Combustion Performance and Emissions Optimization through Integration of Miniaturized High-Temperature Multi-Process Monitoring System

May 4, 2022

Award No. DE-FE0031680

NATIONAL ENERGY TECHNOLOGY LABORATORY

2022 Spring Project Review

For Energy and Environmental Solutions

REACTION ENGINEERING INTERNATIONAL

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No proprietary information is included in this presentation

Agenda

- Project Overview
- Technical Discussion
  - R&D for Real-Time Ash Deposition Monitoring
  - R&D for Real-Time Corrosion Monitoring
  - Summary
- Plan
- Acknowledgements

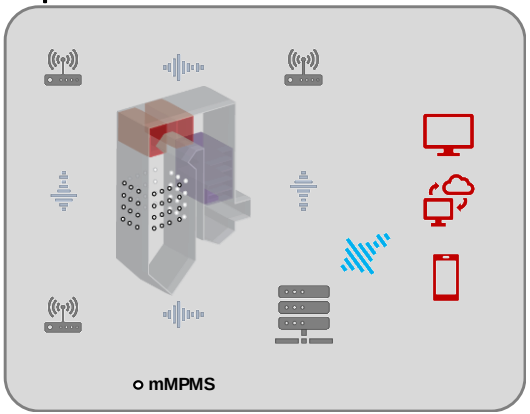
Reaction Engineering International

- Founded 1990 with Strong University and Specialist Affiliations
- Managed more than 40 government R&D projects in the past 15 years
- Has both management experience and technical expertise in the combustion and gasification related R&D programs
- Expertise
  - Combustion, Gasification, Fuel Conversion & Pollutant Emissions
  - Unique, Proprietary Modeling Capabilities & Tools
  - Laboratory and Field Testing
  - Specialized Equipment & Controls

Project Objectives

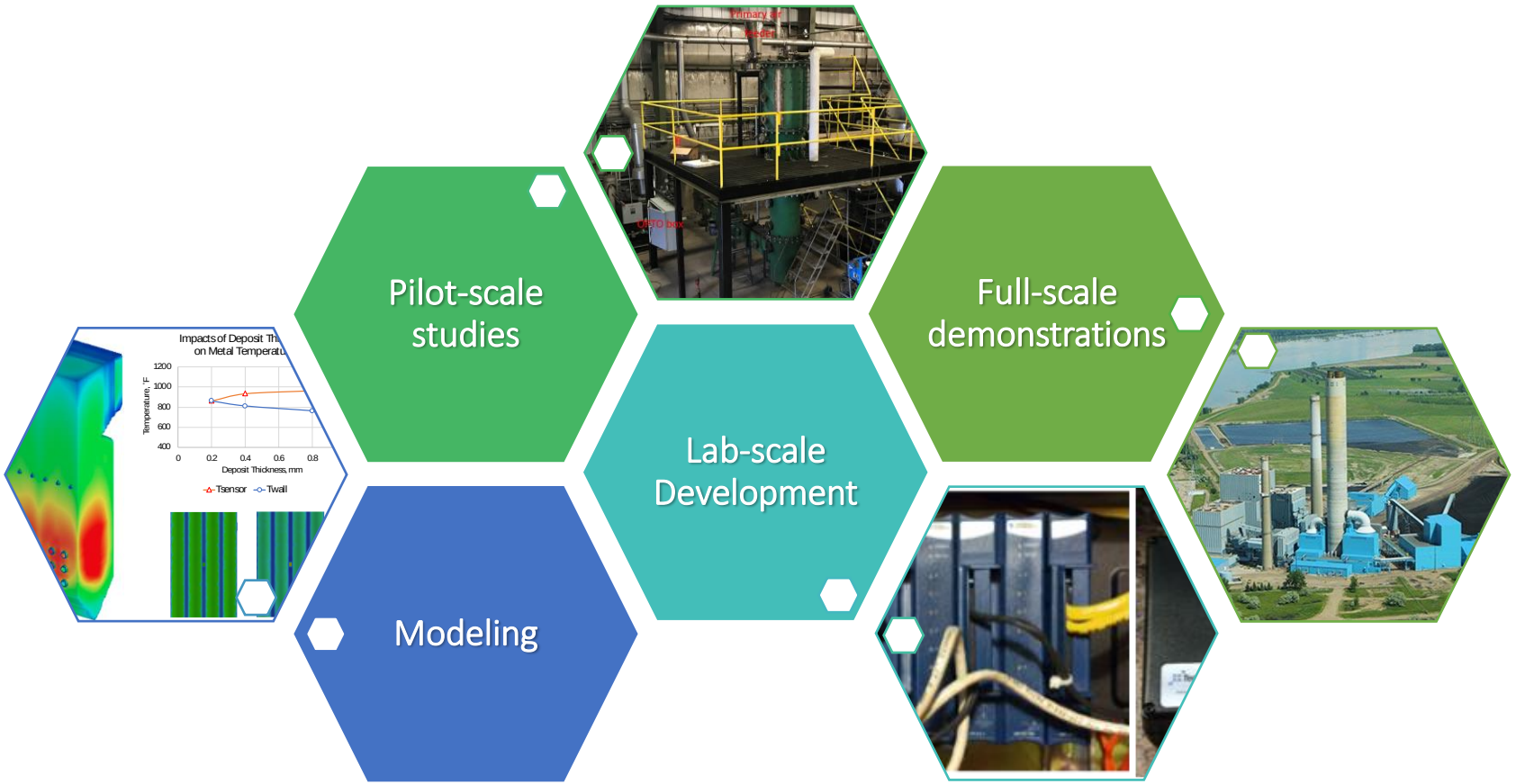
- Develop and demonstrate a miniaturized high temperature multi-process* monitoring system (mMPMS) that can provide a real-time indication of boiler condition in a ***lignite-fired*** full-scale boiler
- Develop and implement logic algorithms for the plant DCS to ***improve boiler energy efficiency, soot blowing, and NOx emissions*** by automated control of boiler operations

**metal wastage, heat flux, metal surface temperature, ash deposit thickness and ash deposition rate*



Conceptual Schematic of Boiler Condition Monitoring using mMPMS

Technical Approach



Project Team

Prime Recipient

REACTION ENGINEERING INTERNATIONAL

- *Project Management*
- *mMPMS Development*
- *Mechanism Derivation*
- *Computational Modeling*
- *Signal Conditioning and Data Communication Module Development*

