DEMONSTRATION OF MULTI-GAMMA BASED SENSOR TECHNOLOGY FOR AS-FIRED COAL PROPERTY MANAGEMENT

(Award No. DE-FE0031750)

DOE NETL's 2021 INTEGRATED PROJECT REVIEW MEETING – JOINT SENSORS

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Jessica Mullen – DOE NETL Project Manager
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U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Project Team

- Technical Team:
  - Microbeam Technologies Inc.
  - Energy Technologies Inc.
  - 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
  - Energy Technologies Inc.
  - Rochester Institute of Technology
- Project Support :
  - Minnkota Power's Milton R. Young Station
  - North American Coal Company

Agenda

- **Project Information**
  - Project Team
  - Project Goal and Objectives
  - Project Structure and Schedule
- **Budget Period 1 Accomplishments**
  - MGA Sensor Lab Testing
  - Accumulation and Analysis Of Attenuation Signals
  - On-site Sensor Installation
  - MGA Data Acquisition and Processing System
  - Neural Network Training and Testing
- **Next Steps**
- **Questions**

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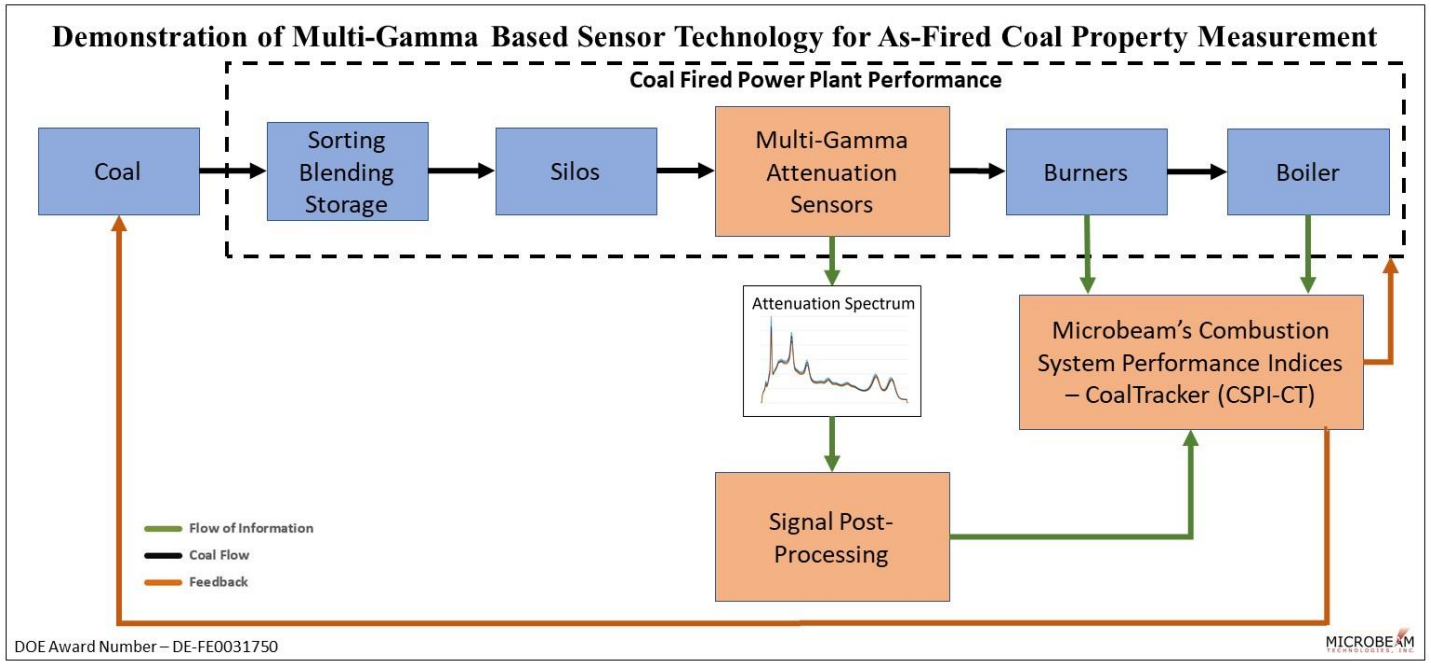
Project Goal

The overall goal of this project is to demonstrate the application of the use of an advanced multigamma attenuation (MGA) sensor to accurately and precisely measure fuel properties at the point of injection into burners.



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Objectives

- Test MGA sensors on a range of selected coal samples in laboratory
- Accumulate and analyze attenuation signal information
- Develop relationships for coal quality parameters with statistical and neural network analysis
- Install MGA sensors on-site and develop MGA output database
- Develop MGA-FSEA correlations with neural networks and install MGA data augmented CSPI-CT on site
- Conduct a field test to validate augmented CSPI-CT findings
- Install a validated version of CSPI-CT on-site

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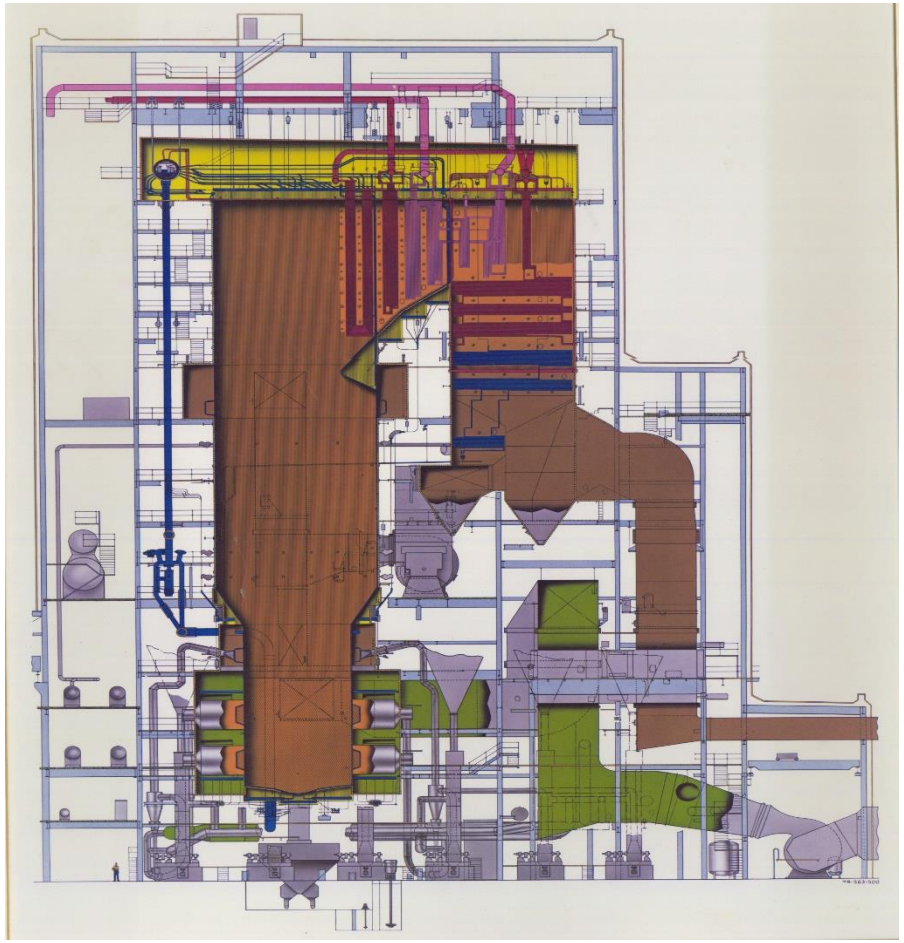
FSEA – Full Stream Elemental Analyzer
CSPI-CT – Microbeam's Combustion System Performance Indices – CoalTracker program
MGA – Multi-Gamma Attenuation

