DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

1.2.2.7801 Real time, Integrated Dynamic Control Optimization to Improve the Operation Reliability of a Biomass Dryer

04/05/2023

Feedstock Conversion Interface Consortium

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Project Overview

- **Objective:** Develop a real-time control-optimization solution that ensures a reliable and continuous feeding and conveying of biomass through a continuous dryer, while controlling the temperature to achieve the target moisture content of wood fiber.
- **Why:** Variations in feedstock characteristics (e.g., particle size distribution, moisture, ash, and heat content) negatively affect the integration of biomass feeding systems and result in low or unreliable on-stream time and long start-up times.
- **Project Goals:**
  - Integrate on-line instrumentation with adaptive control methods to produce a real-time optimal control model
  - Achieve 90% on-stream time and with 90% of the material meeting specified output moisture content of 12%-16% (wet basis)
- **Relevance to Industry:** This project addresses feedstock handling and preprocessing issues that have plagued the industry. If this project is successful, costs will decrease and system reliability will increase

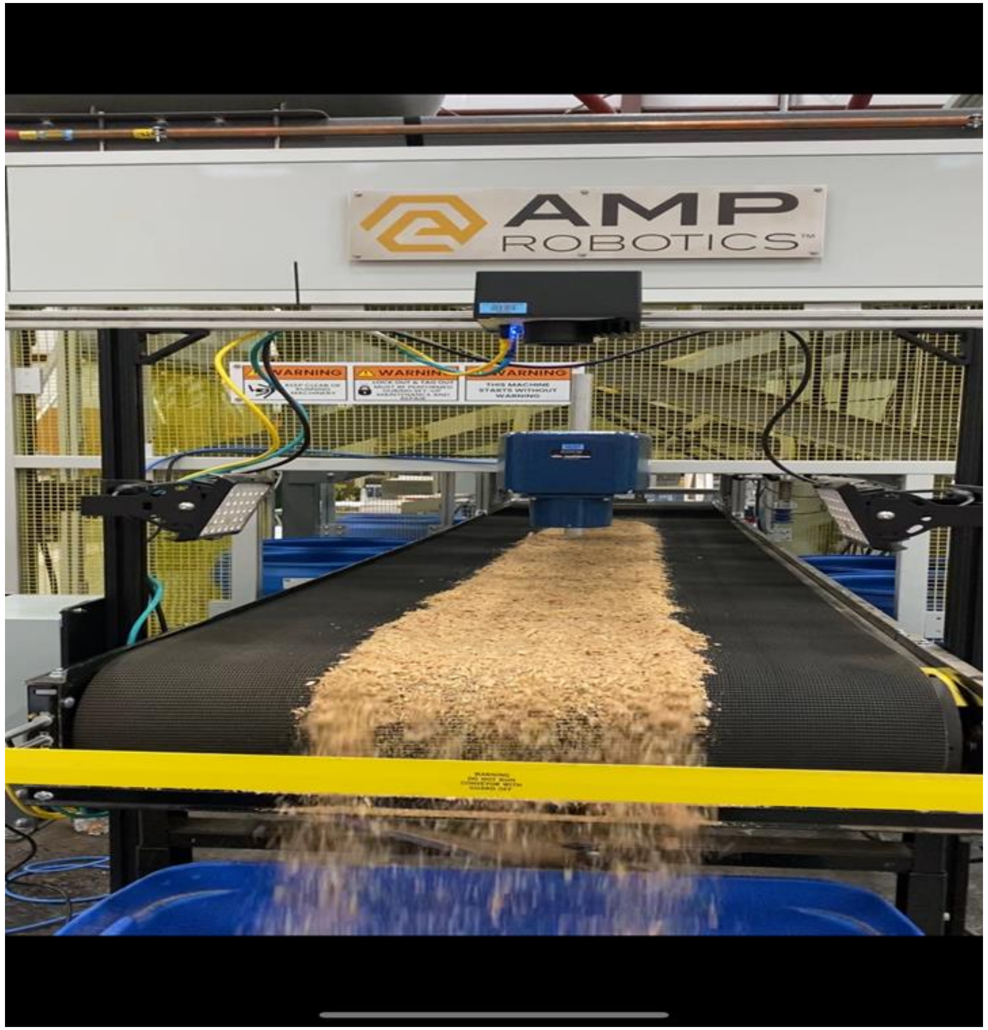
1 – Approach

Technical Approach

- Collect data for baseline run and identify root causes of feed system failure
- Collaborate with researchers and leverage existing knowledge to design in-line sensor arrays that can characterize feedstock moisture content, particle size and particle shape.
- Collect performance data for various conditions and system settings to serve as the base data set for model development
- Design and Implement optimal control algorithm

Technical Challenges

- Collecting data at relevant temporal scales
- Computational requirements of running models
- Safety and safe operations



1 – Approach

Go/No-Go Decision Point

- The Go/No-Go decision point was based on the ability of the proposed system to be able to acquire and process data quickly enough to improve on base line performance
- The Go decision point was met in Q2 of FY22
  - Showed a reduction in system latency from 5 min to 5 sec

Risks and Mitigation

- Safety of operating
  - Idaho Forest Group undertook additional safety requirements to become operational
  - No-cost extension to extend project

