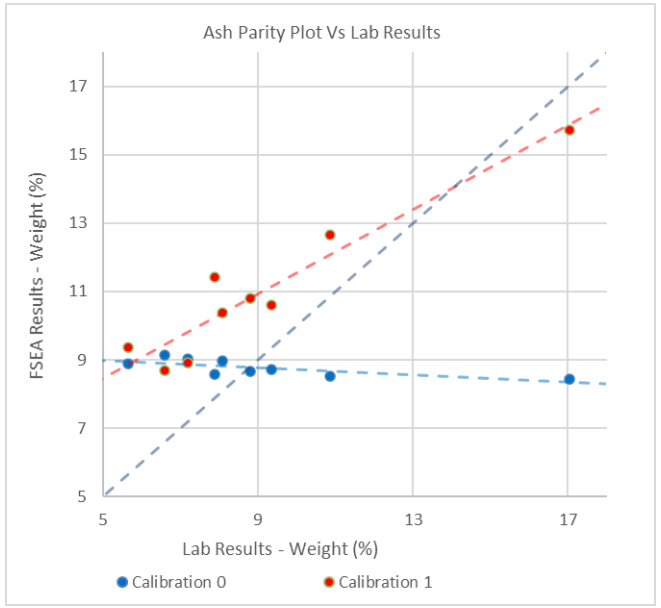
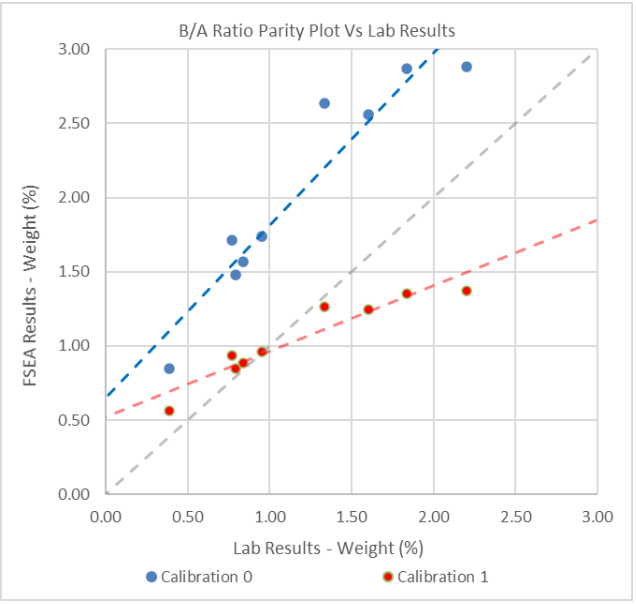
Full Stream Elemental Analyzer (FSEA) Calibration – July 2019

FSEA Calibration with coal bags





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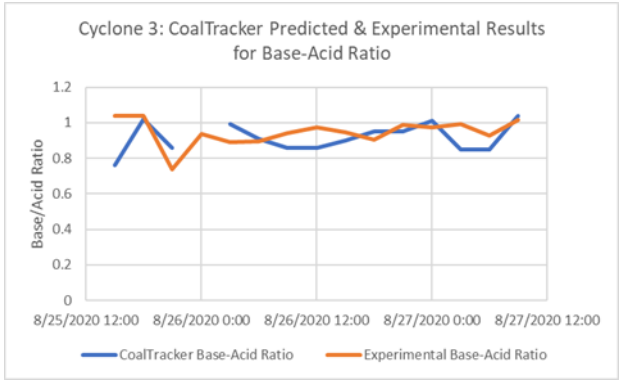
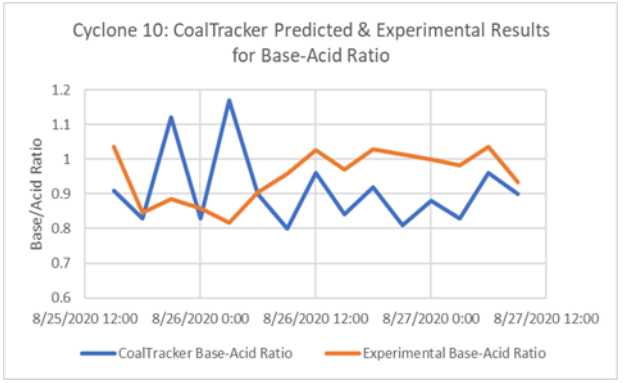
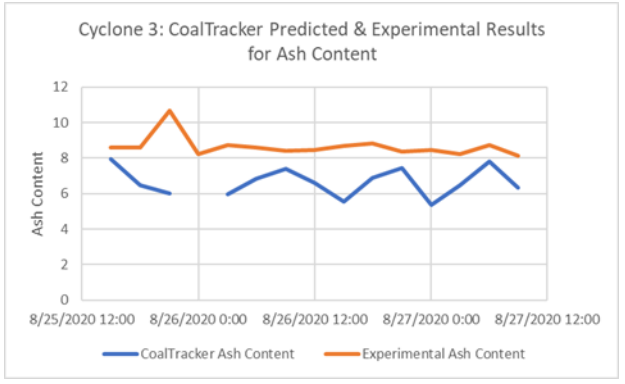
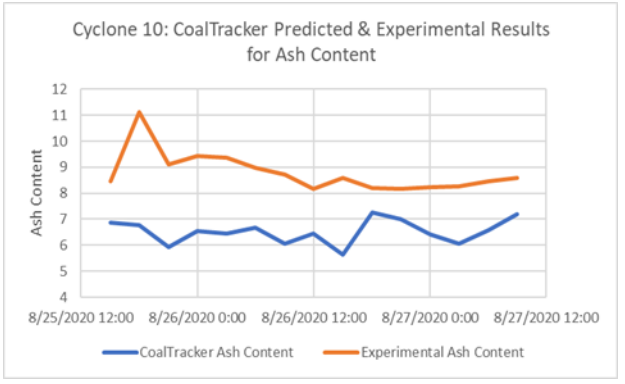
CoalTracker Validation
August 2020 Field Test