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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Schedule

			2019			2020											2021											2022								
	Start Date	End Date	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
Task Dates			Budget Period 1																		Budget Period 2														
Task 1 - Project Management & Reporting	10/1/2019	9/30/2022																																				
Task 2 - Factory testing of MGA Sensors	11/1/2019	4/30/2020																																				
Task 3 - Installation of MGA at Coyote Station	3/1/2020	8/31/2020																																				
Task 4. MGA Database and Correlations Development	9/1/2020	3/31/2021																																				
Task 5. Field testing MGA	4/1/2021	4/30/2022																																				
Task 6. Integrate with CSPI-CT	5/1/2022	9/30/2022																																				

Total Project Length – 36 Months

Budget Period 1 – 10/1/2019 – 3/31/2021
Budget Period 2 – 4/1/2021 – 9/30/2022

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Technology

- On-line analyzer adapted for analysis of fuel flowing through feed pipes to burners that utilizes multi-energy gamma attenuation measurements of fuel properties that include heating value, ash content, and selected ash-forming components.
- System calibrated to different inorganic components through machine learning that contribute to the total ash composition.
- The core of the technology is a multi-energy gamma attenuation (MGA) source.
- This source improves the accuracy and precision of measuring the ash-forming materials for full-stream fuel delivery applications.
- This source is produced by Oak Ridge National Laboratory.

Technology Benefits

- Inexpensive method to accurately monitor coal properties at the burner
- Small footprint allows for small scale application (belt and pipe applications)
- Easily adaptable to enable feedback control for fuel sorting and blending
- Can enhance the use of existing tools to predict plant performance, maintenance schedule, and impacts of plant cycling.

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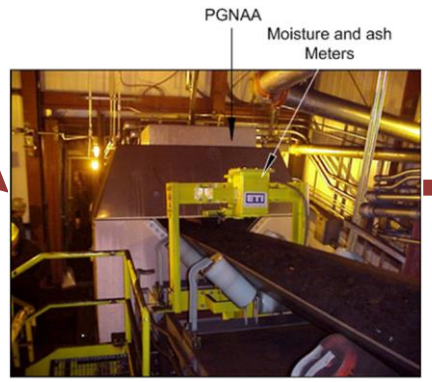
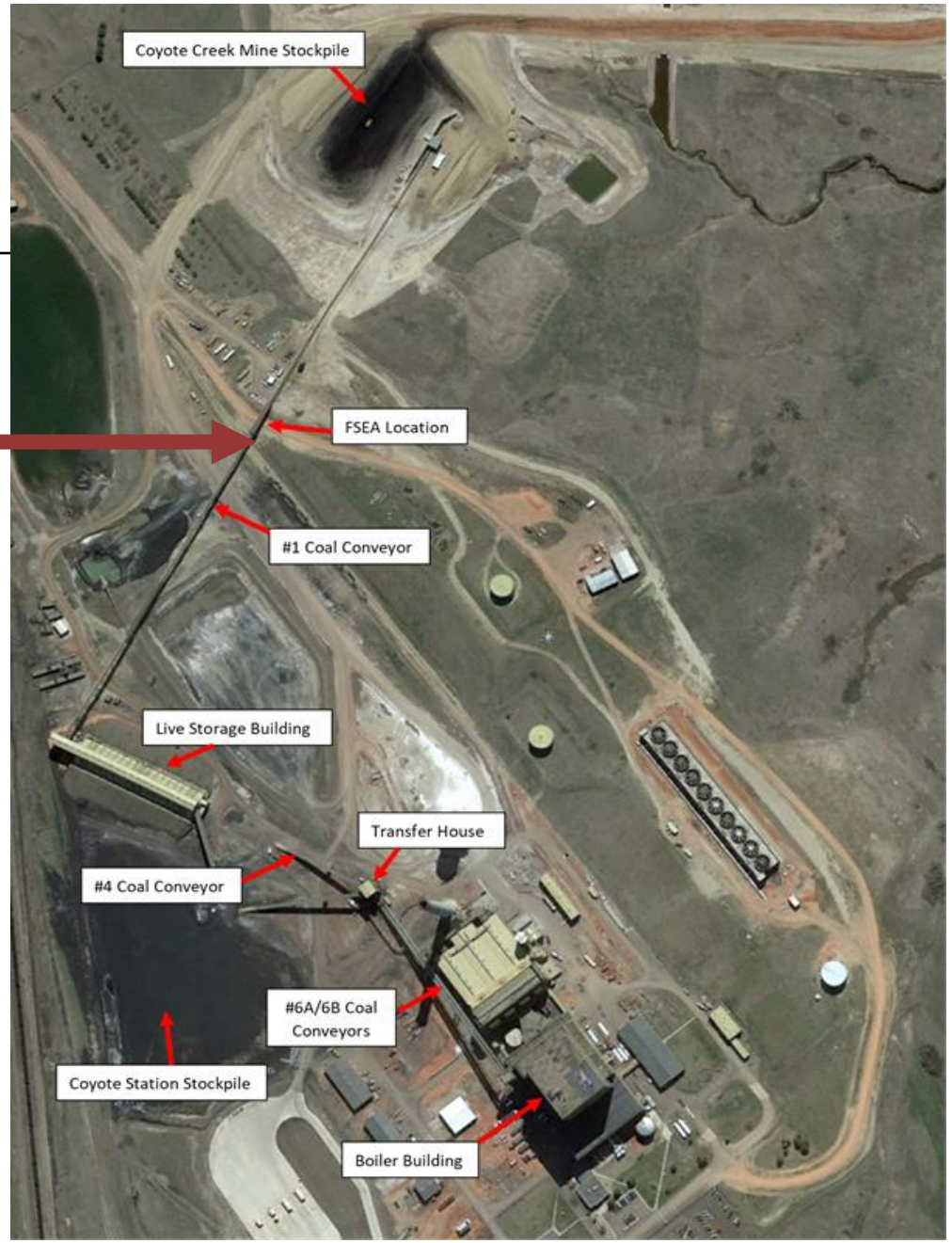
OtterTail Power Coyote Station's Coal Handling System