Sub-Awardees

THE UNIVERSITY OF UTAH

Pilot-scale Testing

BASIN ELECTRIC POWER COOPERATIVE
A Touchstone Energy® Cooperative

PACIFICORP

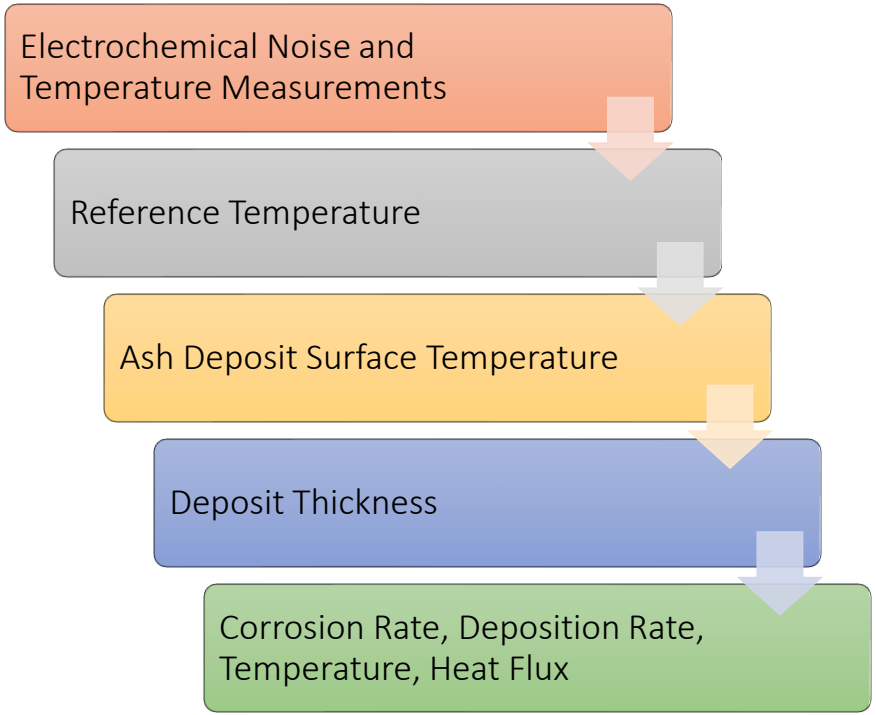
Full-scale Demonstrations

Bill Smith Engineering, LLC

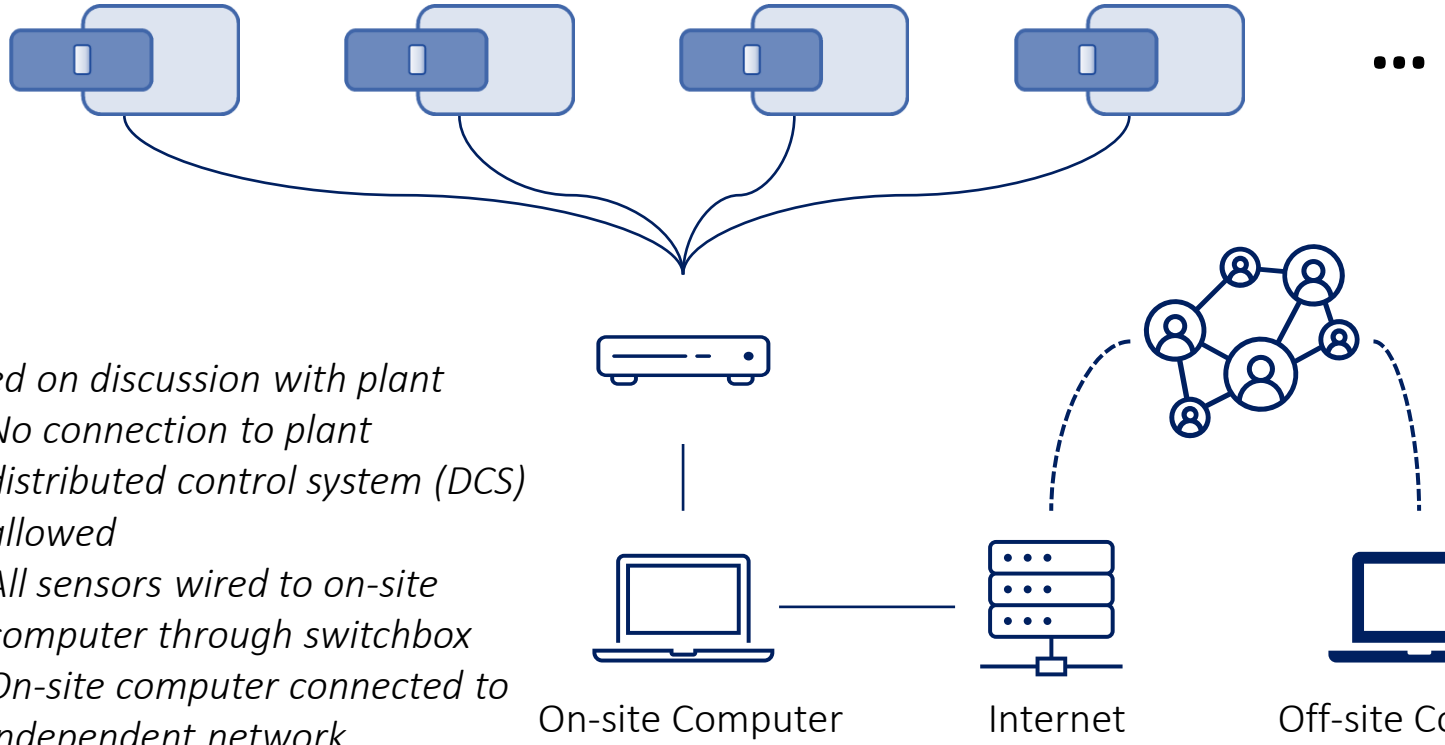
Boiler Control Logic

Multi-Process Monitoring

- Leveraged the legacy metal wastage monitoring capability
- Developed quantitative heat flux and deposition correlation based on sensor signal
- Tested and validated during pilot-scale testing



Remote Access & Data Communication



Based on discussion with plant

- *No connection to plant distributed control system (DCS) allowed*
- *All sensors wired to on-site computer through switchbox*
- *On-site computer connected to independent network*
- *Remote desktop software to connect to on-site computer*

Basin Electric Power Coop (Demonstration)

Leland Olds Station

BASIN ELECTRIC POWER COOPERATIVE
A Touchstone Energy® Cooperative

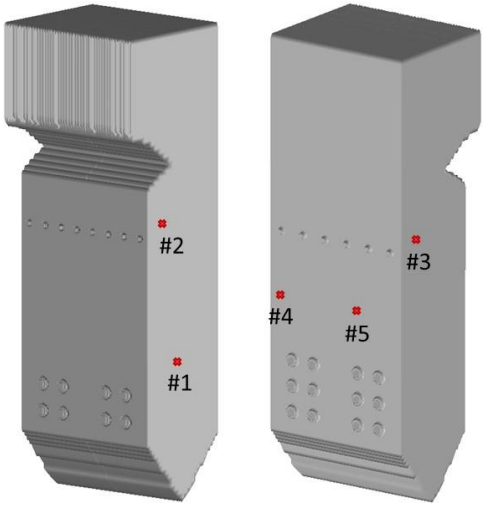
Plant is interested in ash management and boiler tuning

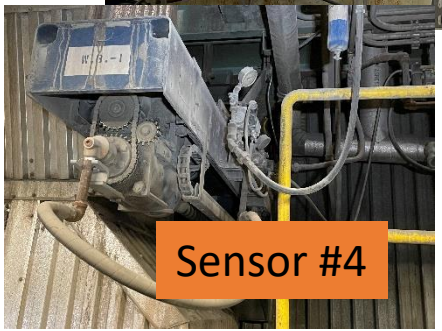
- Located near Stanton, North Dakota
- Two lignite-fired units with total generating capacity 669 MW
  - Unit 1 – 222 MW opposed wall-fired PC (demonstration plant)
  - Unit 2 – 447 MW opposed wall-fired cyclone

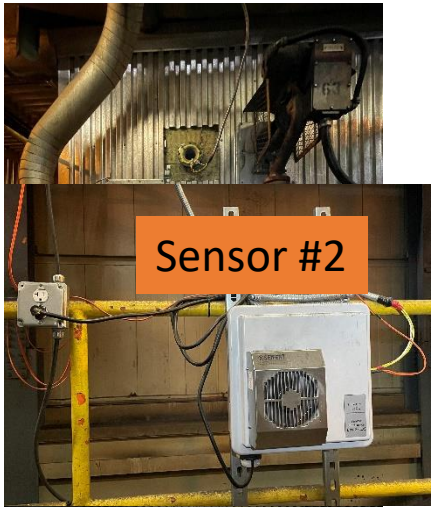
Hunter Plant: Demonstration Host

- Located near Castle Dale, Utah
- Three units with total generating capacity 1,320 MW
- Plant is interested in combustion optimization and NOx reduction while avoiding tube failure