- Coal samples - Cyclone 3 and Cyclone 10 feeder pipe.
- The coal composition results obtained from proximate, ultimate and ash composition analysis were compared with CoalTracker predicted as-fired coal.
- The CoalTracker predicted base-to-acid ratios compare well with the measured base-to-acid ratios.
- CoalTracker predictions of ash content are consistently lower than the measured ash content values; this difference is likely due to lower moisture content of the coal at the burner as compared to entering the coal handling facility.









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Task 3
Database Development and Software Training

- Subtask 3.1: CSPI-CT Plant Performance Parameter Database Development
- Subtask 3.2: Statistical Correlations Development
- Subtask 3.3: Neural Network Development
- Subtask 3.4: Neural Network Testing and Refinement

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
S	164	9072
T	365	20124
U	1899	88107
V	1060	58299
W	1217	66986
X	187	10337
Y	338	18529

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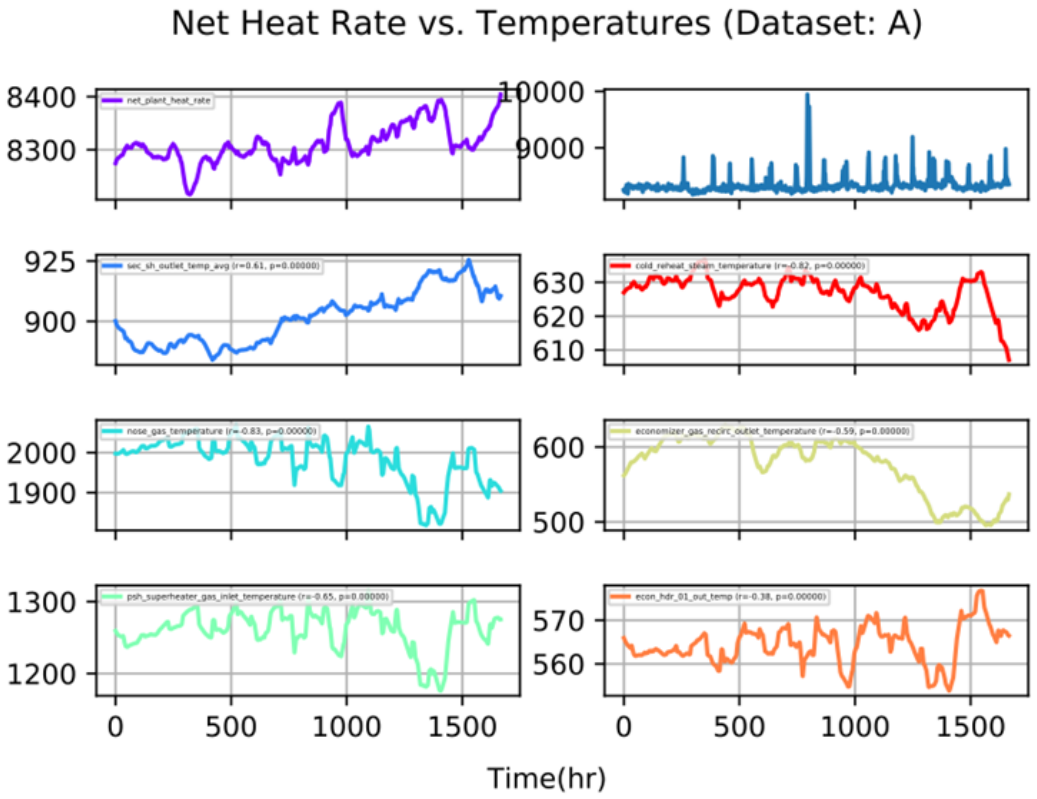
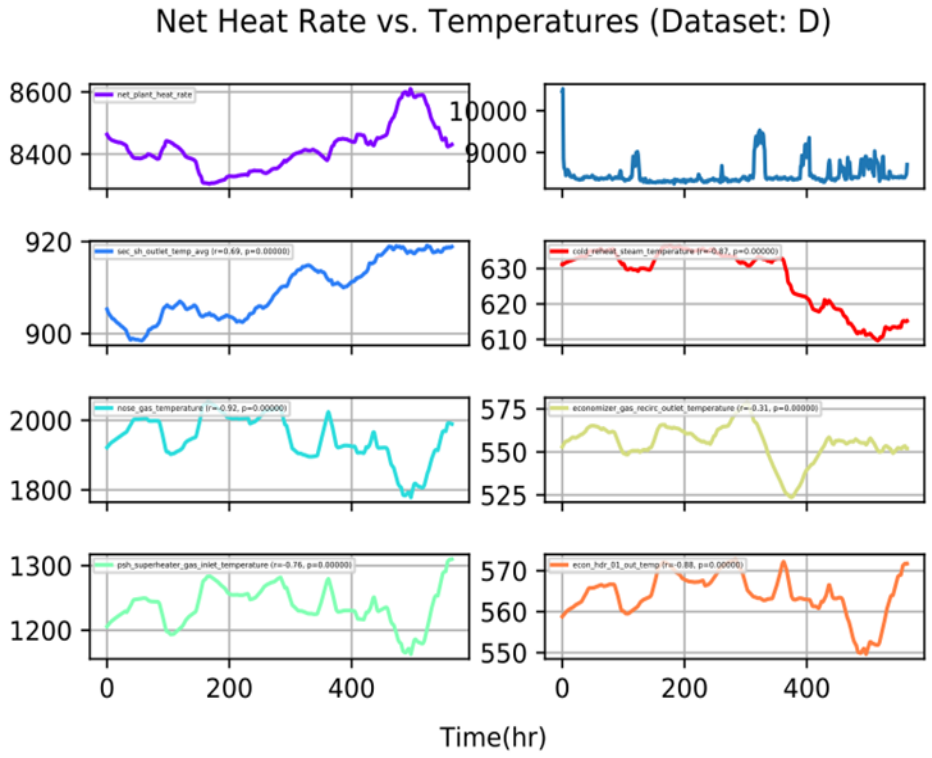
Data Analysis