- As-delivered Fuel
- Belt 1
- Live Storage
- Transfer House/Tower
- Belt 7/10
- Coal Silos 1-12
- Cyclone Feeder Pipes
- Boiler



Multi-Gamma Attenuation Sensor



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Budget Period 1 Accomplishments

- Successfully completed lab testing of the MGA sensor
- Designed MGA sensor frame and housing
- Installed MGA sensors on-site with Cesium and Americium gamma sources
- Data pipeline was established
- Conducted two field tests
- MGA spectral data collected from installed sensors (with only Americium and Cesium sources) on two cyclones at the Coyote Station indicates a strong correlation between attenuation peaks with ash content and base-to-acid ratio of the fuel ash.

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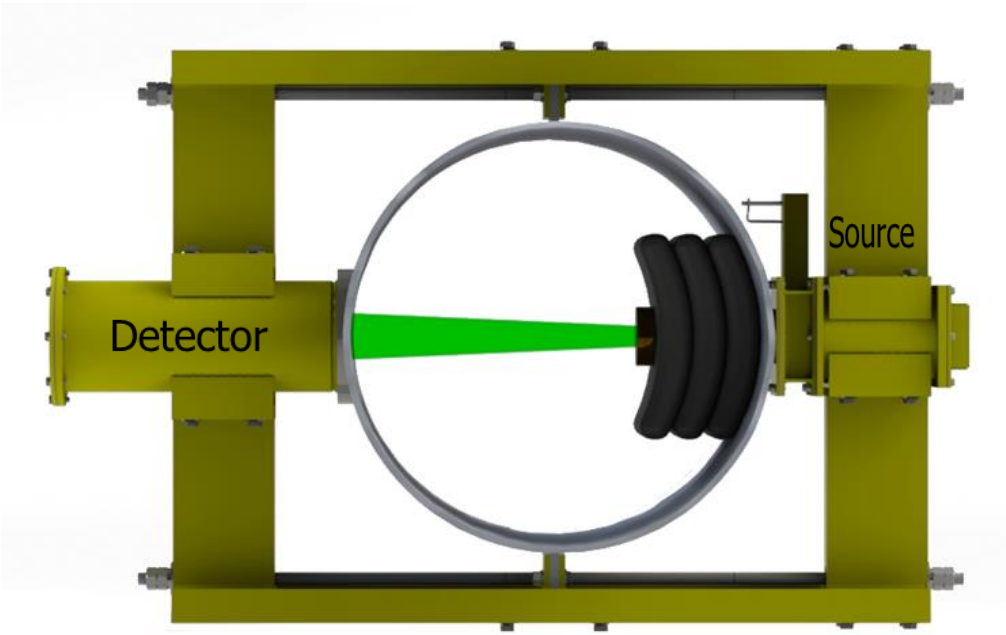
Base-to-acid= $(Na_2O+MgO+K_2O+Fe_2O_3)/(SiO_2+Al_2O_3+TiO_2)$

CoVID-19 Delays

- Oak Ridge National Lab (ORNL) is providing the multigamma source.
- ORNL has provided the project team with 10 millicurie of the multigamma source which is currently being used for lab testing.
- An additional 30 millicurie of multigamma source is required for on-site sensor installation.
- ORNL was partially shutdown due to CoVID-19 which has resulted in a delay of multigamma source installation in the sensors.
- The project team is working closely with ORNL to determine the potential date by which the additional multigamma source will be available and based on the currently available information and assumption that ORNL can stay open in the near future, the project team anticipates on-site sensor installation towards the end of June 2021.

Factory Testing Setup with Source and Detector – Pipe Application



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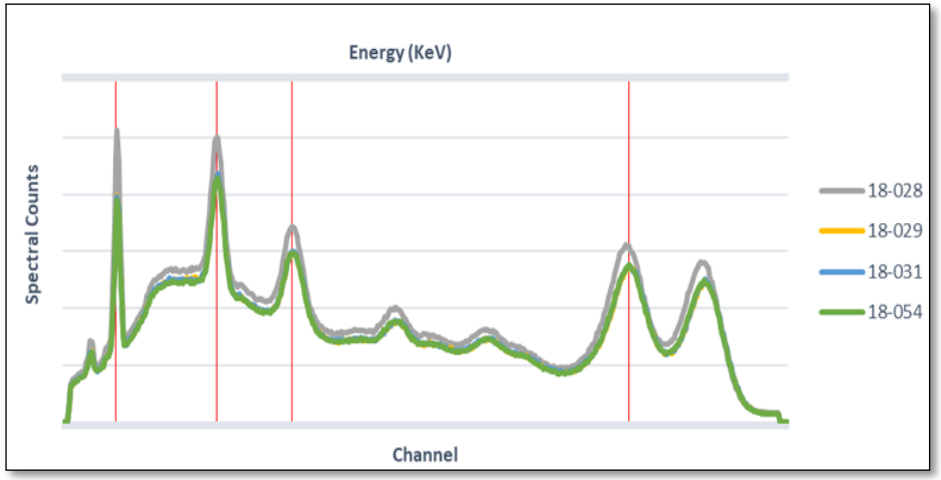
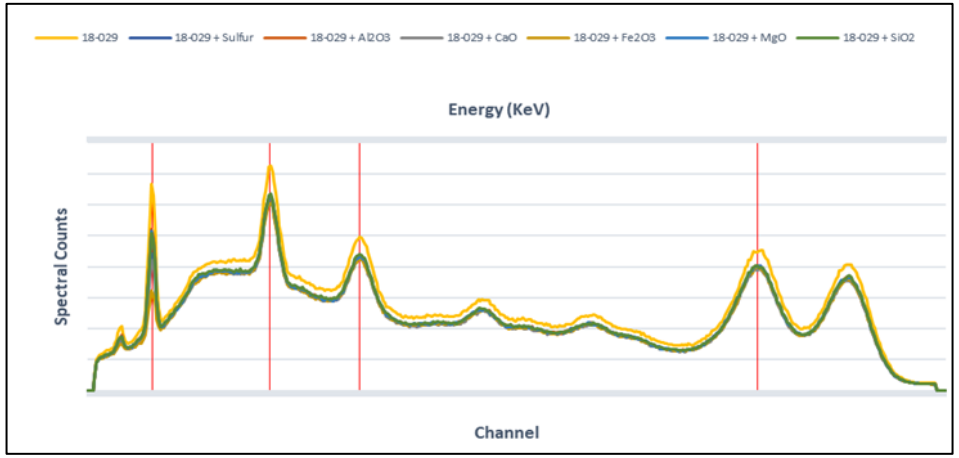
Lab Testing Results - MGA Spectra

