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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

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Novel Energy-Efficient Drying Technologies for Food, Pulp and Paper, and other Energy Intensive Manufacturing Industries | IEDO

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DE-EE0009125 | June 15, 2020 – June 14, 2023 (NCE May 15, 2024)

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Project Overview

Reduce manufacturing drying energy consumption by 25-35%, cut material waste, and improve product quality:

- Develop 3 novel drying technologies for food and pulp & paper, applicable to other energy intensive industries
- Advance sensor technology for more robust operating conditions (in-situ temperature, moisture content, and strain measurements)
- Develop artificial intelligence (AI) for real time process optimization for increasing energy efficiency and improving product quality

Project Outline

Innovation: Three novel technologies pursued to deliver up to 25% energy efficiency increase and integrate advanced sensors and AI for optimal process optimization and up to 10% additional energy efficiency

Project Lead: Jamal Yagoobi (WPI)

Project Partners: University of Illinois at Urbana-Champaign, Oak Ridge National Lab

Timeline: June 15, 2020 to June 14, 2023 (NCE requested, May 15, 2024), progress 75%

Budget:

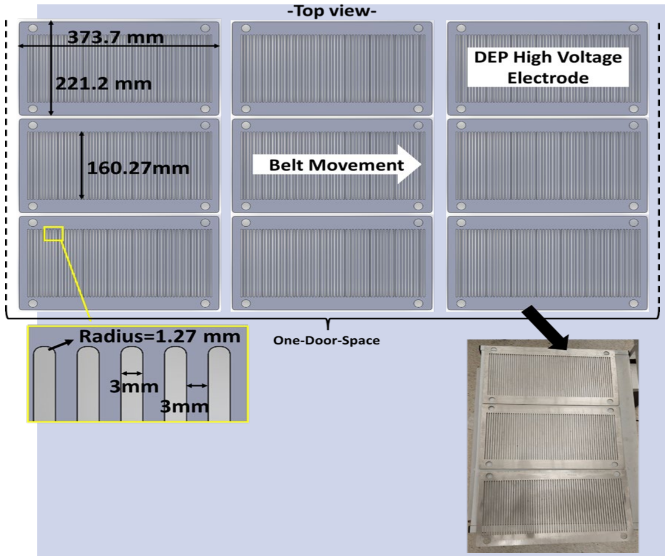
	FY21 Costs 10/1/19 to 9/30/20	FY22 Costs 10/1/20 to 9/30/21	FY23 Costs 10/1/21 to 9/30/22	FY24 Costs 10/1/22 to 9/30/23	FY25 Costs 10/1/23 to 9/30/24 NCE requested till 5/15/25	Total Planned Funding
DOE Funded	117,232	737,883	767,224	812,605	784,916	3,219,860
Project Cost Share	0	318,537	281,497	251,574	207,560	1,059,168

End Project Goal: Develop pilot scale testbeds, test and evaluate pilot lines in partnership with industry

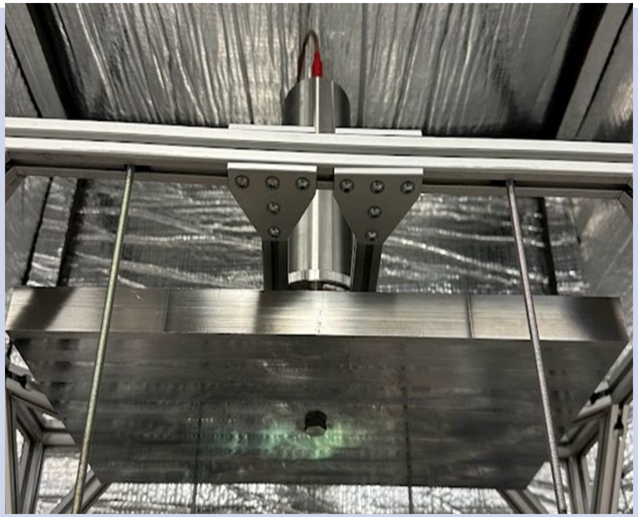
Background & Strategic Approach – Novel Techs.