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Task 4 - Neural Network Correlation Integration

- Subtask 4.1 - CSPI-CT Program Upgradation with Statistical and Neural Network Correlations
- Subtask 4.2 - Upgraded CSPI-CT Program On-Site Installation and Testing

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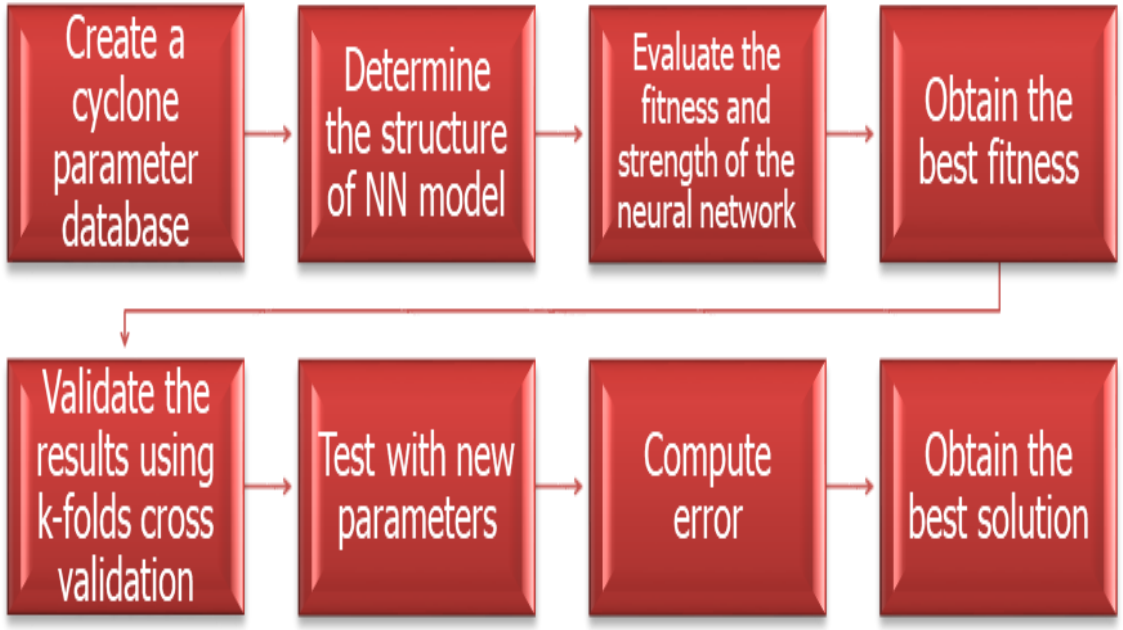
Neural Network Development and Testing