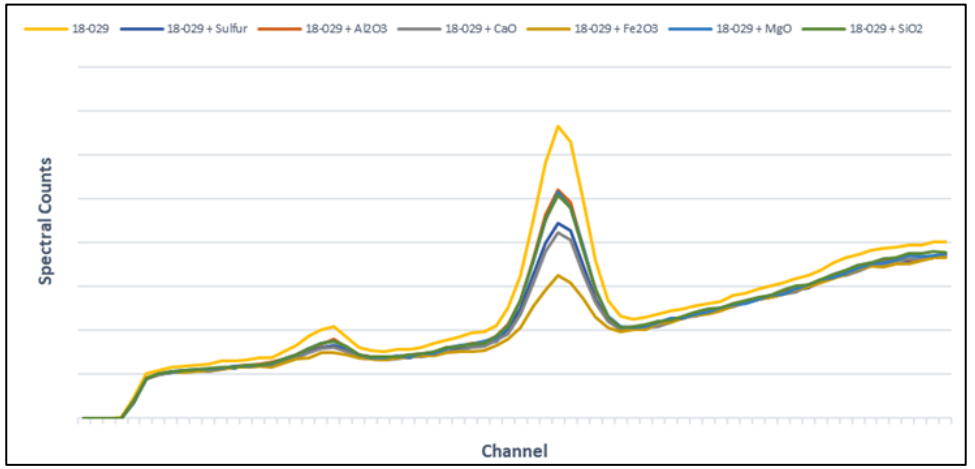
Coal Samples Spectral Results Comparison



Effects of Spiking Elements on Spectral Results



Peak 1 Spectral Comparison



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Lab Testing Summary

- 110 Runs Complete
  - 26 coal sample runs
  - 79 runs with spiking elements
  - 3 runs with clay minerals
  - 3 runs with different petri-dish placement

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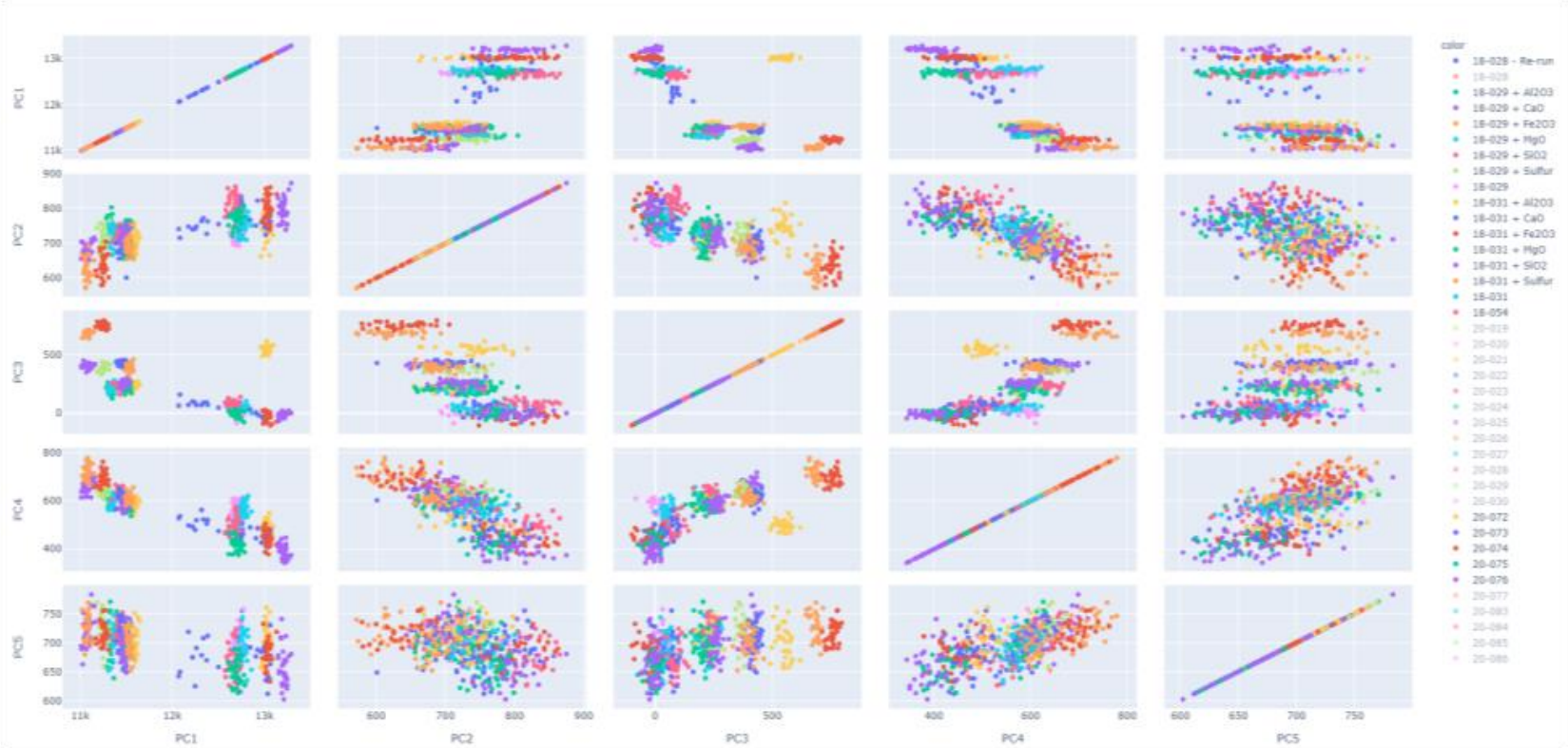
Principal Component Analysis



Note: Each colored cluster represents a different coal sample.

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Task 3
Installation of MGA at Coyote Station

- Subtask 3.1 Design of MGA Sensor Frame and housing
- Subtask 3.2 Identification of installation locations and install
- Subtask 3.3 Set up data compilation system

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Locations for MGA Installation

- Cyclone 3 - High oil flow – low flame intensities in Aug 2019 database

- Cyclone 10 – Microbeam has past field test data and showed good performance in Aug 2019 database

Cyclone 3 Feeder Pipe

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Coyote Feeder Pipe Weldlets Installation – June 2020

- Coyote installed weldlets during the June 2020 shutdown.
- Parts installed during the outage included:
  - Weldlets (source and detector side)
  - Weldlet Lenses (source and detector side)
  - Frame Mounting Brackets

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Coyote Feeder Pipe – Sensor Installation – August 2020

- Sensors installed in August 2020 with Am and Cs.
- Sensors will be upgraded in 2021 with Multigamma Source.