System Installation



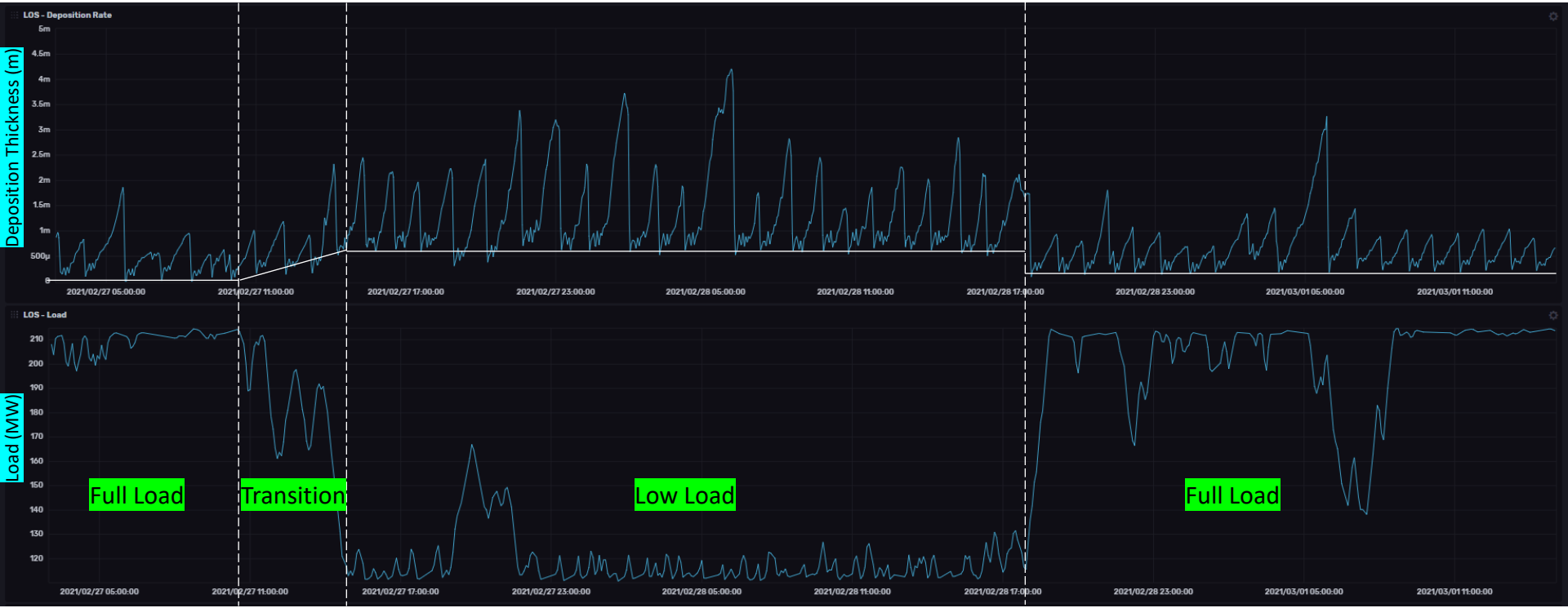




Real Time Data: Deposition Thickness

Sensor #1, 3:00 Feb 27 – 15:00 Mar 1

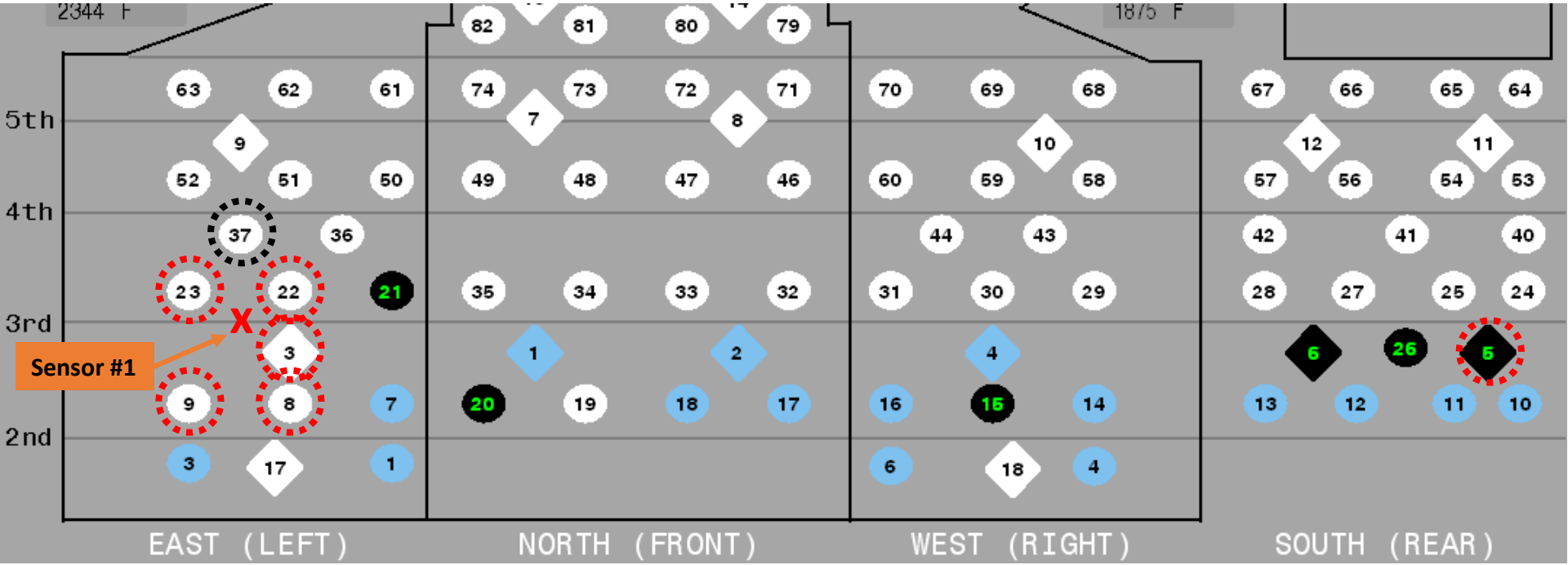
Tref = 1407 K



- The peaks in deposition thickness reflect the operation of the IR type soot blowers near the sensor (the frequency is about once per hour)
- The white bottom line represents a clean condition (~ 0 mm thickness) of the sensor after soot blowing

Test 1: Testing Procedure

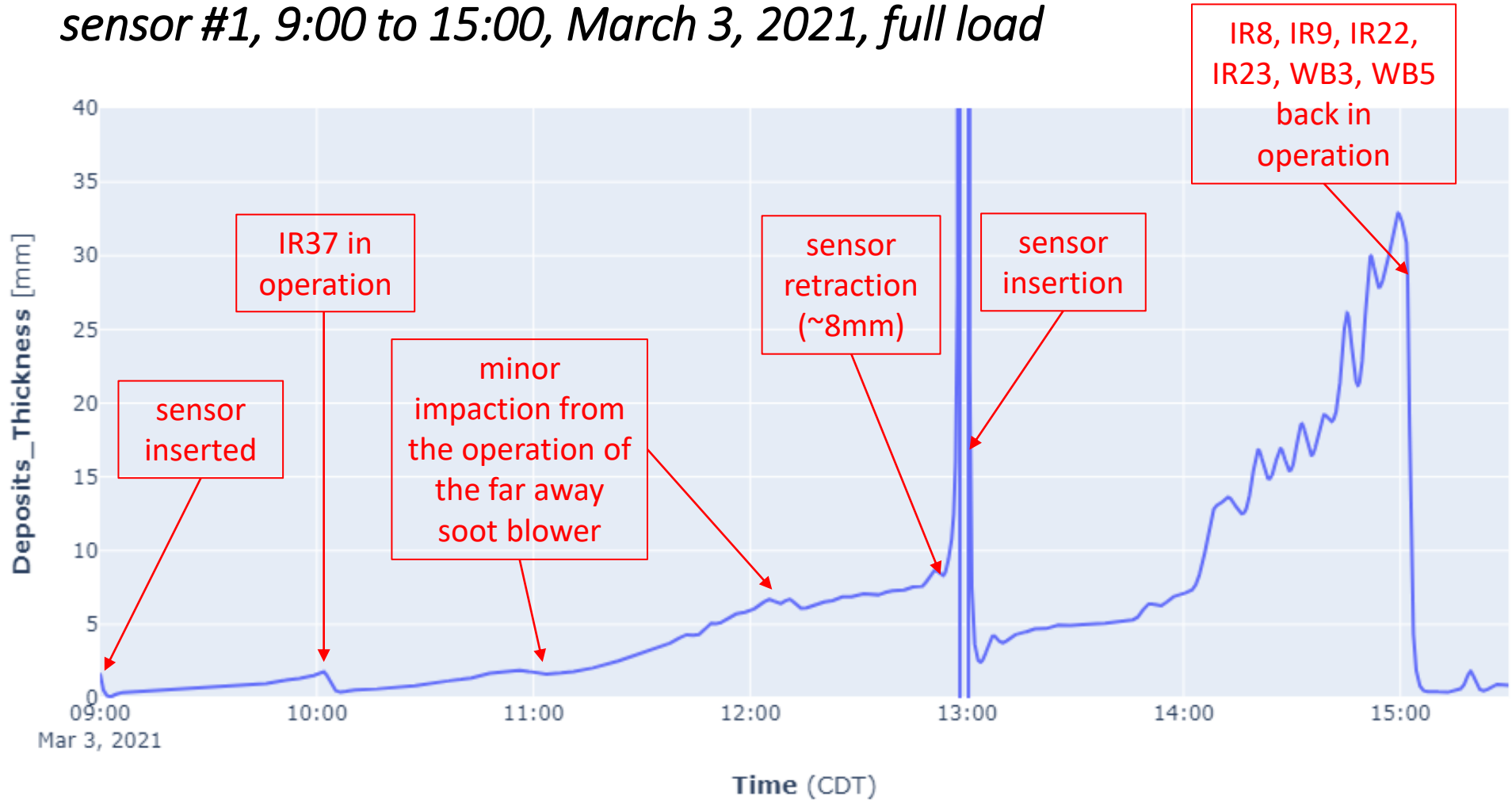
sensor #1, 9:00 to 15:00, March 3, 2021, full load