- Database
  - Fuel properties – CoalTracker Data
  - Cyclone parameters – 18 months
  - Boiler parameters – 24 months
- Algorithms
  - Evolutionary eXploration of Augmenting Memory Models (EXAMM)
  - Evolutionary eXploration of Augmenting LSTM Topologies (EXALT)
  - Ant Colony Optimization



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Highlights

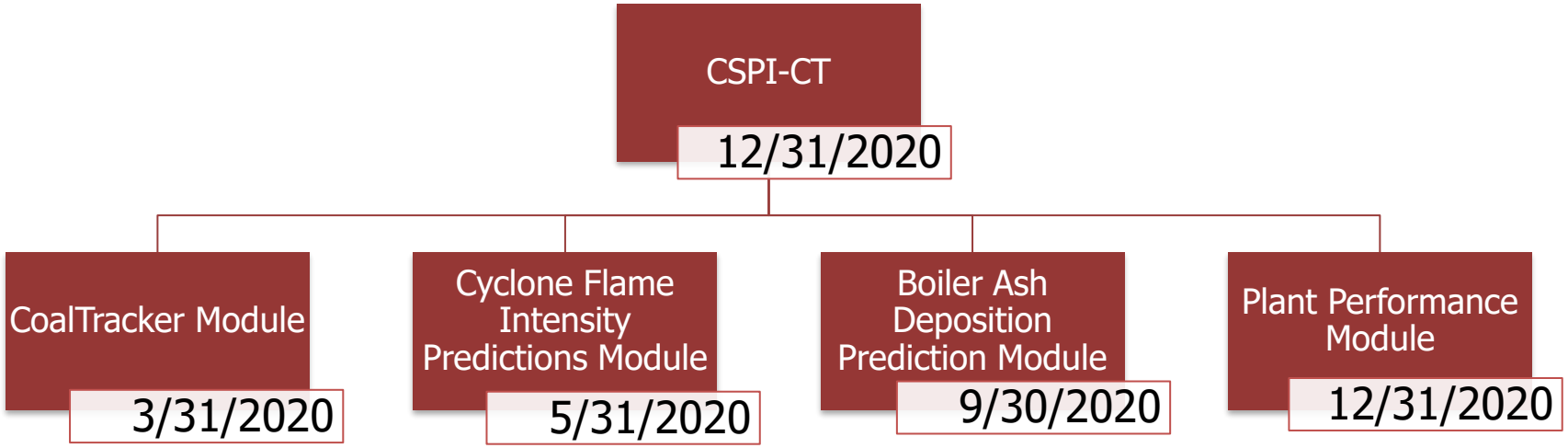
- We have implemented two novel algorithms for neural architecture search to attack the problem from two directions - one generates progressively larger networks while the other samples subnetworks from a large superstructure.
- Using high performance computing resources at RIT, we have trained over 42 million RNNs with varying structures to generate results.
- The best evolved RNNs can be plugged in to Microbeam's CSPI-CT program.
- Utilized new fuel properties data from Microbeam and showed it provided better predictions.
- We have investigated the benefits of various architectural decisions, e.g., which memory cells to use and how to apply deep recurrent connections; and have found interesting results which advance on current best practices.
- We have begun predicting farther into the future than the next time step, something not commonly done (in part due to the difficulty).
- Software installed at plant is benefitting operation – decreased outages and decreased ash depositions.

Neural Network Future Work

- Algorithmic improvements:
  - Layer-based mutations for EXAMM
  - Investigating better strategies for speciation to improve search properties
  - Self-tuning EXAMM/ANTS to determine and dynamically adapt the parameters they use.
  - Utilizing improved training methods (non-gradient based) for better predictions.

- Plant Optimization improvements:
  - More investigation of future predictions -- updating training/testing data to focus on important spiking events.
  - This will better predict boiler tube fire side fouling, slagging, corrosion, combustion stoichiometry and/or boiler gas temperature profiles.
  - Enhances ability to predict impact of fuel properties on boiler operations.