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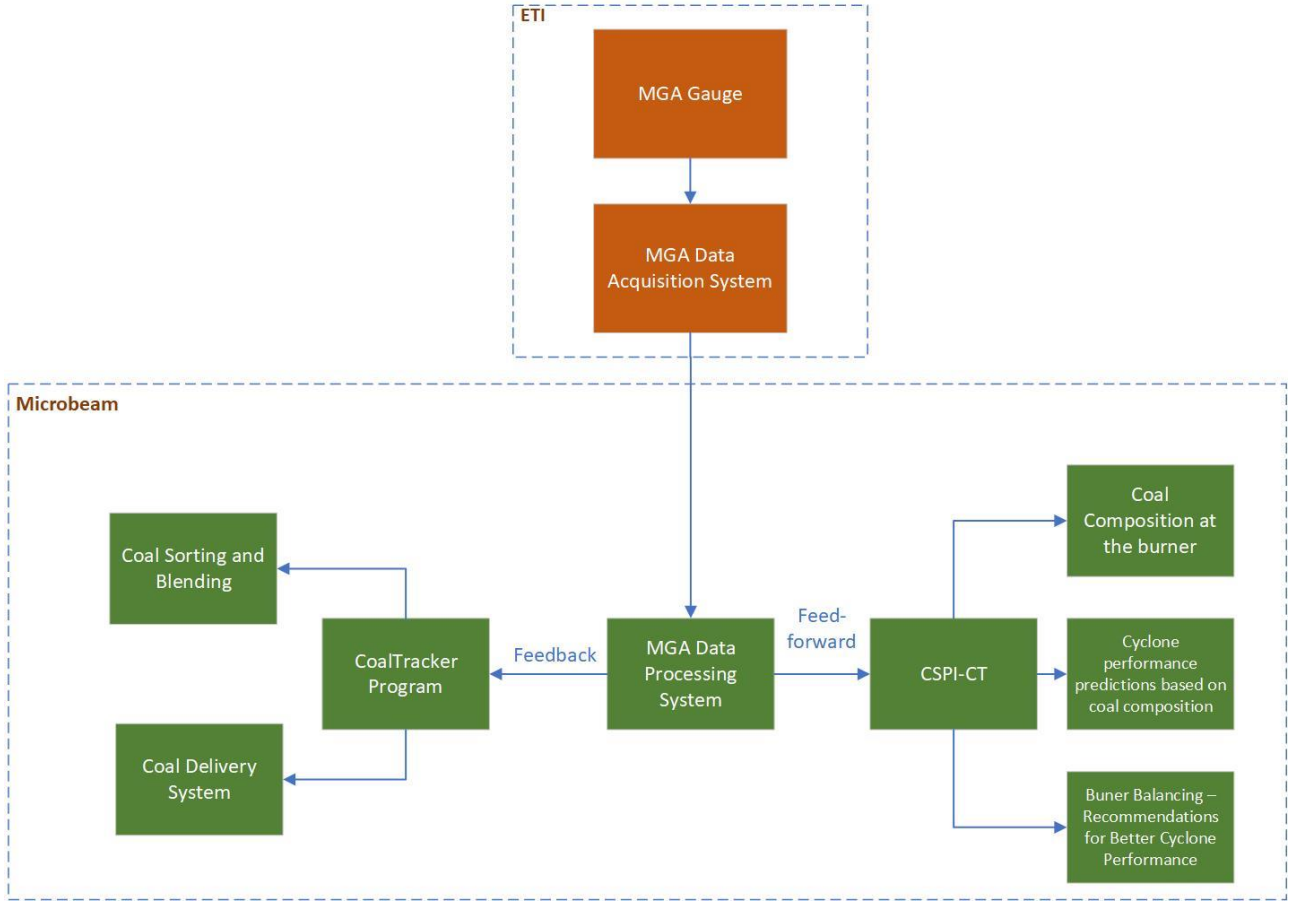
MGA Data Acquisition and Processing System



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Field Test - Database Development

- Two field tests :
  - August 2020 – Collected 26 coal samples
  - February 2021 – Collected 20 coal samples
- Analysis
  - Proximate and Ultimate
  - Ash Composition
  - Computer Controlled Scanning Electron Microscopy (Selected Samples)

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Field Test 1 – August 2020

Date	Condition	Time	Feeder Pipe 3	Feeder Pipe 10	Slag Samples	Fabric Filter/Hopper Ash Samples
25-Aug-20	D1C1	3:00 PM	X	X	X	X
	D1C2	6:00 PM	X	X	X	X
	D1C3	9:00 PM	X	X	X	X
26-Aug-20	D2C1	12:00 AM	X	X	X	X
	D2C2	3:00 AM	X	X	X	X
	D2C3	6:00 AM	X	X	X	X
	D2C4	9:00 AM	X	X	X	X
	D2C5	12:00 PM	X	X	X	X
	D2C6	3:00 PM	X	X	X	X
	D2C7	6:00 PM	X	X	X	X
	D2C8	9:00 PM	X	X	X	X
27-Aug-20	D3C1	12:00 AM	X	X	X	X
	D3C2	3:00 AM	X	X	X	X
	D3C3	6:00 AM	X	X	X	X

- Goal – Conduct a field test to test and calibrate the sensors
- Collected 26 coal samples, 13 slag samples and 13 fly ash samples
- Plant operations – full load with relatively steady operation.