Performance Metrics

- Time on stream
- % of material in moisture content window

1 – Approach

Team

- Robert Kinoshita (INL) – Sensors/Data Interface
- Shaw Wen (INL) – Data Scientist
- Jason Mangano (IFG) – Project Coordinator
- Brian Riga (IFG) – Vice President of Technology

Communication/Collaboration

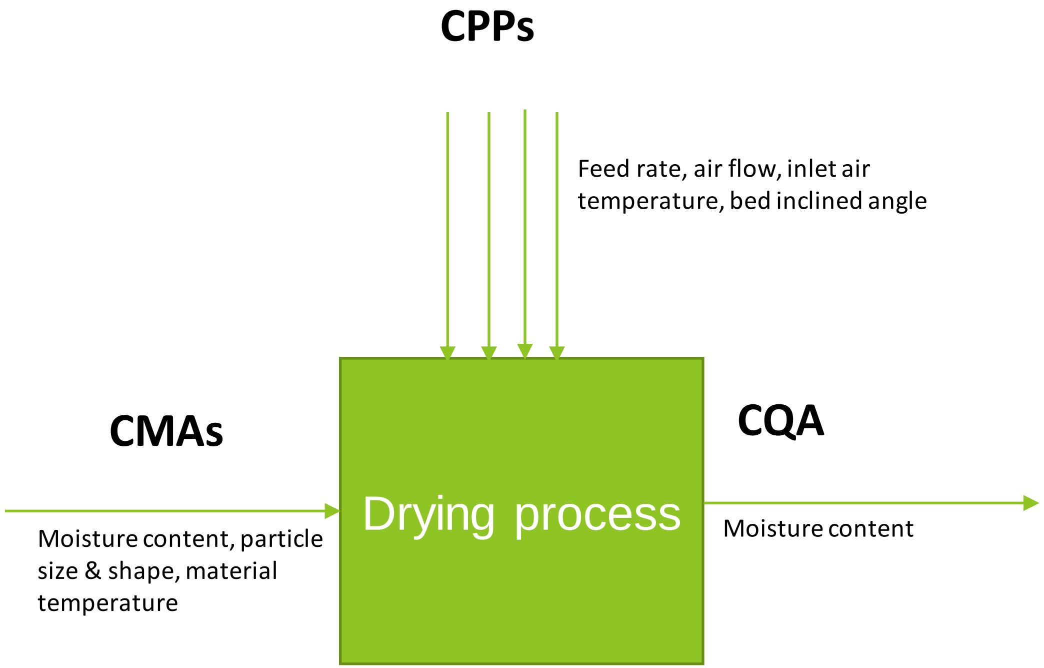
- Bi-weekly Team meetings to discuss progress
- Quarterly Check-ins with BETO
- Four Quarterly Milestones per Year

MoistTech: Non-contact moisture sensors appropriate for use in a continuous process

Diversity, Equity and Inclusion: While diversity, equity and inclusion is not a formal goal of this project, success in this project with help rural businesses and increase the wealth in rural communities

2 – Progress and Outcomes
Proposed Process

- **Drying technology**:
  - Vibrating fluidized bed (1 ft wide x 7.5 ft long)
- **Capacity**:
  - Depending on moisture removal: 400 – 500 lb/hr (dry basis)
- **Current status**:
  - Designing the feed bin and feed conveyor to accommodate the particle image sensor
- **Critical Quality Attribute (CQA)**:
  - Moisture content (10%)
- **Critical Material Attribute (CMA):**
  - Moisture content (~20%), particle size & shape, material temperature
- **Critical Process Parameter (CPP):**
  - Biomass feed rate, air flow, inlet air temperature, bed inclined angle