CSPI-CT On-Site Installation



Capabilities :

- As-delivered fuel properties
- Predicted live storage fuel properties
- Predicted cyclone silo fuel properties
- Predicted As-fired fuel properties

Capabilities :

- Modified coal quality index (CQI)
- Flame intensity neural network-based predictions – 8 hours in the future
- Recommendations for coal blending

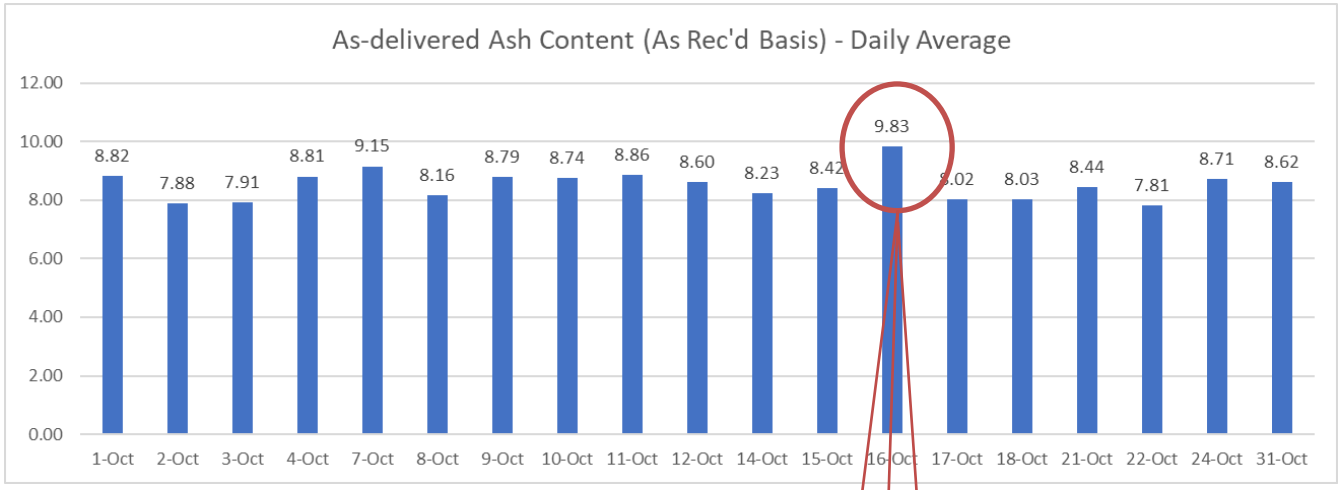
Capabilities :

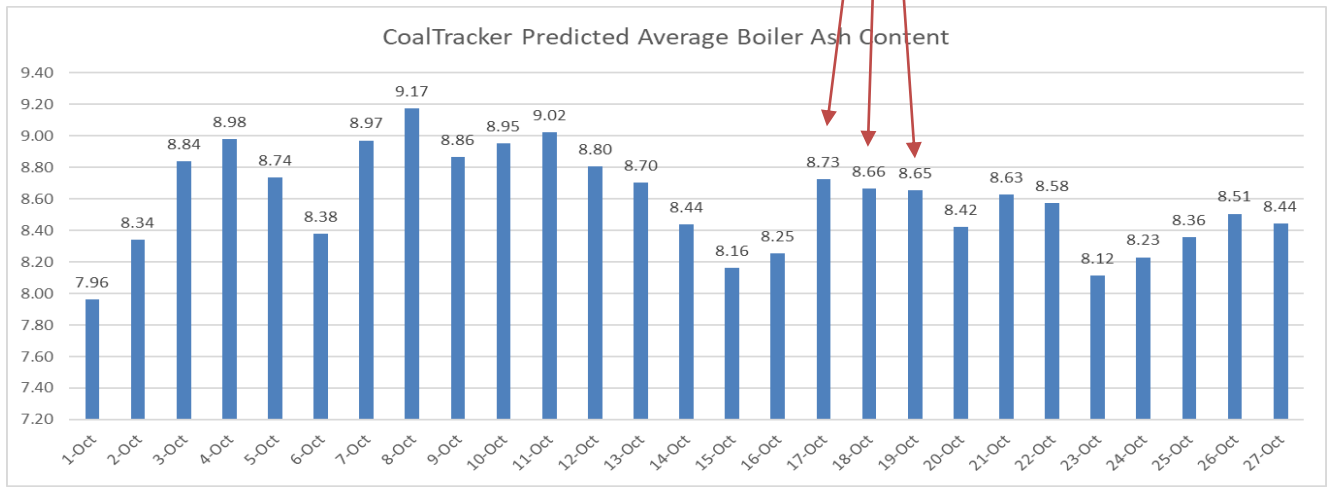
- Prediction and management tool for ash deposition in primary superheater, secondary superheater and reheater
- Test and upgrade neural network augmented deposition indices – include correlations in CSPI-CT
- Recommendations for optimal operations

Capabilities :

- Revised plant performance index (PPI)
- Net Plant Heat Rate predictions
- Nose gas temp. predictions
- Recommendations to improve plant performance

CoalTracker Program On-Site Application





- Microbeam's CoalTracker program is currently being used on-site to make coal blending decisions.
- Example : Coyote station received high ash coal (9.83%) on October 16 – this coal was blended with lower ash coal in the barn to avoid slagging and fouling issues.