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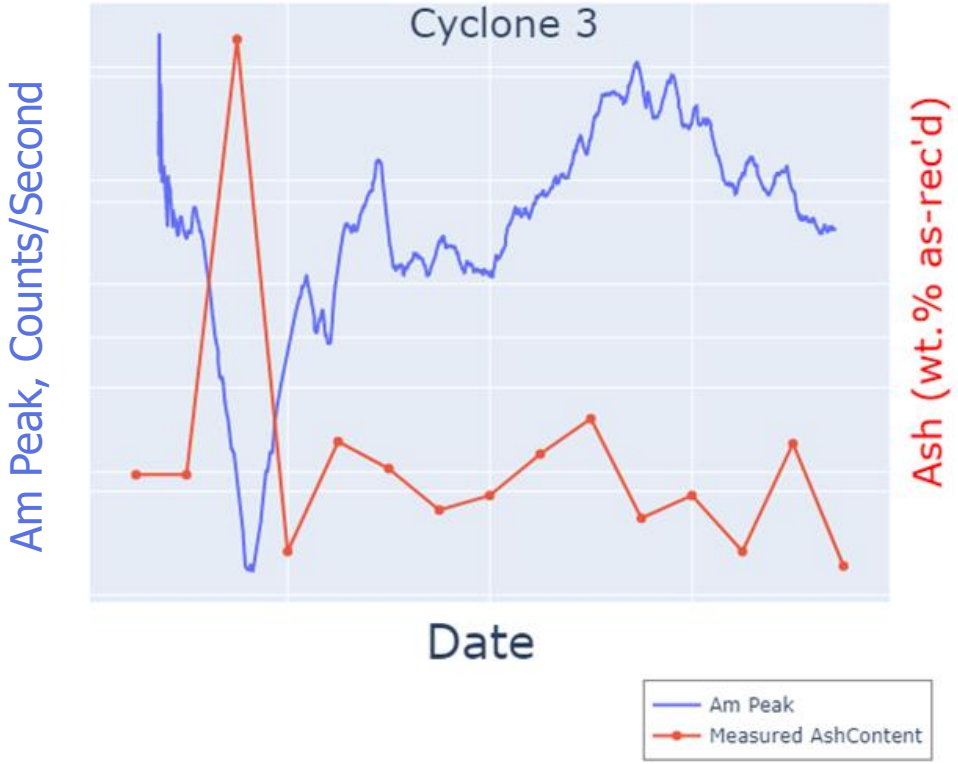
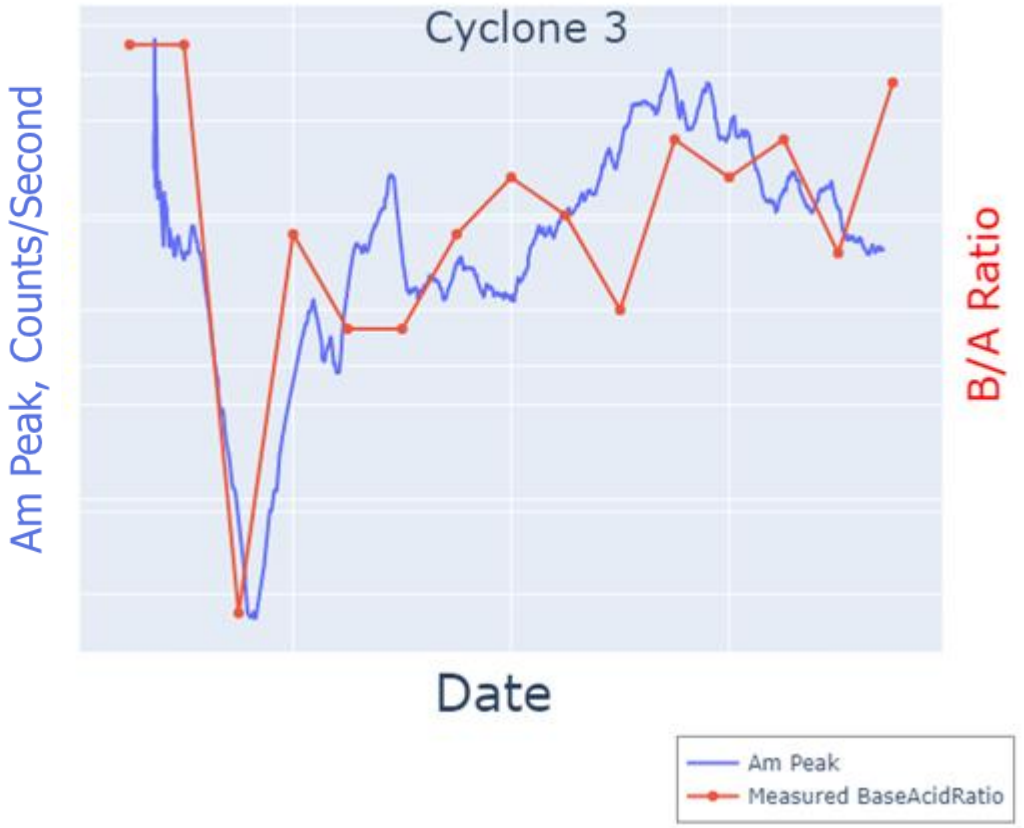
Field Test 1 - Ash Content and B/A Ratio Comparison with Americium (Am) Peak – Cyclone 3





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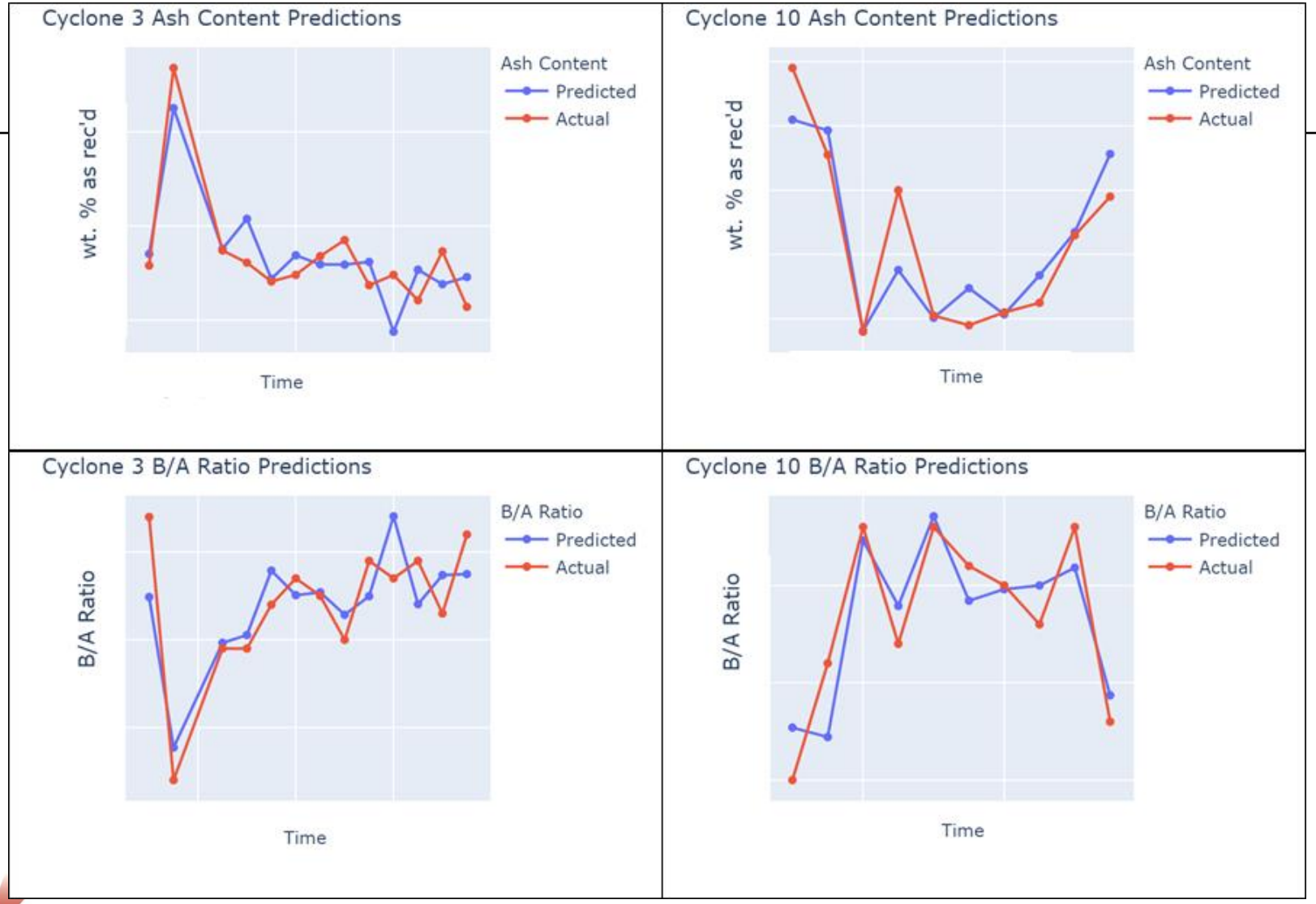
Field Test 1 - Predicted Fuel Properties