- Three technologies pursued to deliver up to 25% energy efficiency increase:
  - Slot Jet Reattachment Nozzles (SJR)
  - Di-electrophoresis (DEP)
  - Ultrasonic (US)
- Scale high performing drying technologies
- Integrate advanced sensors and AI for optimal process control and up to 10% additional energy efficiency

Novel Technologies



DEP electrode for testbed



Airborne US

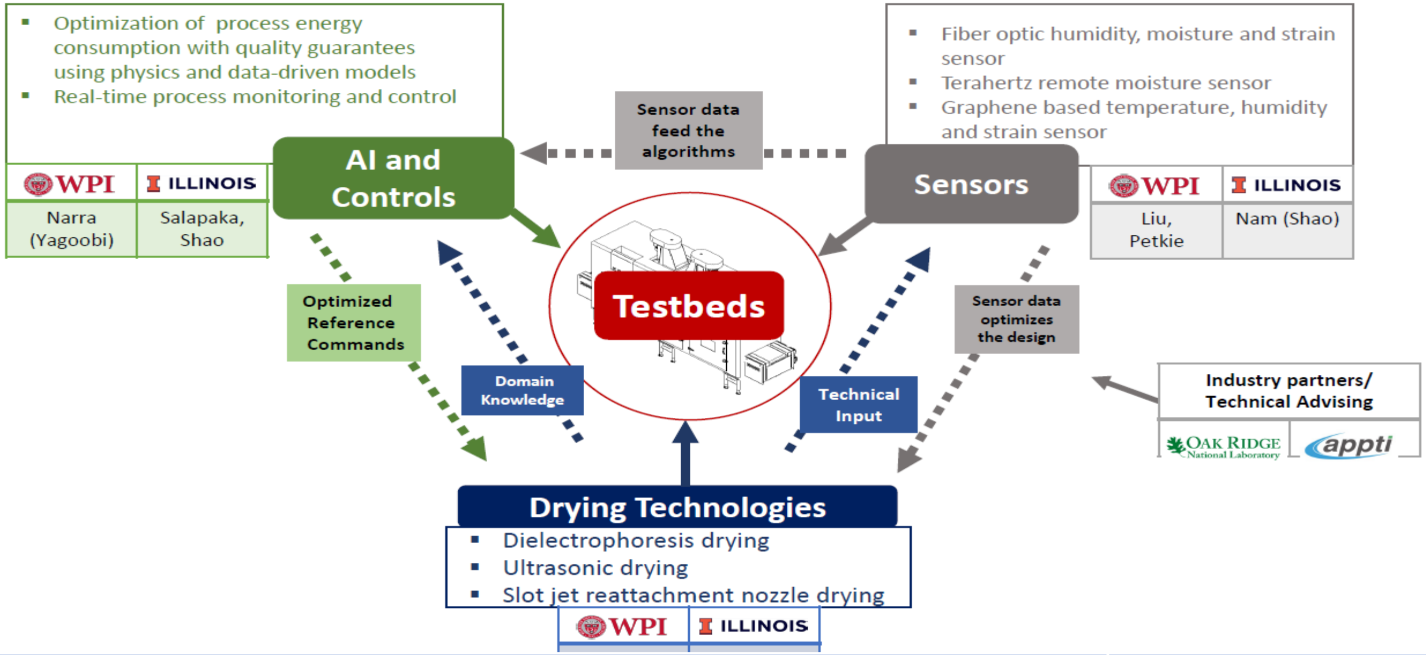
SJRs & IR emitters in testbed at WPI

Risk and Mitigation

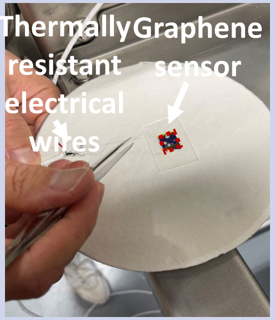
- Failure in transfer of technologies being developed in this project
- Use the pilot scale novel testbeds developed in this project in close partnership with industry partners

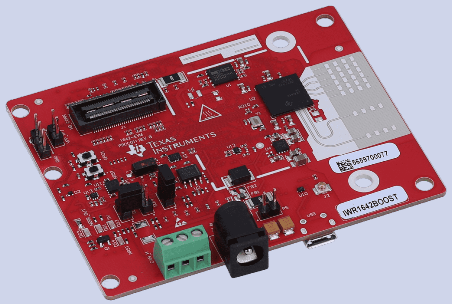
Background & Strategic Approach – Team & Tasks