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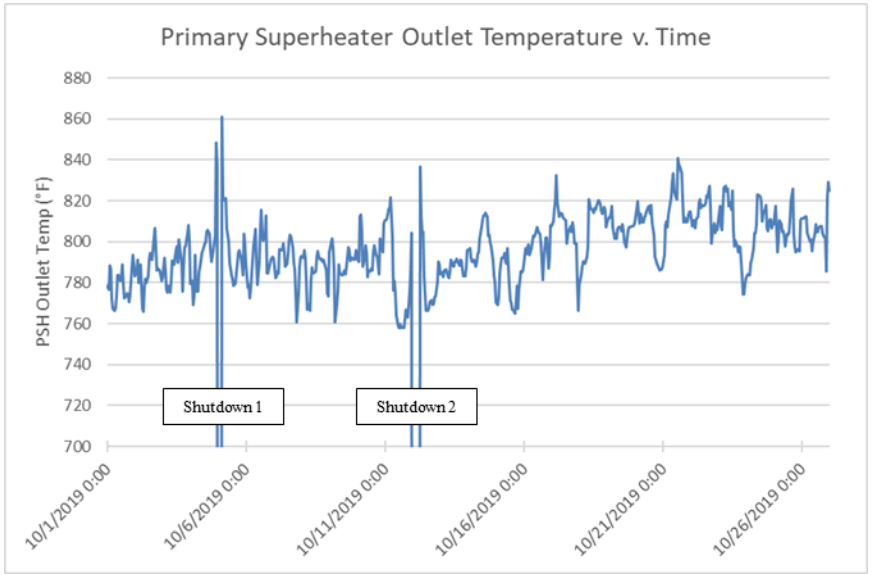
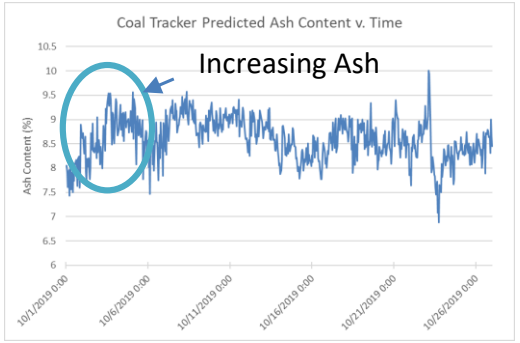
Ash Deposition