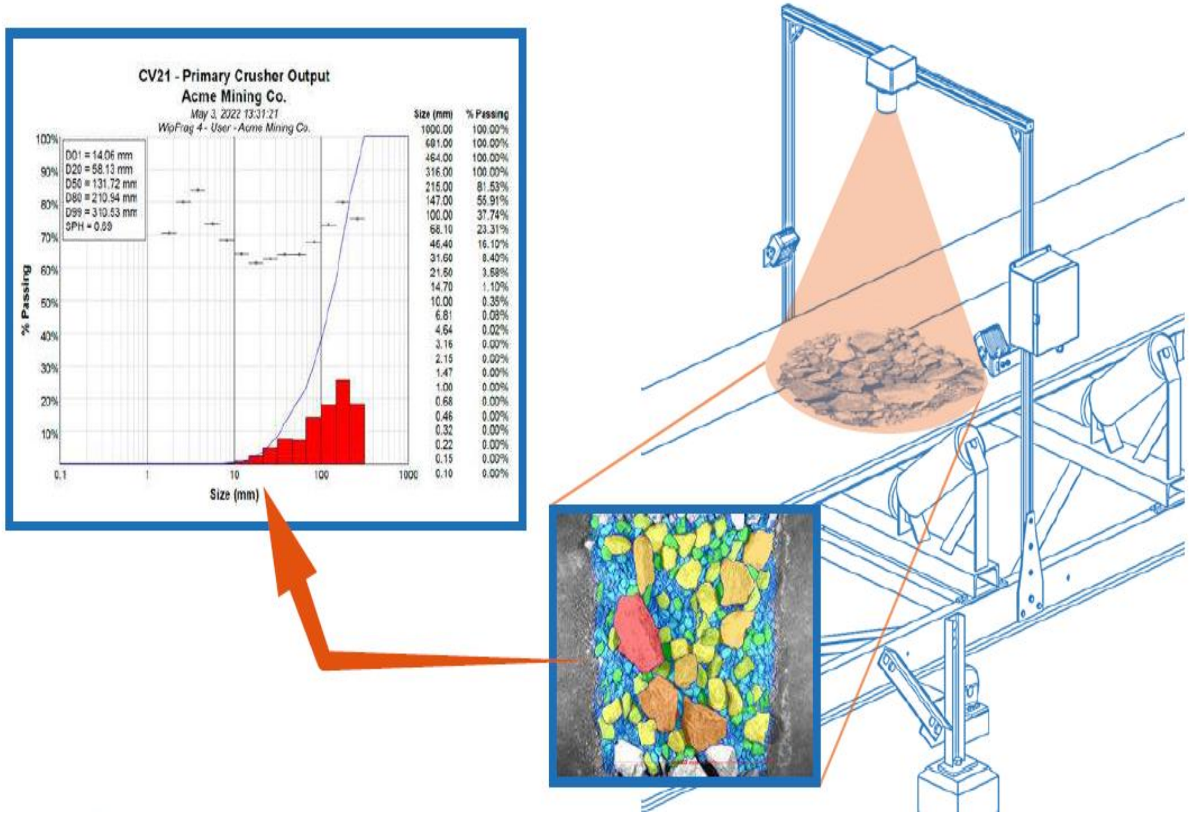


2 – Progress and Outcomes
Examining in-line sensor performance – Moisture Sensors

- Sensor Type: Near Infrared

2 – Progress and Outcomes
Examining in-line sensor performance – Particle Size

- Sensor Type: Image Processing



2 – Progress and Outcomes
Examining in-line sensor performance – Experimental Design

Exp	Belt speed	Material Depth	Camera Settings
1	-1	-1	0
2	-1	1	0
3	1	-1	0
4	1	1	0
5	-1	0	-1
6	-1	0	1
7	1	0	-1
8	1	0	1
9	0	-1	-1
10	0	-1	1
11	0	1	-1
12	0	1	1
13	0	0	0

Belt speed
- -1=5 Hz (9 fit/min)
- 0=15 Hz (26.8 ft/min)
- 1=25 Hz (43.6 ft/min)

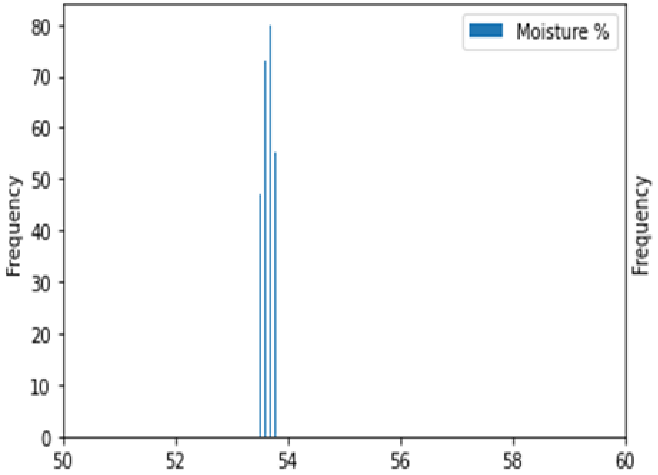
Depth of material
- -1=0.25 inch
- 0=0.5 inch
- 1=0.75 inch

Camera Settings

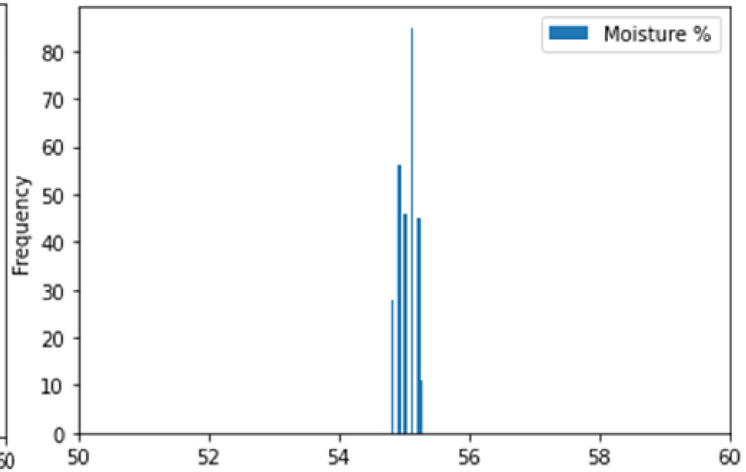
	Threshold	Valley Threshold	Blur	Search Dark	Search Radius	Window Size
-1	-50	-1.0	2.0	15	15	20
0	-30	-2.0	1.0	15	15	20
1	-10	-3.0	0.5	15	15	20

2 – Progress and Outcomes
Examining in-line sensor performance – Precision (Moisture)