Team participation an



Novel Sensors



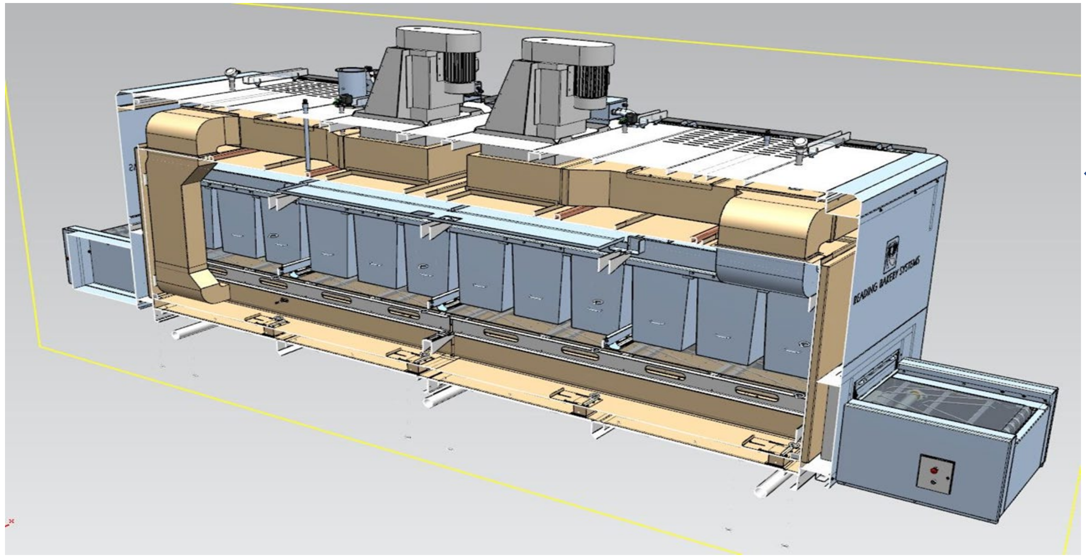


in-situ MC & strain measurements in-situ MC measurement mm-wave/THz non-contact vol MC

Target Metric

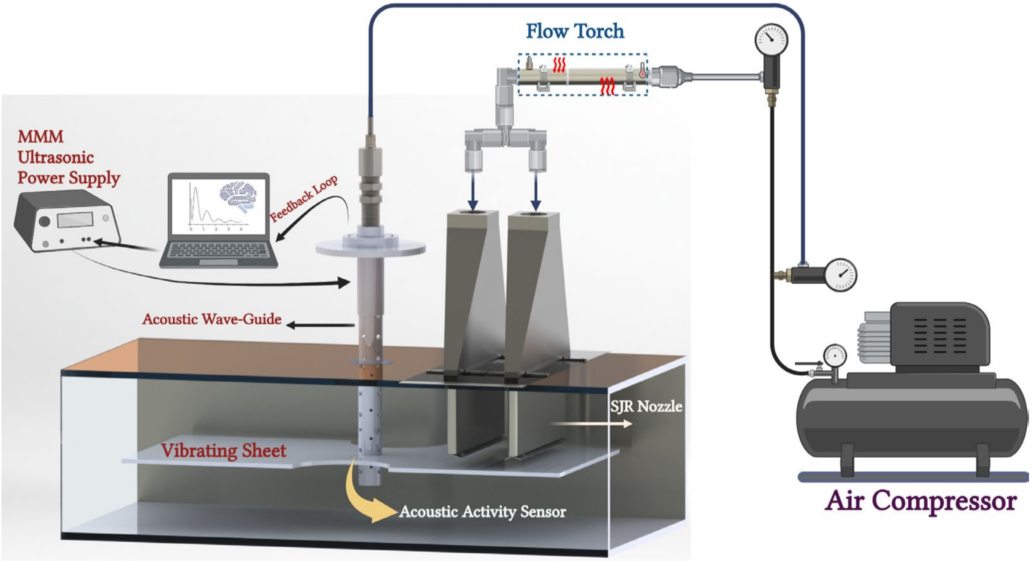
- Industrial drying consumes 1.2 quads annually. DOE estimates up to 40% or 0.5 quads can be saved with advanced drying technologies.
- To deliver up to 0.3 quads of energy savings annually when adopted by food, paper/pulp and other energy intensive industries.