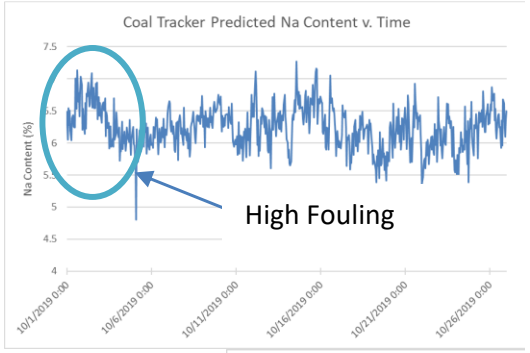
Diagnosing problems - Forced outages

Shutdown

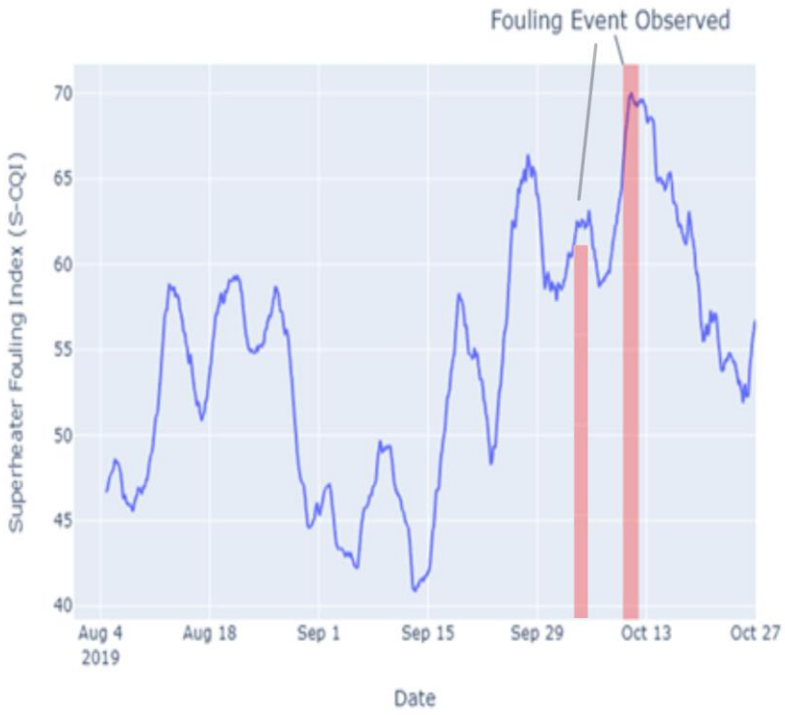


As-Fired Coal Properties





Predictions – On-line



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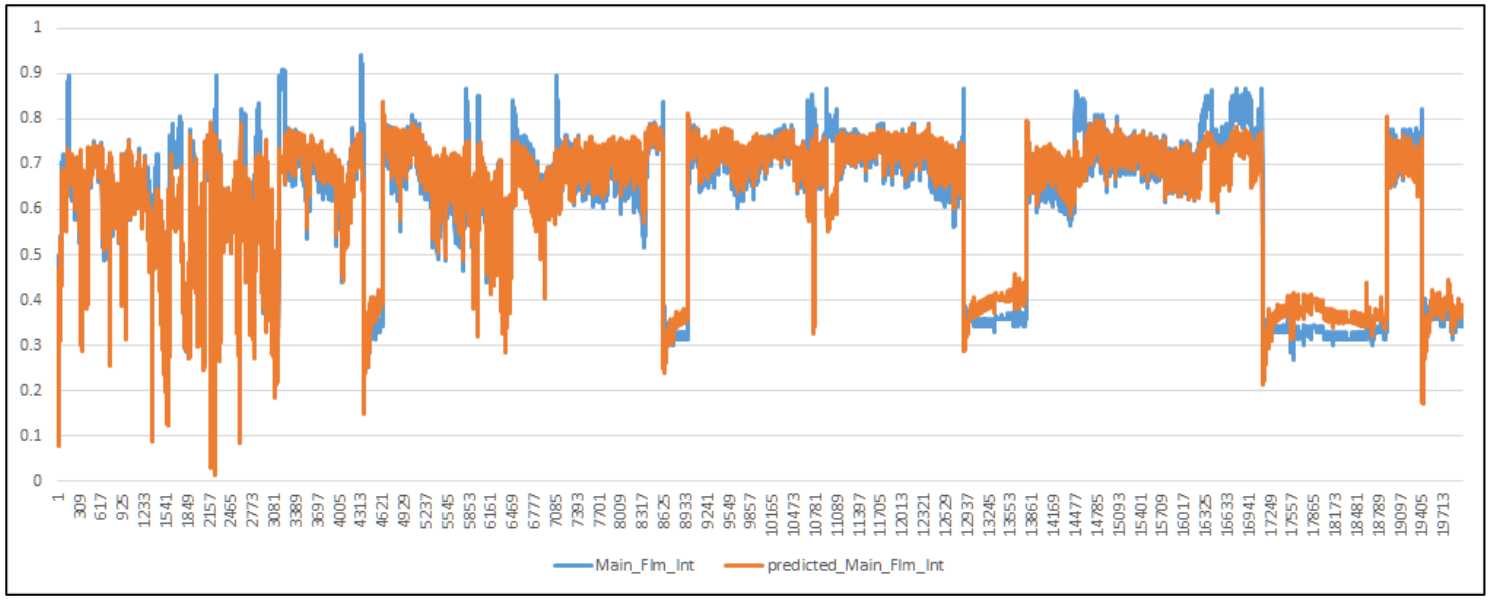
Cyclone Performance Predictions

Neural Network Predicted Cyclone Flame Intensity

Predicted vs Actual Flame Intensity



X axis: Jan. 31 - Feb. 13 2019 (Cyclone Slagging Issues)
Y Axis: normalized flame intensity
%Error: 4.09%