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Field Test 2 – February 2021

Date	Time	Belt 1	Belt 10	Feeder Pipe 3	Feeder Pipe 10
8-Feb-21	9:00 AM	X	X	X	X
9-Feb-21	12:00 AM	X			
10-Feb-21	9:00 AM	X	X	X	X
11-Feb-21	9:00 AM	X	X	X	X
12-Feb-21	9:00 AM	X	X	X	X
15-Feb-21	9:00 AM	X	X	X	X

- Next Steps – Improve fuel properties predictions
- Validate CoalTracker Model

- Goal – Work with Coyote Station to collect coal samples to improve sensor predictions
- Collected 21 coal samples
- Analyzed coal samples for proximate, ultimate and ash composition analysis
- Improved the training database

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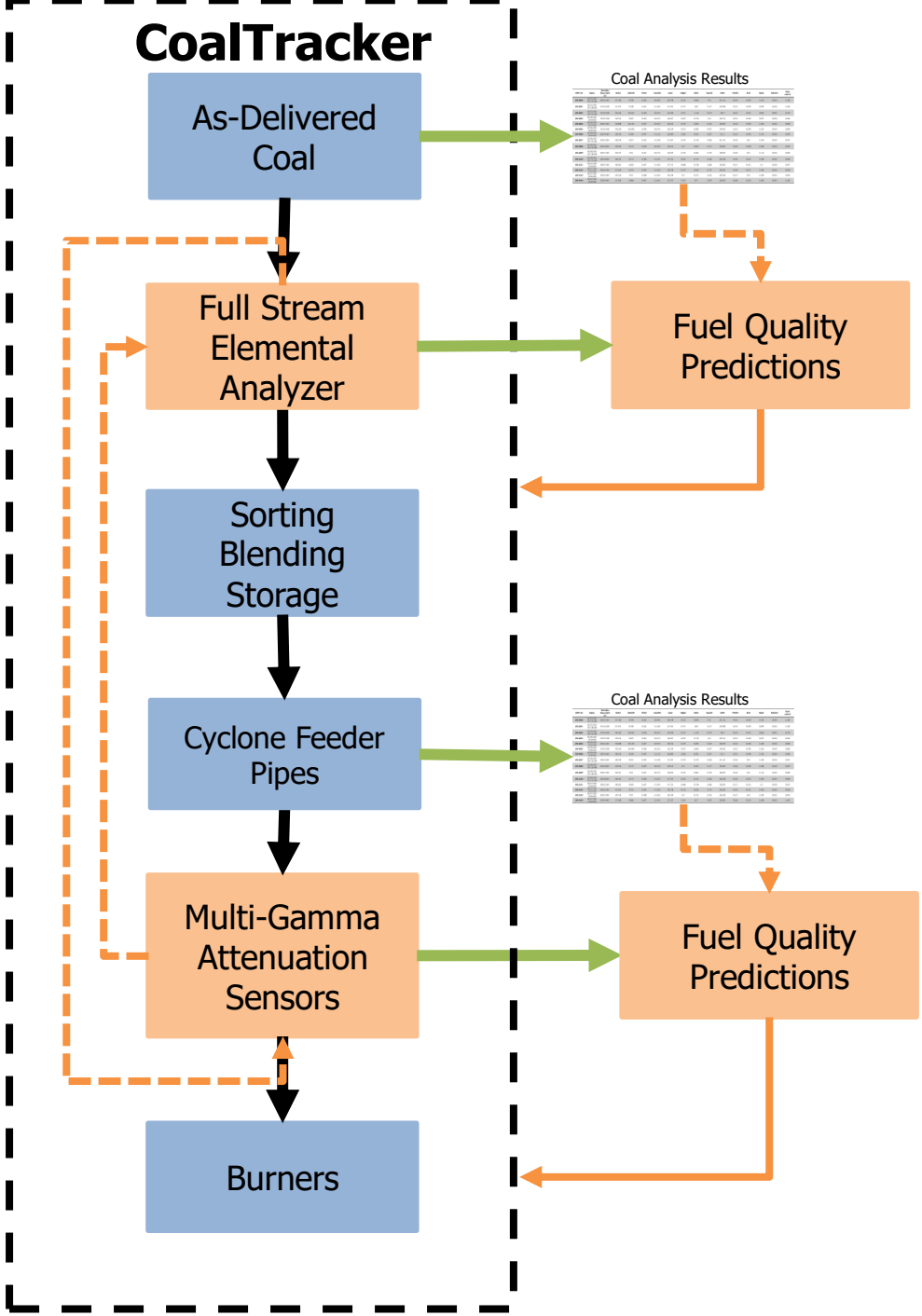

CoalTracker Calibration Philosophy

- Two analyzers provide the ability to calibrate both the analyzers and the tracking system.
- Two-way calibrations/adjustments can be used to iteratively optimize both the prediction of tracked and as-fired properties.