Background & Strategic Approach - Testbeds



A

B



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- Developed one testbed at WPI and one testbed at UIUC
- A: schematic of a novel testbed at WPI (continuous and batch)
- B: Actual photo of 10 m long novel testbed at WPI (supported by DOE & MassCEC)
- C: schematic of a novel ultrasound testbed at UIUC (batch)

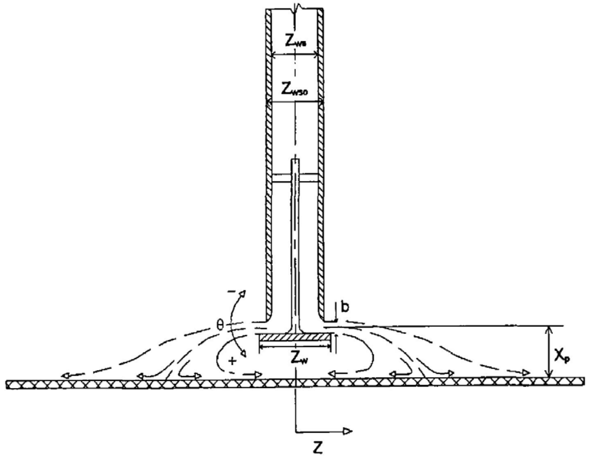
Results and Achievements: Slot Jet Reattachment (SJR) Nozzle

- **Advantages of SJR nozzle:**
- High rate of transfer of heat
- Controlling the exerted force on the impingement surface
- Negative pressure under the nozzle bottom plate

- **Disadvantages of Using SJR nozzles:**
- Higher pressure drop than SJ (not an issue)
- Higher initial cost (a short period on ROI)

Comparison criteria between SJ (Slot Jet) and SJR nozzles:

- Identical air mass flow rate
- Identical fan power
- Identical exerted peak surface pressure

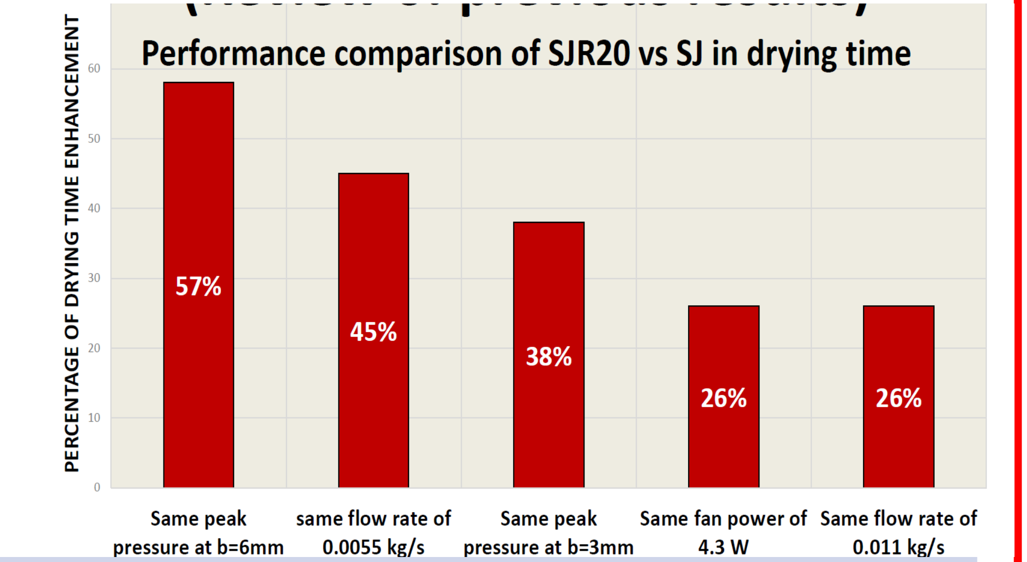


Outcome

- SJR performance exceeds the proposed metrics.
- Significant increase in energy efficiency and throughput and decrease in gas consumption (carbon footprint).
- Successful retrofitting in food industry
- Assisting food industry with incorporation of SJR in existing and new baking ovens.
- Need to work with pulp & paper industry
- Tests to be conducted in testbed with fully integrated techs. (starting summer 2023).