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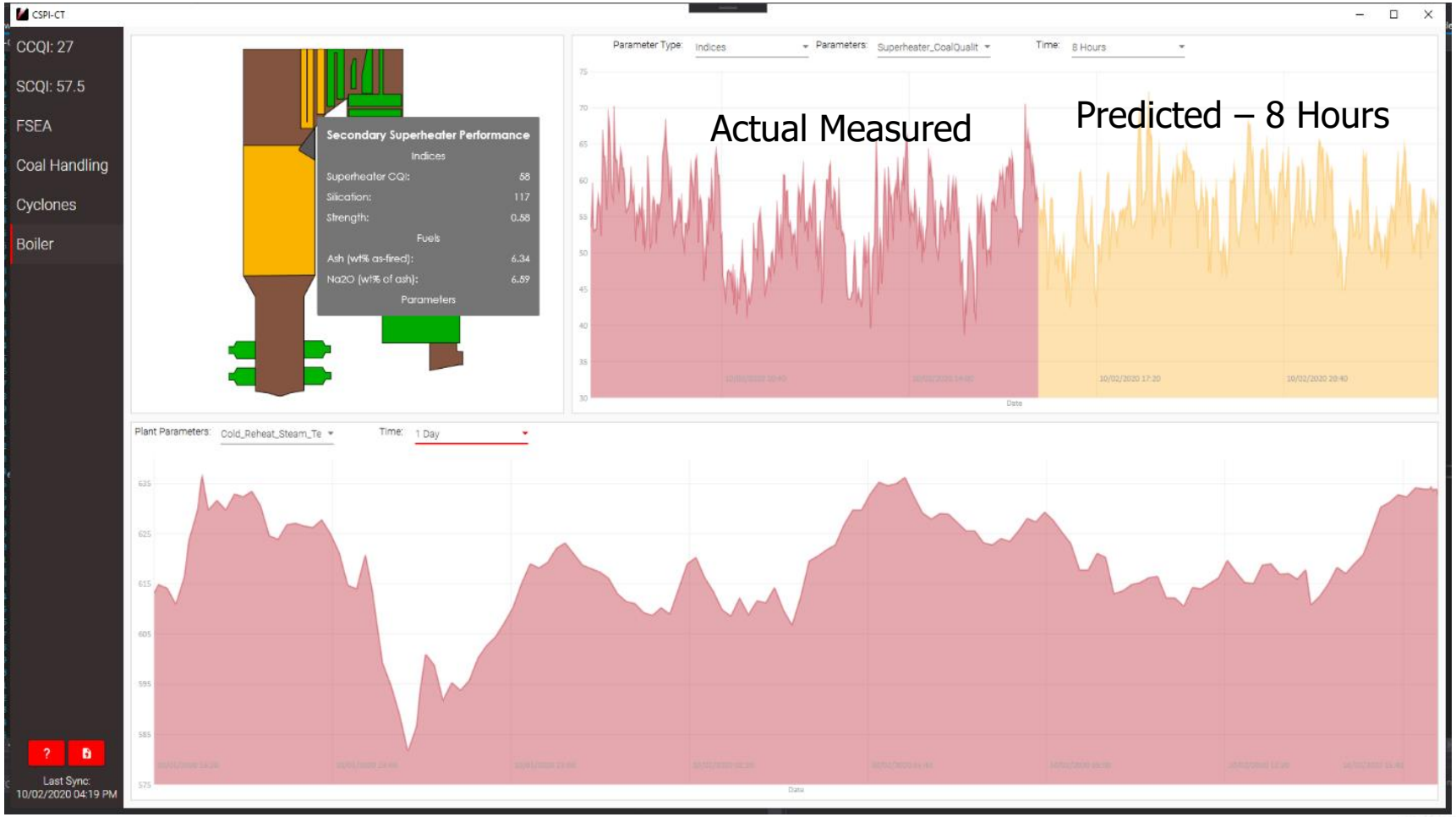
Projecting Performance



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Improvements in Performance of Plant Use of CSPI-CT on site

- Plant Performance Improvement
  - Microbeam's CoalTracker program provides access to minute-by-minute as-fired coal properties for each cyclone
  - CoalTracker provides insight into the barn and allows for more accurate blending decisions
  - Reduced the number of unplanned outages
  - Decreased the number of planned cleaning outages

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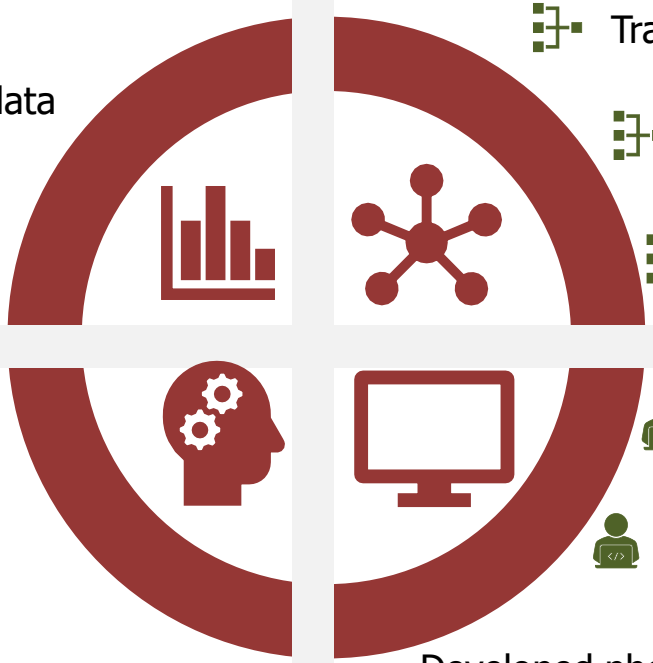
Condition Based Monitoring (CBM) Project Progress Summary

- 25 Databases - 17,000 hours of operational data
- Life of Mine Database - 16,000 data points
- As-delivered fuel properties database - 500,000 data points
- As-fired fuel properties database - 500 coal short prox results



- Implemented 2 Novel Algorithms (EXAMM and EXALT)
- Trained 42 million RNNs
- NN Flame Intensity predictions
- Predicting 8 hours in the future – Net Plant Heat Rate

- Conducted a field test – collected 149 coal samples
- Conducted over 35 project meetings and spent over 1200 hours analyzing data
- Published 12 papers and 1 book chapter
- Currently working on updating indices with modified correlations

- Installed CSPI-CT beta 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 April 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**

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Questions?

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