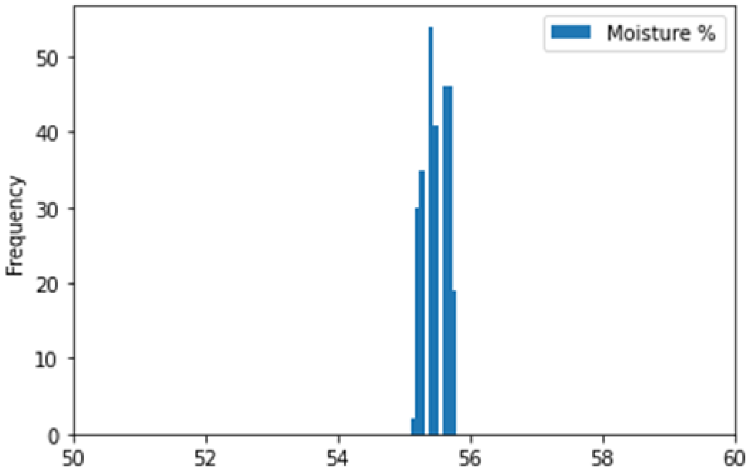
Depth=0.25 inch



Depth=0.5 inch

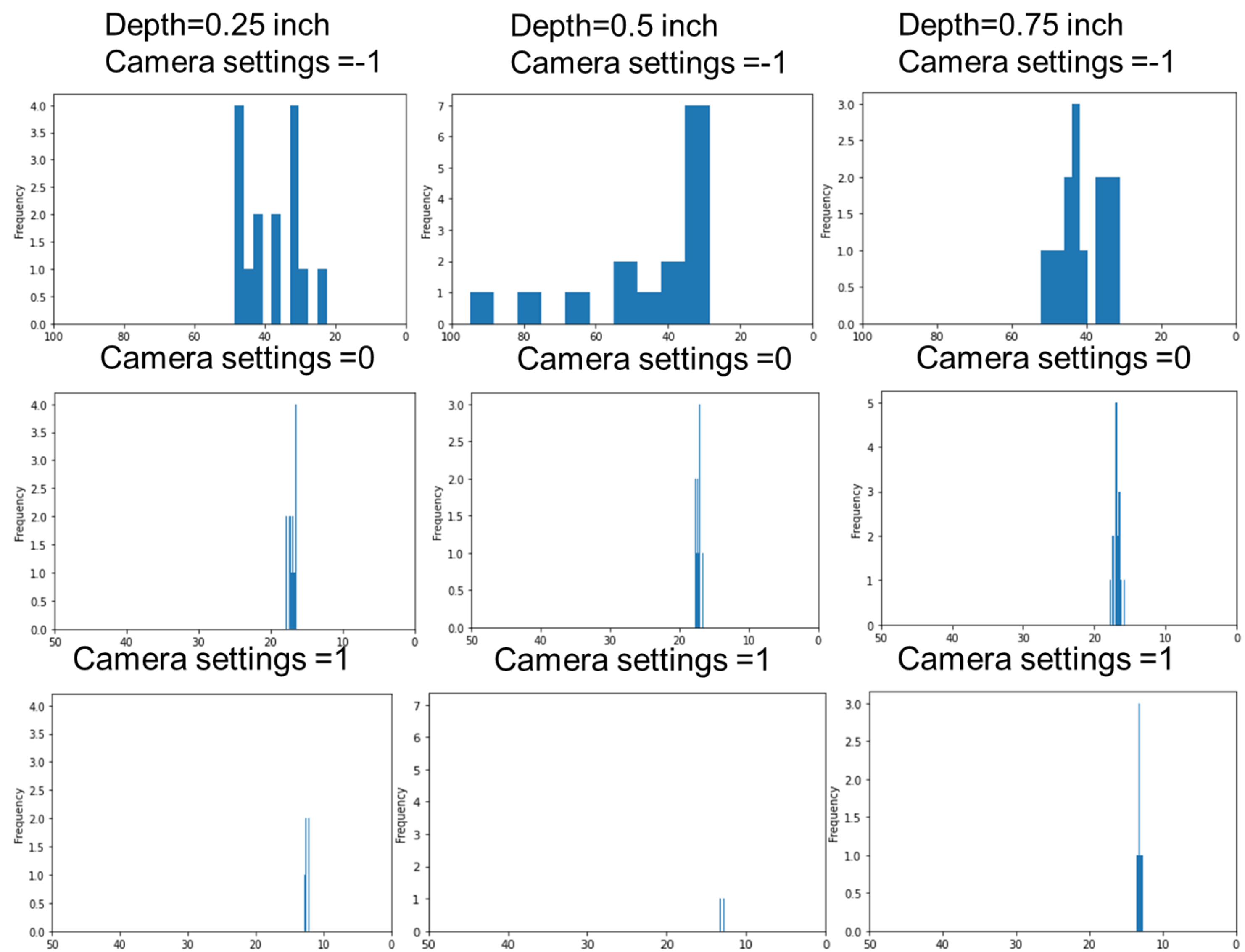


Depth=0.75 inch



Depth	0.25 inch	0.5 inch	0.75 inch
Count	255	271	273
Mean (%)	**53.66**	**55.04**	**55.49**
Std.	**0.10**	**0.14**	**0.18**
CV	**0.33%**	**0.25%**	**0.33%**
Min. (%)	53.5	54.8	55.1
Max (%)	53.8	55.3	55.8

2 – Progress and Outcomes
Examining in-line sensor performance – Precision (PSD)