- The periodic increase-decrease of the real time deposits thickness is truly an interaction between the sensor and the soot blowers
- The reported absolute value of the real time deposits thickness is reasonable

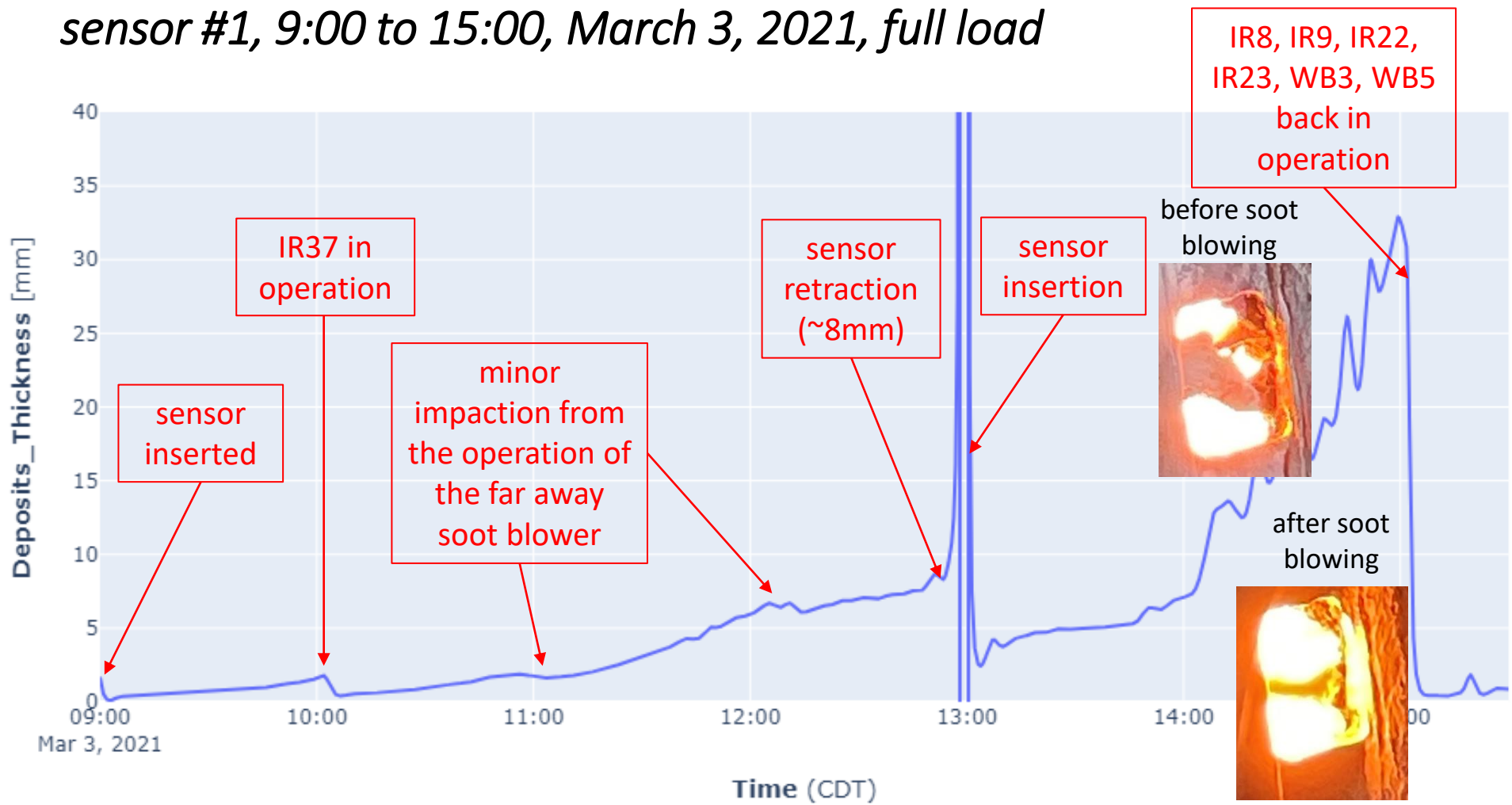
Test 1: Real Time Behavior

sensor #1, 9:00 to 15:00, March 3, 2021, full load



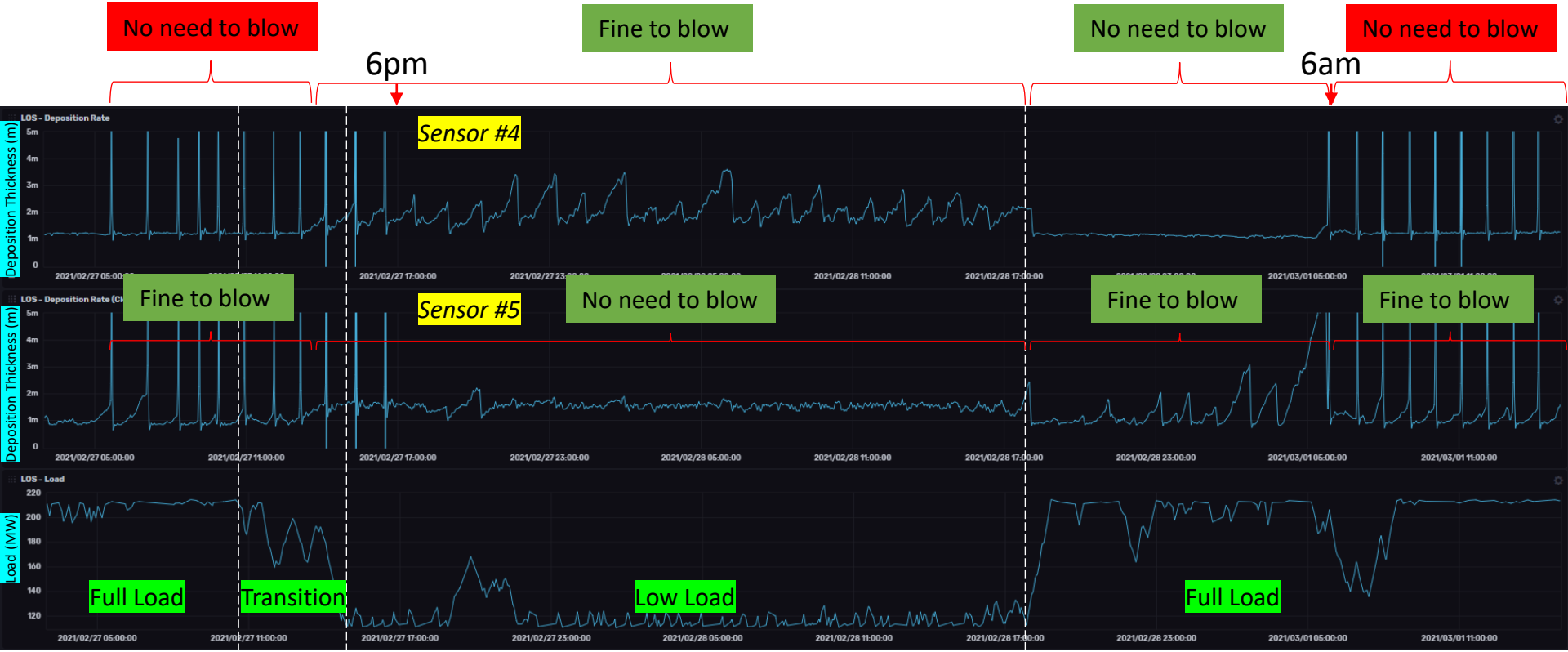
Test 1: Real Time Behavior

sensor #1, 9:00 to 15:00, March 3, 2021, full load



Real Time Data: Deposition Thickness

Sensor #4 & 5, 3:00 Feb 27 – 15:00 Mar 1



R&D for Real-Time Corrosion Monitoring

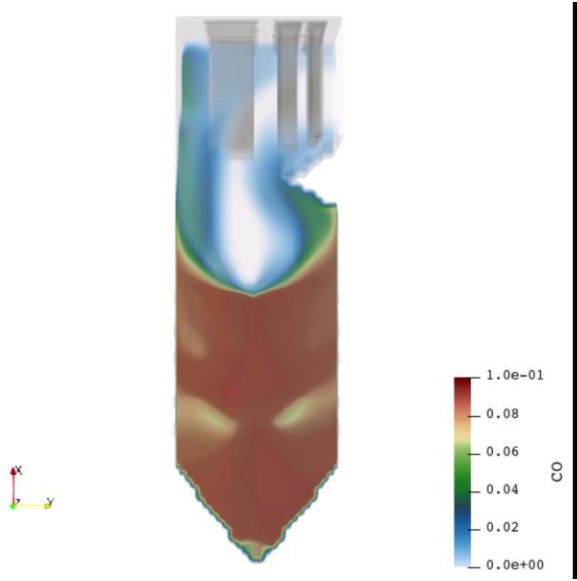
Load Swing at Hunter Plant