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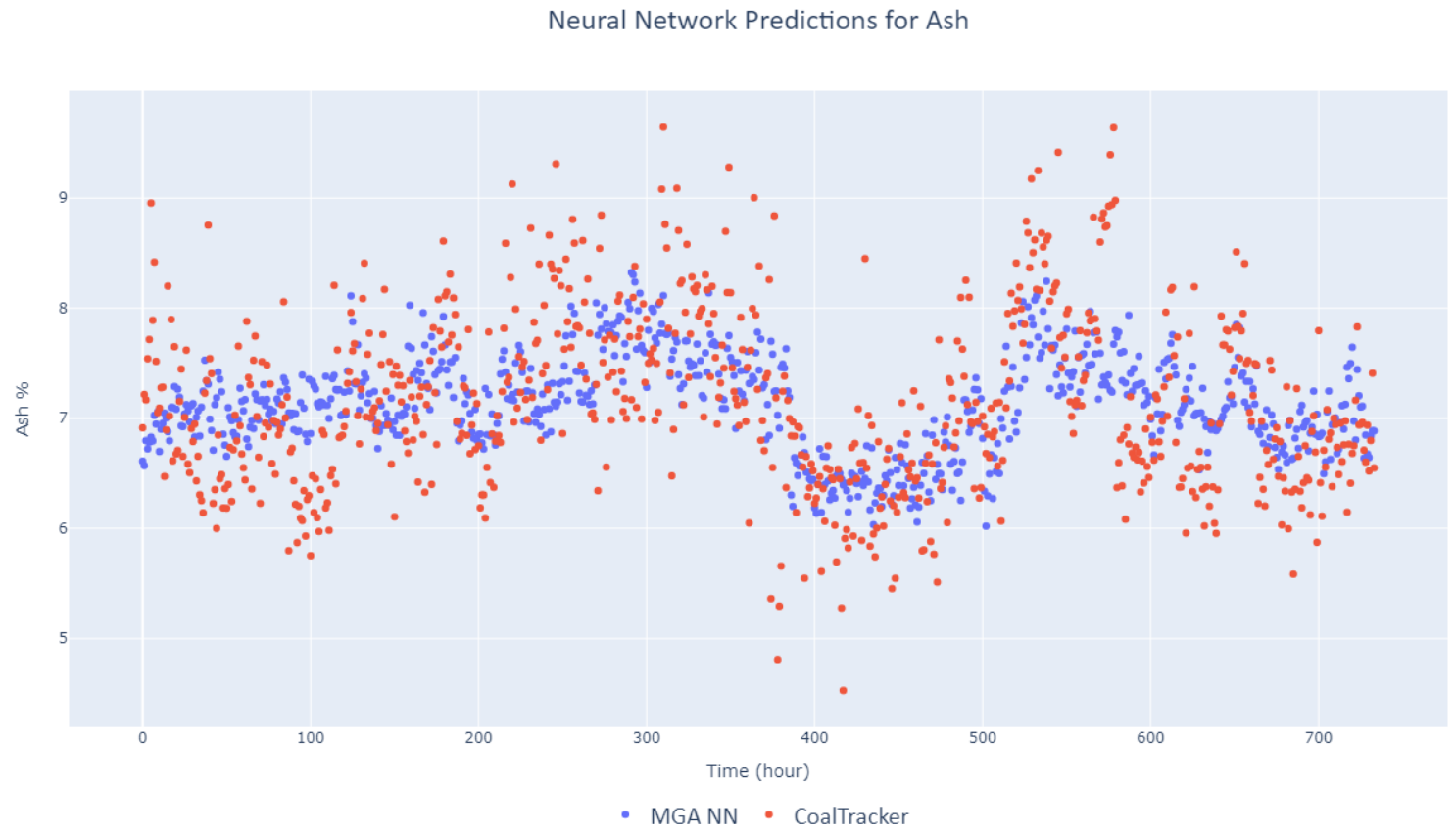
Neural Network Development and Testing

- Unsupervised learning algorithm, DBSCAN, was used to cluster the principal components.
- Regression analysis
- Keras, Tensorflow and Talos ML library
  - Used to train neural network to predict fuel properties from MGA spectra
  - CoalTracker data used as ground-truth
  - Matched CoalTracker's predictions with MAE = 8.1%

CoalTracker-to-MGA Results

(Neural Network Development and Testing)



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Summary

- MGA setup in ETI laboratories
- MGA factory test completion
- Accumulation of attenuation signals
- Development of relationships for coal quality parameters
- Installation of MGA sensor at coyote station – partially complete.
- Successful completion of MGA data compilation system setup – partially complete.
- Develop workforce readiness plan – partially complete.
- Development of MGA output database – partially complete.
- Develop MGA-FSEA correlations – partially complete.
- Upgrade CoalTracker program with MGA-FSEA correlations – partially complete.

Budget Period 2 Plans

- Installation of MGA sensor with Multigamma source at Coyote station
- Develop workforce readiness plan
- Development of MGA output database
- Develop MGA-FSEA correlations
- Upgrade CoalTracker program with MGA-FSEA correlations
- Neural network refinement with MGA data.
- Upgrade CSPI-CT with MGA based neural network algorithms.
- Install CSPI-CT 2.0 at Coyote Station
- Conduct validation field test
- Develop commercialization plan

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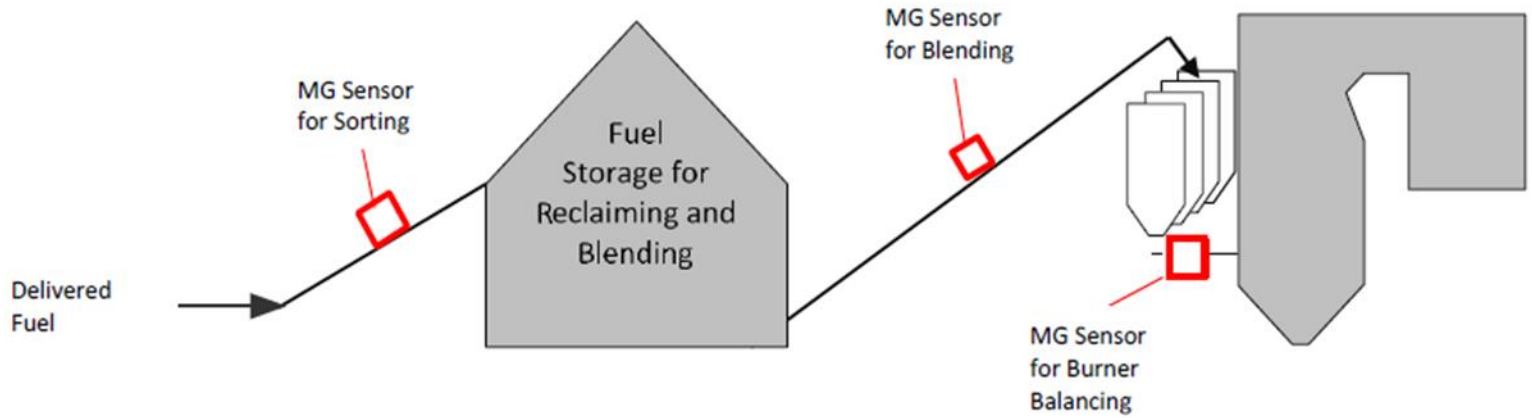
Technology Application



- Fuel Types:
  - Biomass
  - MSW – Processed feedstock (Plastics)
  - Petcoke
- Potential Clients:
  - Coal Mines
  - CFBs
  - Gasifiers

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Questions

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