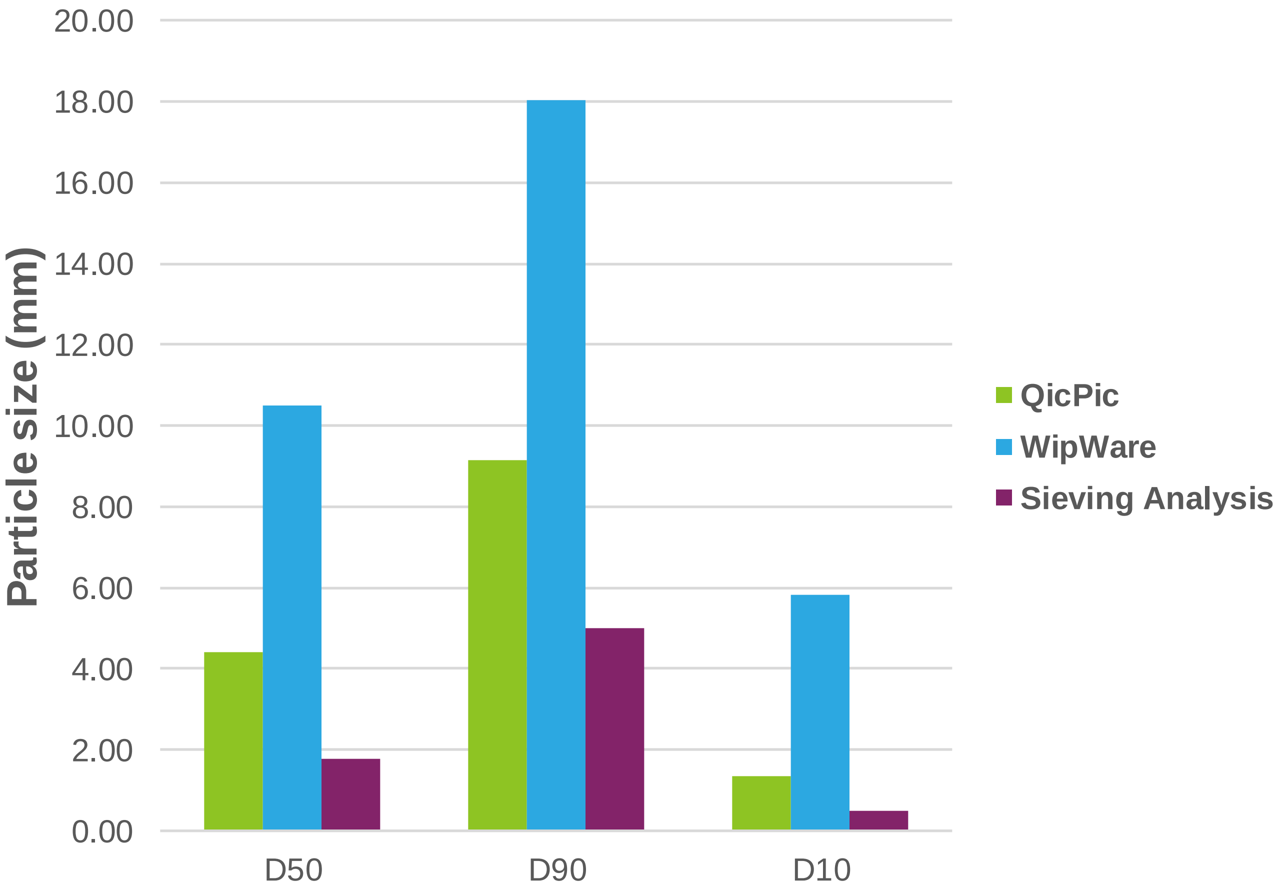
Depth	0.25 in	0.5 in	0.75 in
Count	15	15	15
Mean (mm)	37.93	45.13	40.78
Std.	8.27	19.42	6.28
CV	21.80%	43.03%	15.40%

Depth	0.25 in	0.5 in	0.75 in
Count	15	15	15
Mean (mm)	16.99	17.2	16.78
Std.	0.48	0.3	0.53
CV	2.83%	1.74%	3.16%