- As California solar power ramps up, the unit has cycled more aggressively down to less than 20% of full loading
- The loading changed daily during monitoring
- Load swing related waterwall wastage is a concern

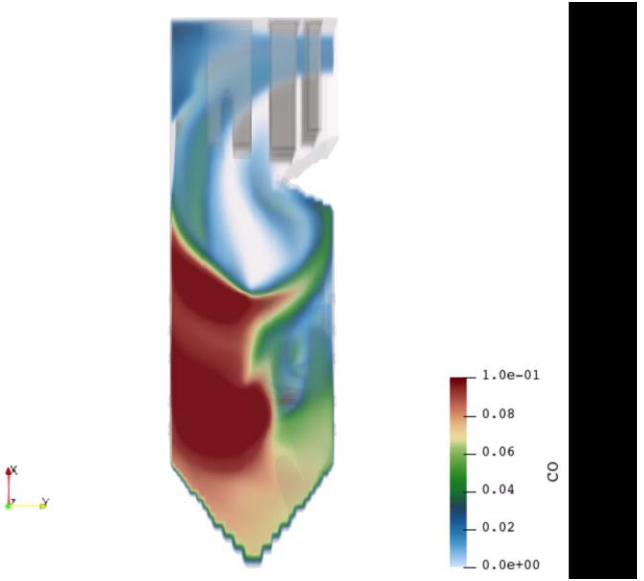
CO

Volumetric rendering showing 3D distribution of CO in the furnace

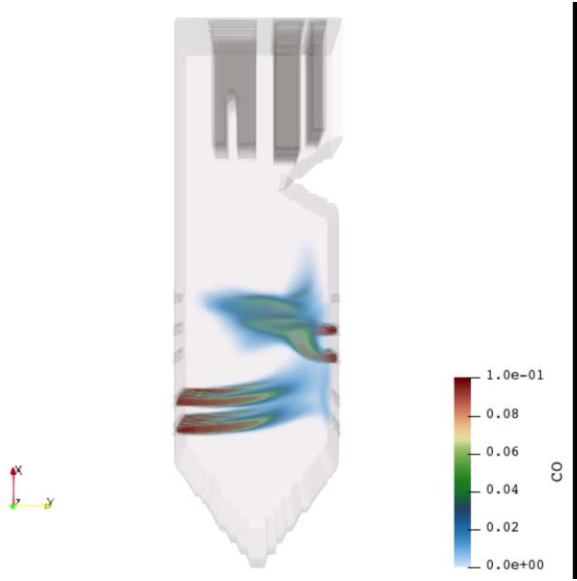
Baseline



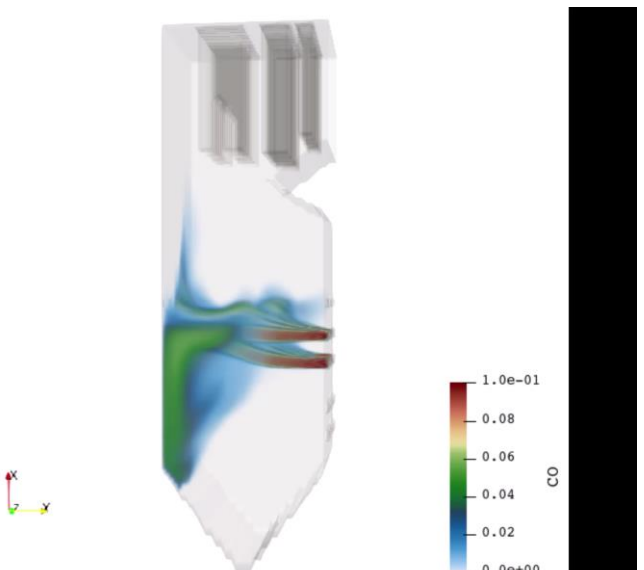
380 MWe



90 MWe



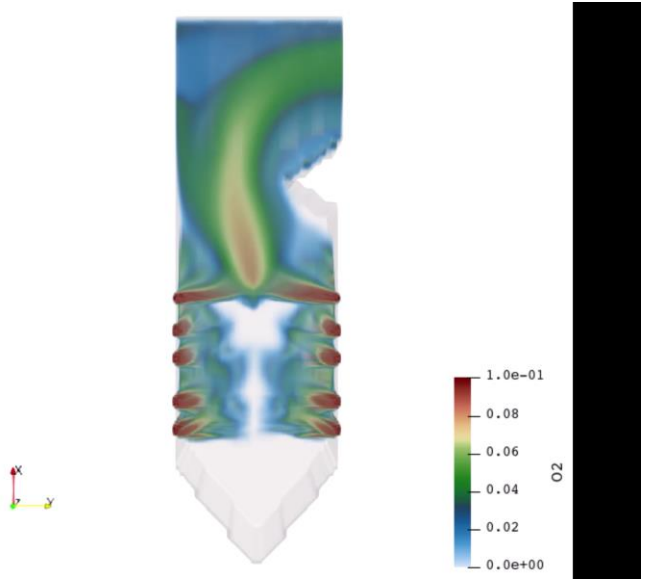
60 MWe



O_2

Volumetric rendering showing 3D distribution of O_2 in the furnace

Baseline



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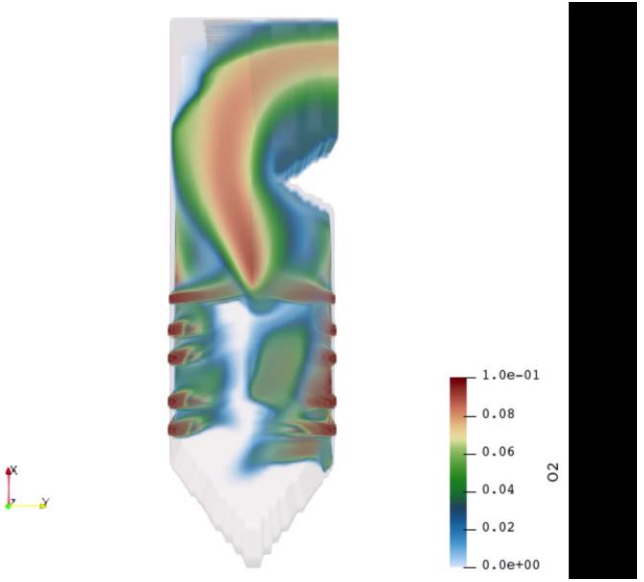