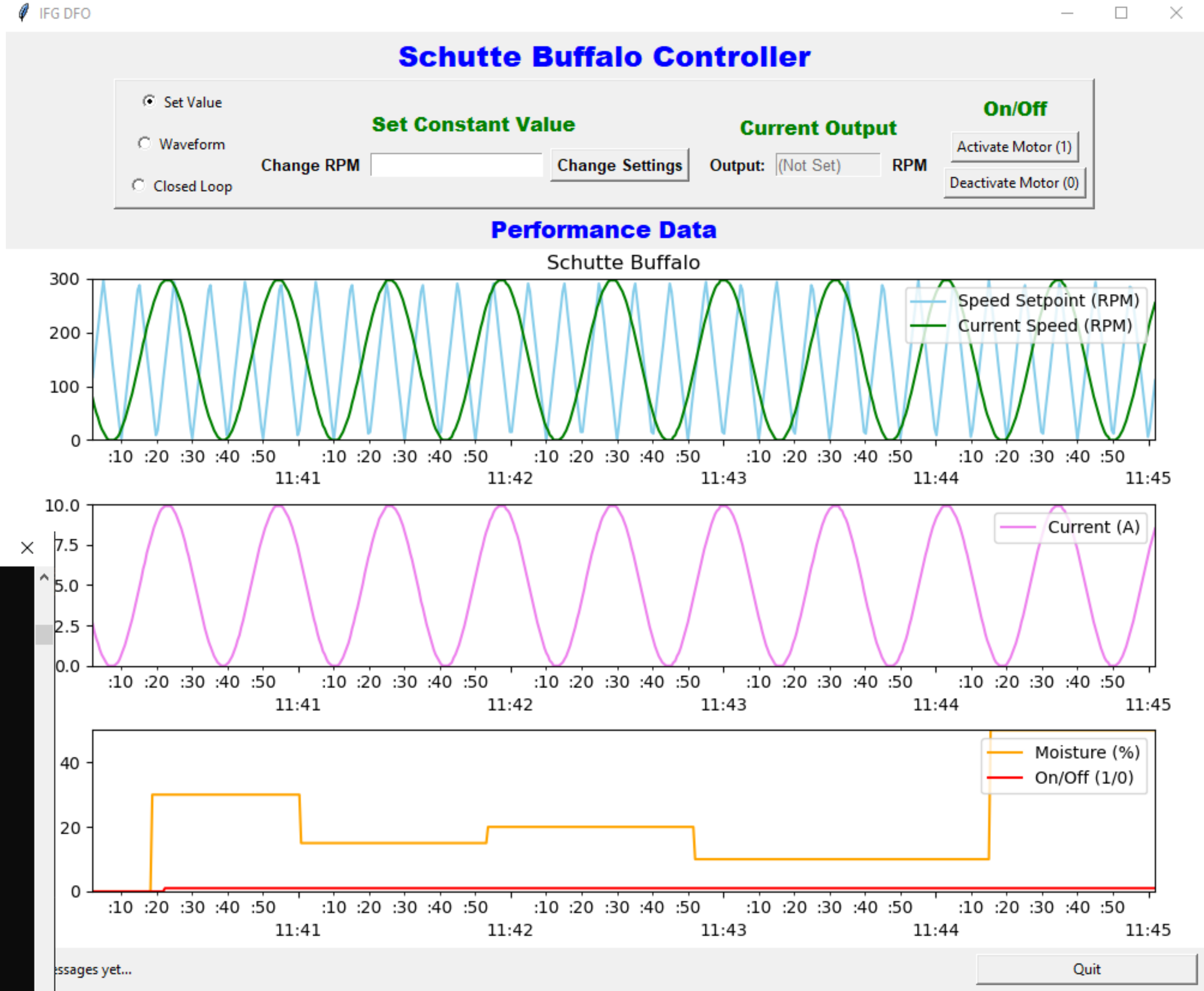
Depth	0.25 in	0.5 in	0.75 in
Count	15	15	15
Mean (mm)	12.52	12.98	13.16
Std.	0.23	0.12	0.27
CV	1.84%	0.92%	2.05%

2 – Progress and Outcomes
Examining in-line sensor performance – Accuracy (PSD)

- Compared Sensor with two laboratory methods
- Sensor Overestimated Particle Size, but relative level of error appears to be consistent
- For use in the system, the true size of the particles is not necessary, but it is more important that a relative change in size can be detected.
- Optimizing camera settings and improvement in software may lead to higher accuracy



2 – Progress and Outcomes
Integrating Sensors and Reading Sensor Data



Anaconda Prompt (An

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2022-04-15 09:22:39,491 MainThread      INFO     TestIR3000     :65        Block Text IR3000 Constituent 2 Name is: Constituent2
2022-04-15 09:22:39,537 MainThread      INFO     TestIR3000     :65        Block Text IR3000 Constituent 3 Name is: Constituent3
2022-04-15 09:22:39,600 MainThread      WARNING  TestIR3000     :57        Returned data length mismatch (16 requested, 1 returned)
2022-04-15 09:22:39,600 MainThread      INFO     TestIR3000     :65        Block Text IR3000 Temperature Name is:

(ifg_dfo_twisted) C:\Users\BOBK\Documents\Repos\IFG_DFO\Test Code\Moisttech IR3000>python TestIR3000.py
2022-04-15 09:23:19,627 MainThread      INFO     TestIR3000     :32        IR3000 Setup Bytes is: 0
2022-04-15 09:23:19,674 MainThread      INFO     TestIR3000     :32        IR3000 Reading 1 is: 81
2022-04-15 09:23:19,721 MainThread      INFO     TestIR3000     :32        IR3000 Reading 2 is: 0
2022-04-15 09:23:19,783 MainThread      INFO     TestIR3000     :32        IR3000 Reading 3 is: 0
2022-04-15 09:23:19,830 MainThread      INFO     TestIR3000     :32        IR3000 Pyrometer Reading is: 0
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2022-04-15 09:23:20,033 MainThread      INFO     TestIR3000     :32        IR3000 Span 1 is: 1874
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2022-04-15 09:23:20,174 MainThread      INFO     TestIR3000     :32        IR3000 Wheel Frequency x 100 is: 3004
2022-04-15 09:23:20,221 MainThread      INFO     TestIR3000     :32        IR3000 Status Bits is: 97
2022-04-15 09:23:20,283 MainThread      INFO     TestIR3000     :32        IR3000 +5 Volt Rail is: 527
2022-04-15 09:23:20,330 MainThread      INFO     TestIR3000     :32        IR3000 -12 Volt Rail is: 604
2022-04-15 09:23:20,377 MainThread      INFO     TestIR3000     :32        IR3000 12 Volt Rail is: 609
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2022-04-15 09:23:20,471 MainThread      INFO     TestIR3000     :65        Block Text IR3000 Constituent 1 Name is: Moisture
2022-04-15 09:23:20,533 MainThread      INFO     TestIR3000     :65        Block Text IR3000 Constituent 2 Name is: Constituent2
2022-04-15 09:23:20,580 MainThread      INFO     TestIR3000     :65        Block Text IR3000 Constituent 3 Name is: Constituent3
2022-04-15 09:23:20,627 MainThread      WARNING  TestIR3000     :57        Returned data length mismatch (16 requested, 1 returned)
2022-04-15 09:23:20,627 MainThread      INFO     TestIR3000     :65        Block Text IR3000 Temperature Name is:

(ifg_dfo_twisted) C:\Users\BOBK\Documents\Repos\IFG_DFO\Test Code\Moisttech IR3000>
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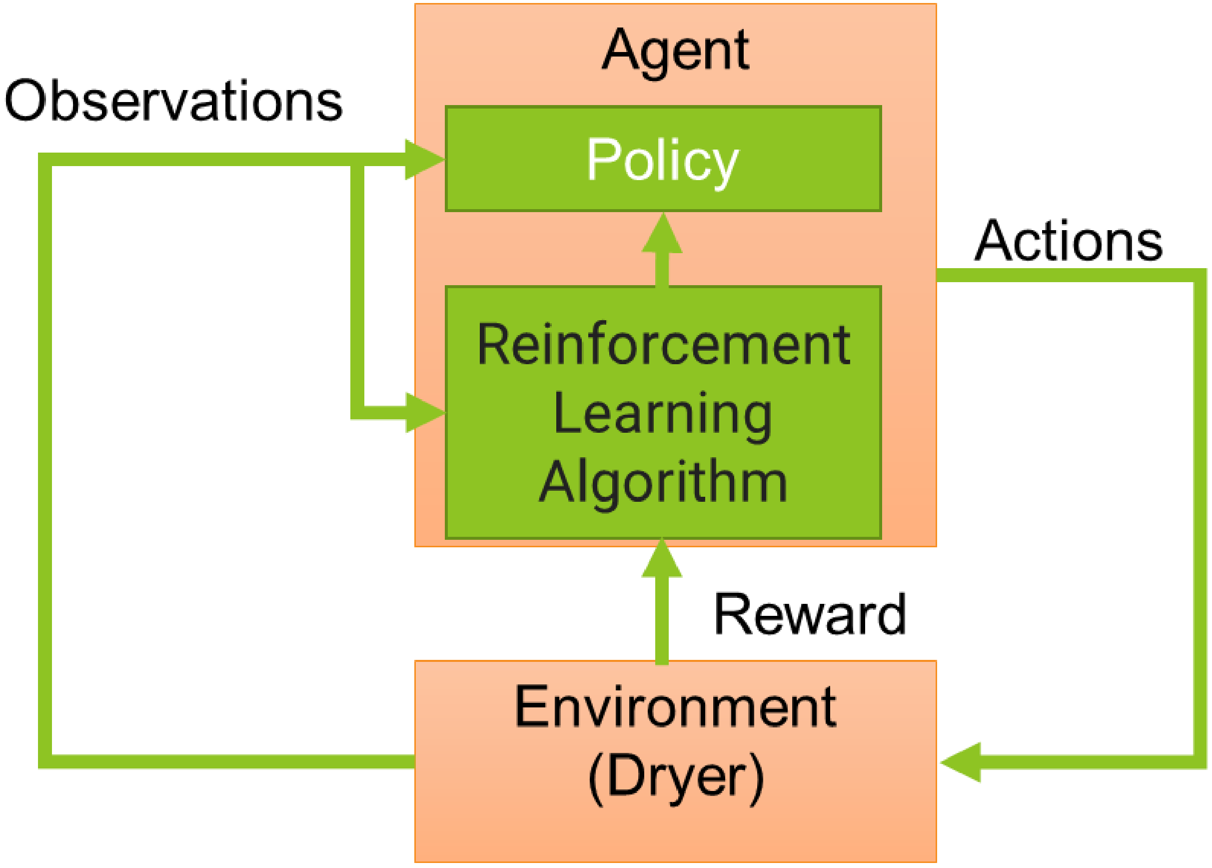
2 – Progress and Outcomes
Reinforcement Learning



Observations

- Input moisture
- Output moisture
- Feed rate
- Firing rate
- Particle Size

Actions

- Increase firing rate
- Slow down firing rate
- Increase feed rate
- Decrease feed rate