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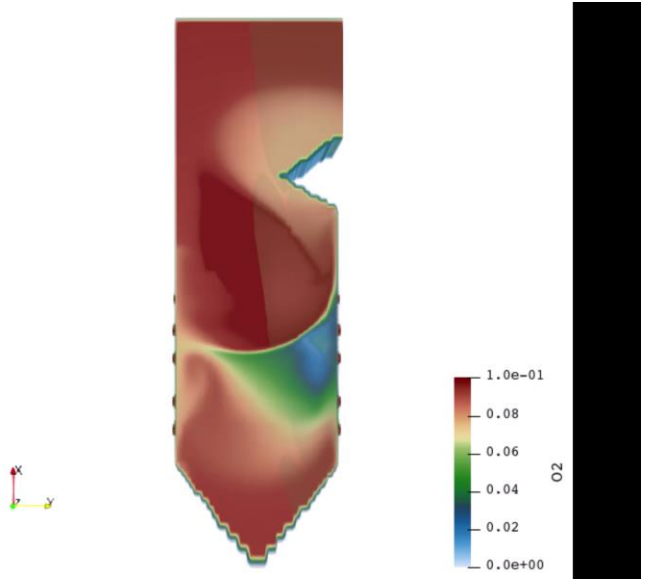

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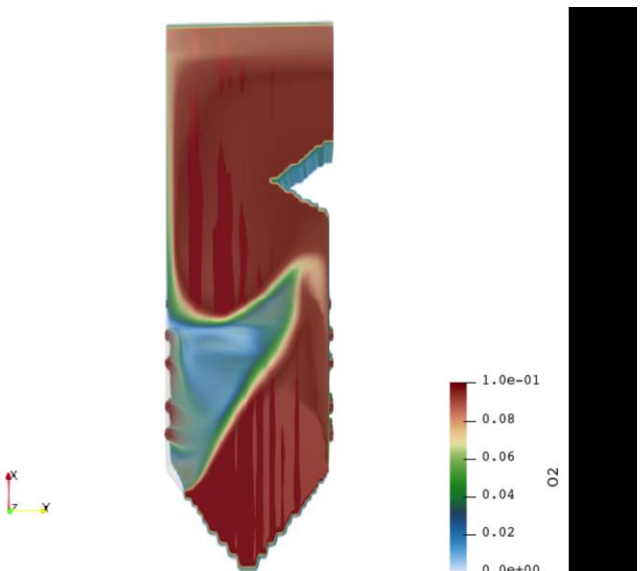
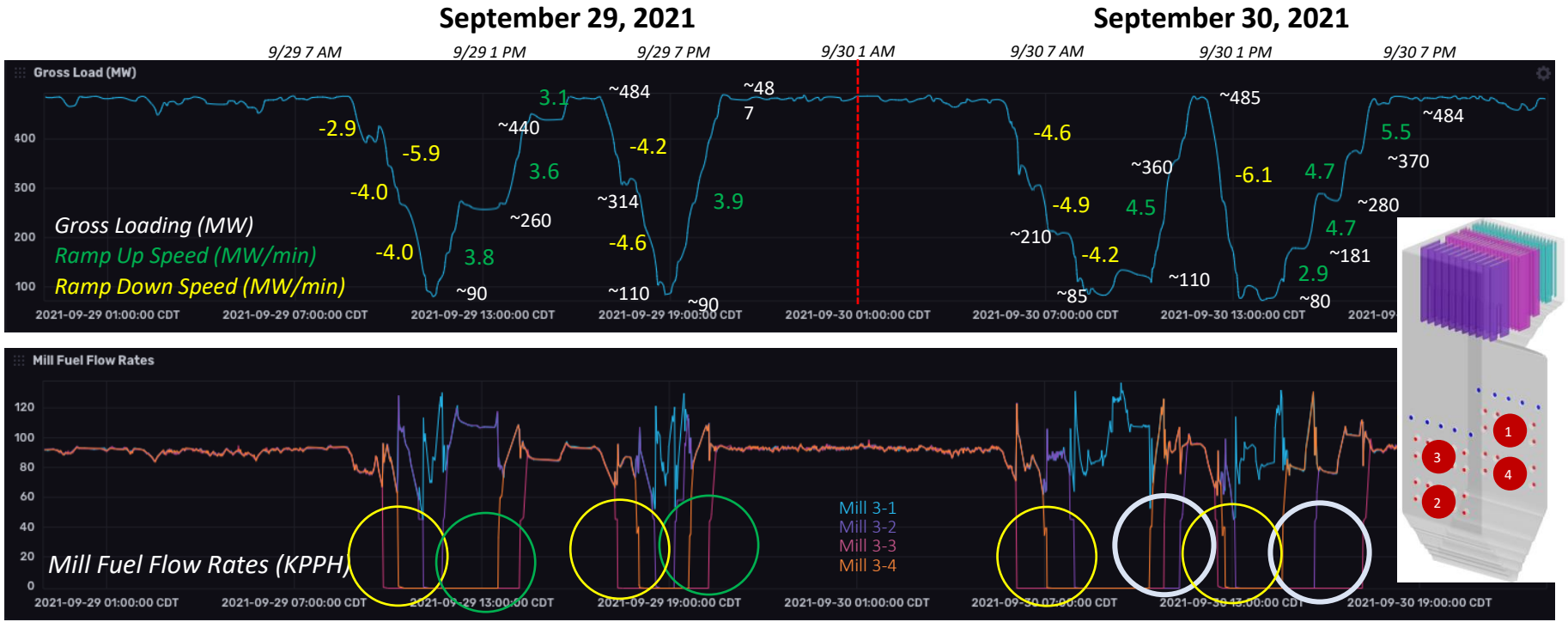


Load and Mill Fuel Flow Rates



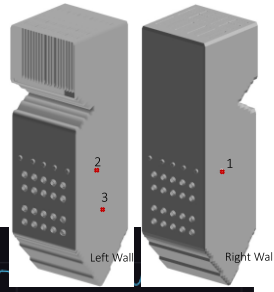
Down342 Up243 *Down342 Up432 Up423*

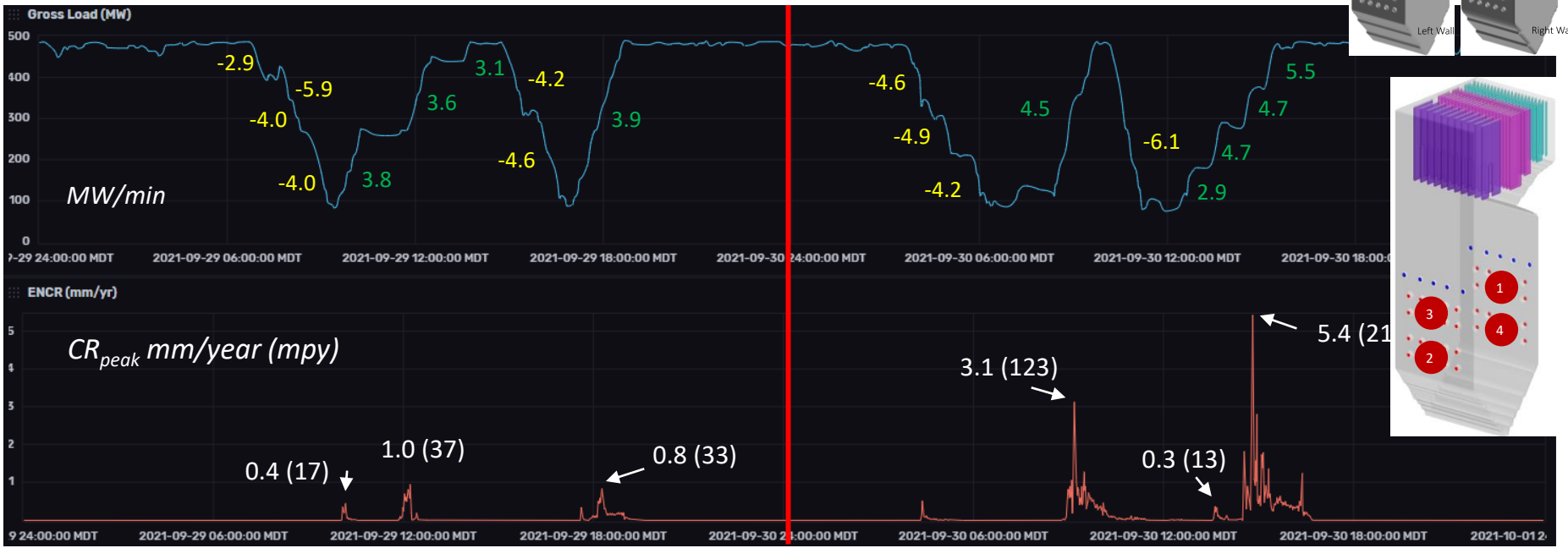
All ramp down used 3-4-2 order

Higher ramp up rates used 4-3-2/4-2-3 instead of 2-4-3 (standard operation)