Reward

- Difference between target moisture and actual moisture

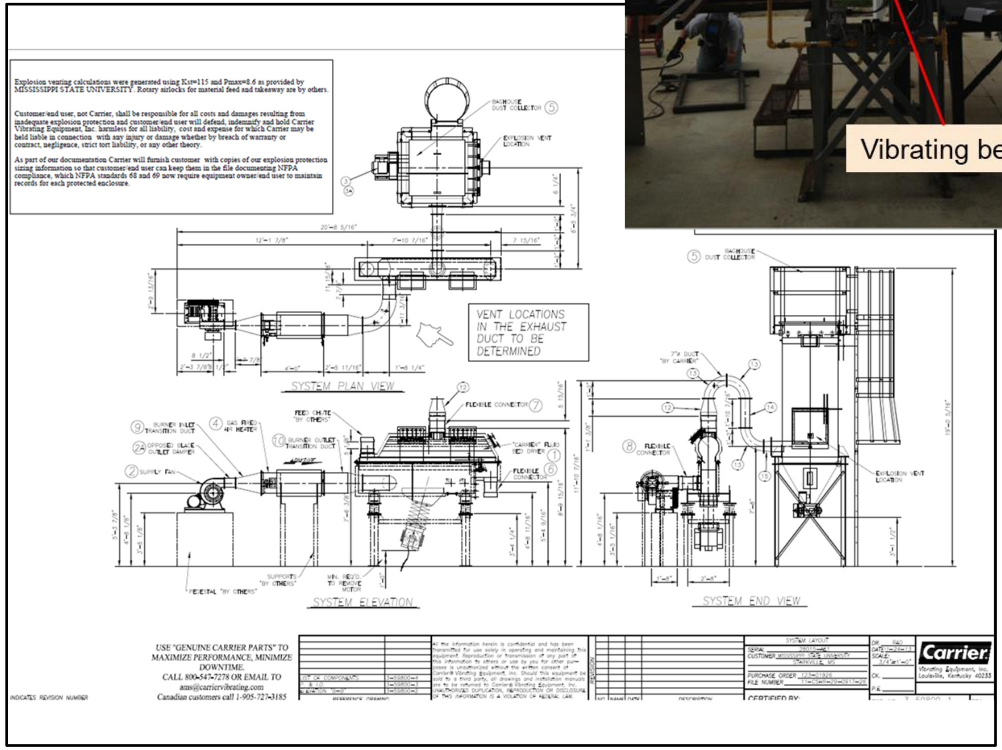
3 – Impact

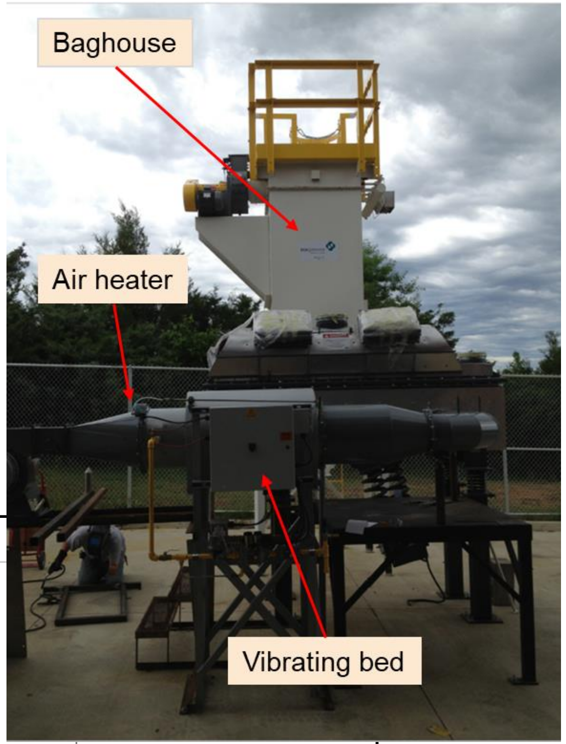
Industry Impacts

- Direct transfer of FCIC Funded research to Industry.
- Provide solutions to material handling issues and reduce system downtime
- Enable processes that reduce the barriers for the production of biofuels

Dissemination of Results

- Control algorithms and interface software will be made available to industry using INL's tech transfer protocols





Summary

- **Challenge:** Variations in feedstock characteristics (e.g., particle size distribution, moisture, ash, and heat content) negatively affect the integration of biomass feeding systems and conversion processes and result in low or unreliable on-stream time and long start-up times
- **Goal:** Develop a dynamic, control system that produces 90% uptime and >90% of the material within 12% - 16% MC (wet basis) window.
- **Requirements:**
  - Use sensors to determine MC and Particle Size Distribution
  - Develop control algorithm that utilizes sensor output to control operation
  - Demonstrate control system on industrial scale equipment
- **Next Steps:**
  - Complete collection of process performance data
    - Parametric study of saw dust drying
  - Characterize amount and sources of variability of critical material attributes entering the dryer
  - Complete controller software
    - Train model based on operational data
    - Validate control of drying system

Quad Chart Overview

Timeline

- *Project Start: 10/1/2021*
- *Project end date: 9/30/2023*

	FY22 Costed	Total Award
DOE Funding	*$391,260*	*$528,000*
Project Cost Share *		

TRL at Project Start: 3
TRL at Project End: 5

Project Goal

Develop a new, real-time, integrated, dynamic, control-optimization solution that ensures a reliable, cost-effective, robust, and continuous feeding and conveying of biomass through a continuous dryer, with heated-air temperature and flow control to achieve the target moisture content of wood fiber.

End of Project Milestone

Demonstrate improved operational reliability to 90% and achieving moisture content of wood fiber in the 12-16% range by integrating FCIC and other collaborator capabilities (e.g., sensors, in-line instrumentation, intelligent adaptive control, predictive model for mechanical behavior of biomass

Funding Mechanism

FCIC Direct Funding Opportunity

Project Partners*

- Idaho Forest Group

*Only fill out if applicable.

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

Additional Slides

Responses to Previous Reviewers' Comments

- This project has not been reviewed previously

Publications, Patents, Presentations, Awards, and Commercialization

Due to the business sensitive nature of the project, no publications or presentations have been made