Sensor #2 @ LSW

- **Ramping Up vs. Down**: More activities during ramping up
- **Ramping Up Rates**: Different behavior from Sensor #1: Higher corrosion rates with faster ramping rates
- **Short Ramp Ups:** Short ramp ups show similar corrosion at a lower ramping rate, but higher at a higher ramping rate
- **Mill Operation Order**: Up423>Up432>Up243





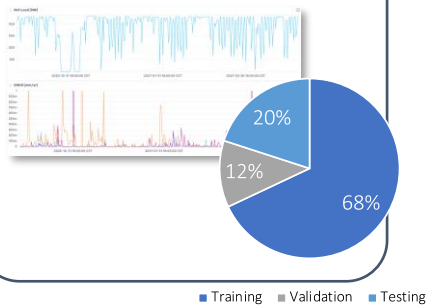
Date Change

Down342 Up243 Down342 Up243 *Down342 Up432 Down342 Up423*

AI/ML Model Development

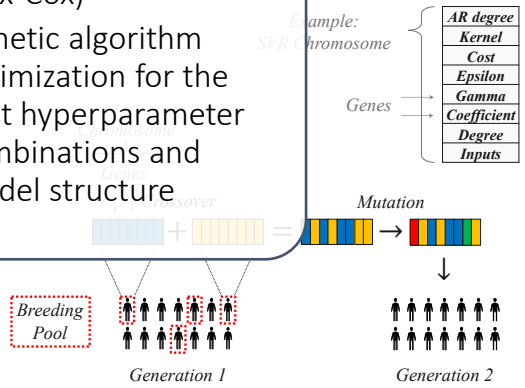
Dataset Preprocessing

- Timeseries plant and sensor data (12/2020 – 4/2021)
- Training, Validation, Testing datasets (68:12:20)



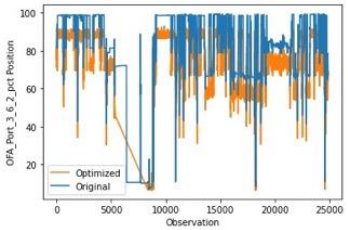
AI/ML Model Development

- Various ML modeling methods: LSTM, SVR, MLR, VARX
- Multiple scaling methods: Normalization, Standardization, IQR, Power Transformation (Box-Cox)
- Genetic algorithm optimization for the best hyperparameter combinations and model structure



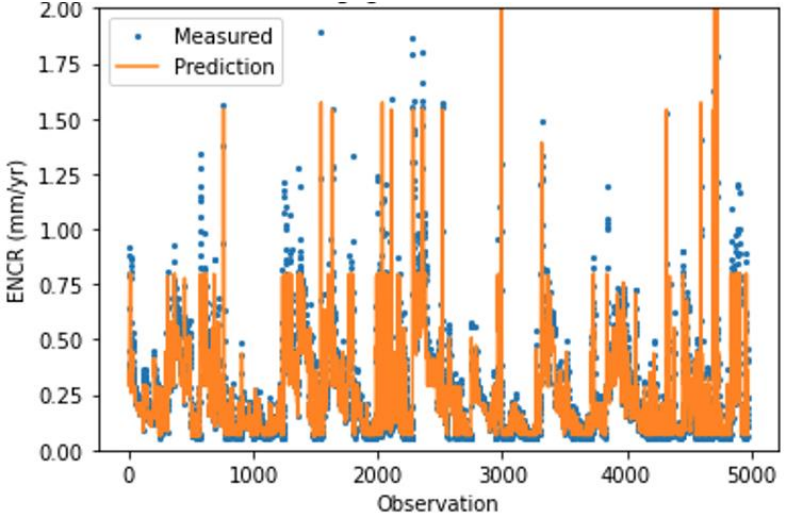
Plant Operation

- Model Predictive Control (MPC)
- Ranking/Optimization of manipulated variables



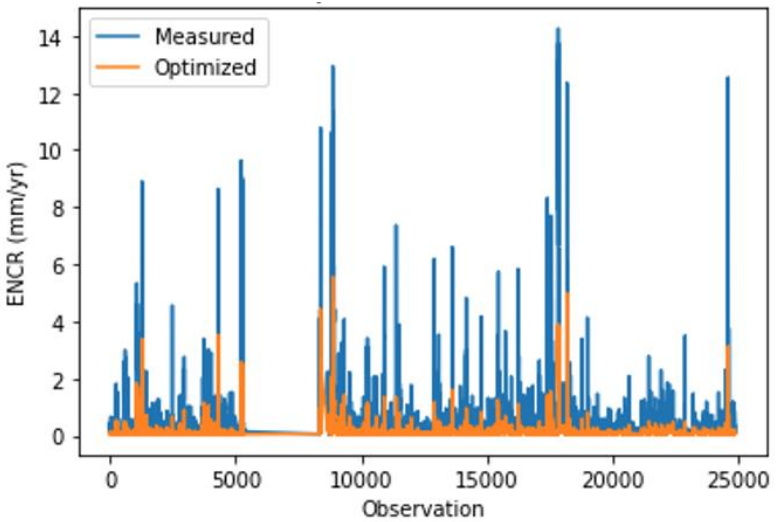
AI/ML Model and Process Optimization

AI/ML Model Prediction



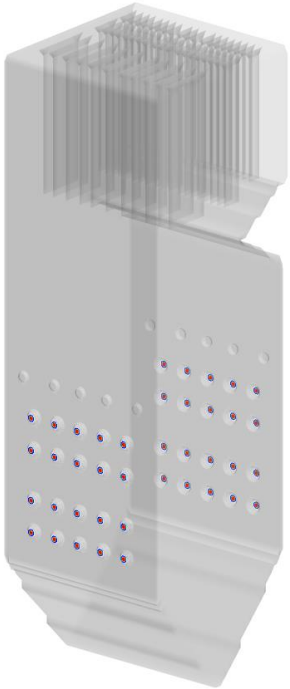
- Random Forest model using previous corrosion rates as input
- Reasonable prediction

Measured vs. Optimized Corrosion Rates



- Simulated optimization of the manipulated variables
- 68% reduction in the corrosion rates

Simulated Optimization of Manipulated Variable
Mill Primary Air Operations

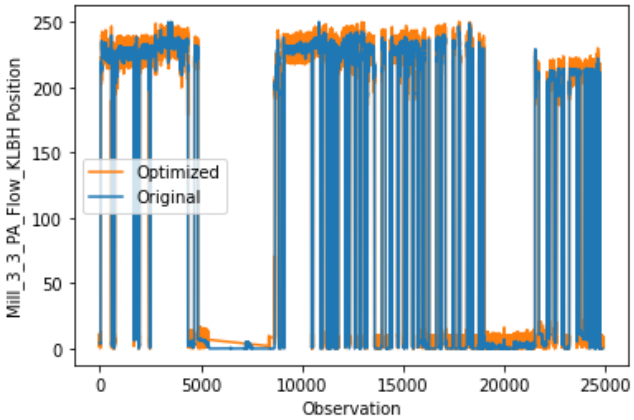


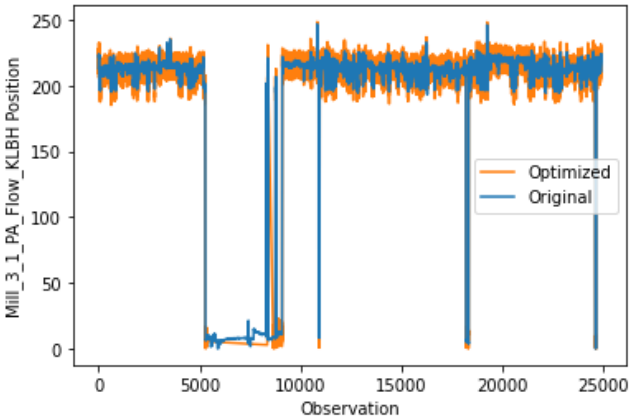
Mill 3-3

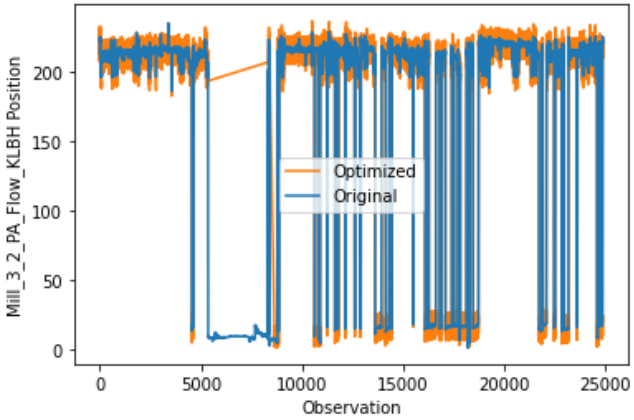
Mill 3-2

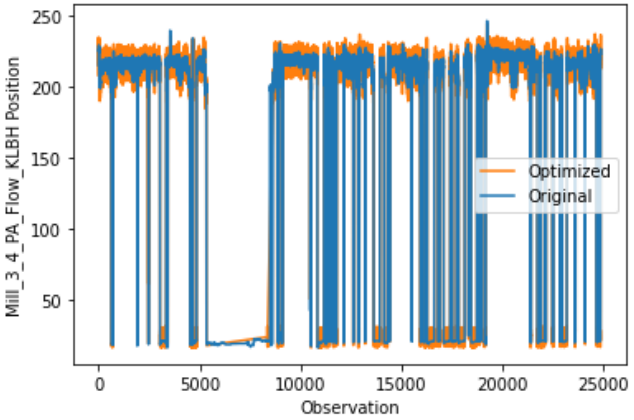
Mill 3-1

Mill 3-4



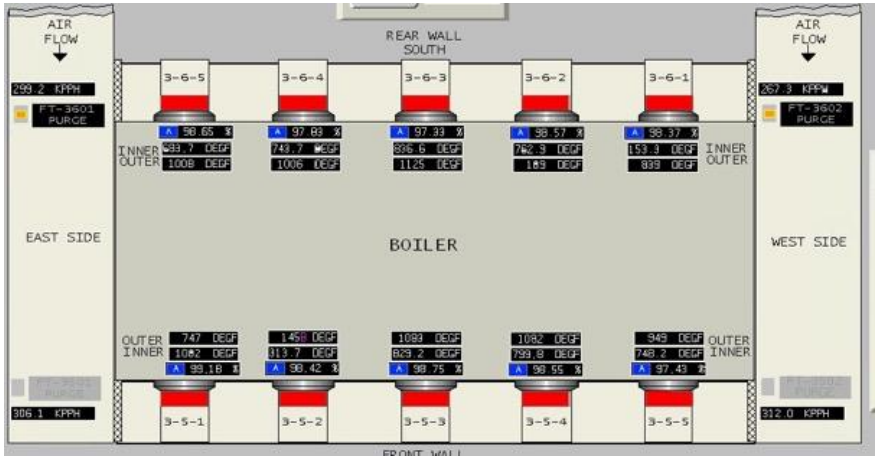


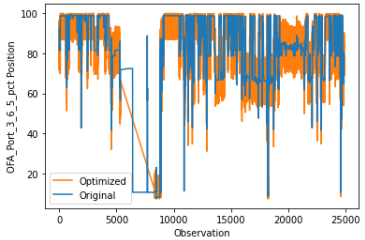




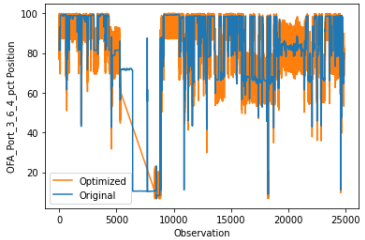
Simulated Optimization of Manipulated Variable

OFA Position

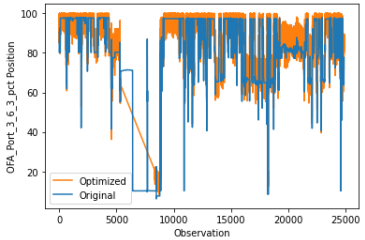




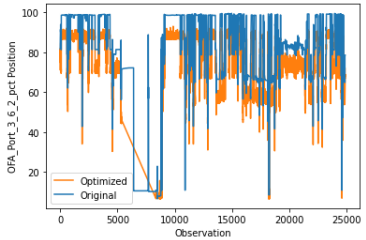
3-6-5



3-6-4



3-6-3



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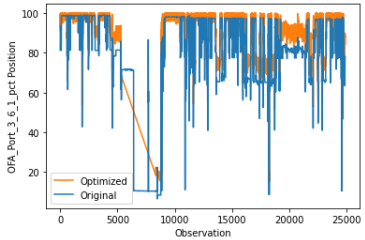
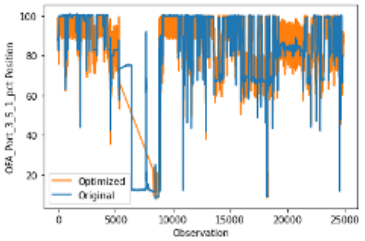
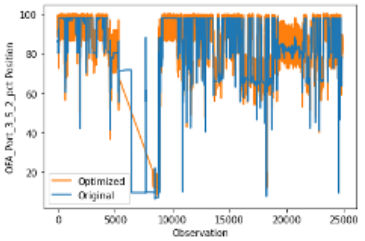


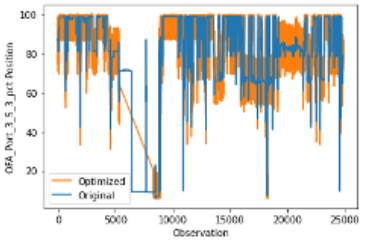
3-6-1



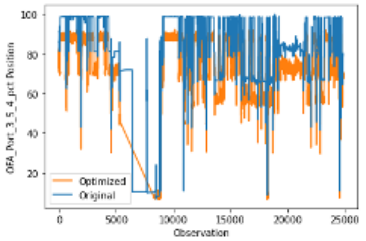
3-5-1



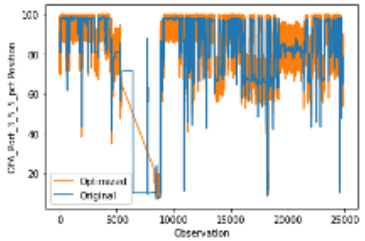
3-5-2



3-5-3



3-5-4



3-5-5

Summary

- Successful development of mMPMS:
  - Miniaturization and modification of the sensors accommodating membrane installation and passive cooling
  - New signal conditioning module with improved data communication and resolution
  - Replacement of legacy data acquisition hardware with easily maintainable and scalable electronics
  - More than 50% of size reduction with updated electronics and smaller form factor
  - Development of new big data platform for collection and analysis
- LOS #1 tests have also confirmed that the sensors are very sensitive to the surroundings including operation of soot blowers and water lances (i.e. deposit growth) and impacts of boiler ramping (i.e. corrosion)
  - Tests demonstrate that the mMPMS deposition measurements are qualitatively and quantitatively reliable
  - Tests show that corrosion rates at the 5 sensor locations are generally very low except for spikes during load ramps
- Hunter #3 demonstration shows:
  - Sensitive to the near wall environment
  - Corrosion activities increase during transition: especially when the unit is ramping up, moderate to high corrosion rates are experienced
  - Burner belt sensor is more sensitive to the mill operation than the other sensors: this may be due to its proximity to the burners
- AI/ML model for corrosion rates was developed and it showed 68% reduction in simulated optimization of the manipulated variables: OFA operation corresponds well with the probe 3 corrosion rates
- Achieved 5000+ hrs continuous operation

Acknowledgements

- This material is based upon work supported by the Department of Energy Award Number DE-FE0031682 and DE-FE0031680
- DOE/NETL Project Managers: Mr. Richard Dunst and Mr. Omer Bakshi
- PacifiCorp Hunter Power Plant and Basin Electric Leland Olds Station for hosting demonstration and providing support