An example of SJR Performance Comparison

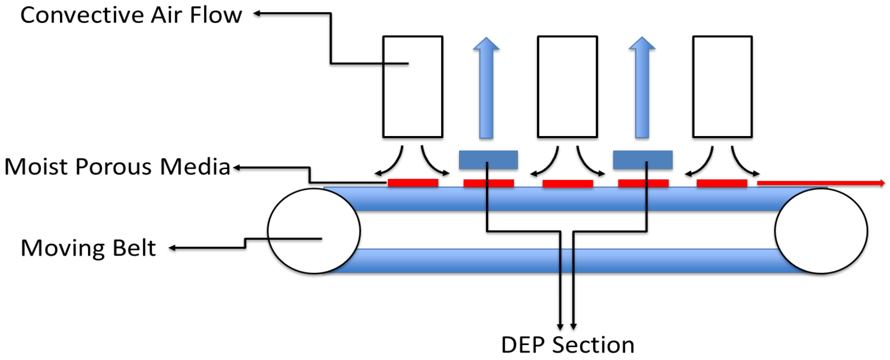
- Results: cookie sample
- Other samples studied: paper, chips, and fruits
- Similar results achieved in commercial/pilot oven under same fan power



Results and Achievements: Drying/Baking with Di-electrophoresis (DEP)

- DEP force extracts the vapor away from the moist porous medium toward low electric field, enhancing the drying process.
- A non-uniform electric field is required.
- Electric field must remain below the electric breakdown level.

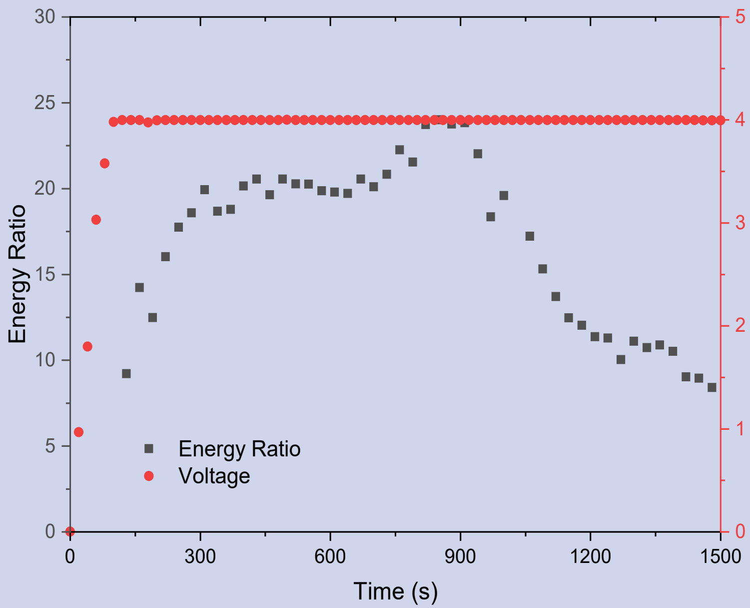
DEP electrode in modular setup

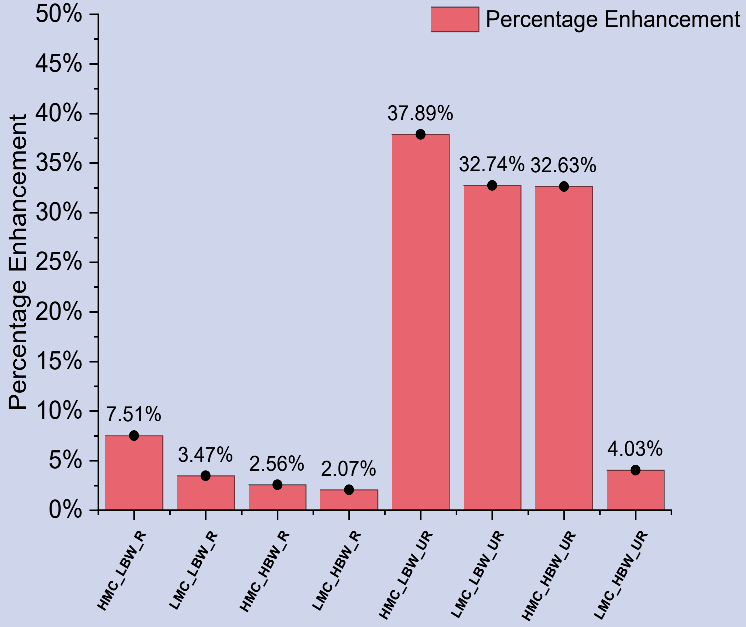


Summary

- DEP enhances drying rate for paper, snacks, and others.
- DEP is electric with negligible energy consumption (high voltage, current in mA).
- DEP exceeds proposed metrics for moist porous medium with high permeability.
- Suitable for batch process since it requires a long residence time.
- Tasks at modular level completed. Scaled-up electrodes to be installed in testbed in summer 2023 for fully integrated techs. tests.

Percentage enhancement and energy ratio for various handsheets

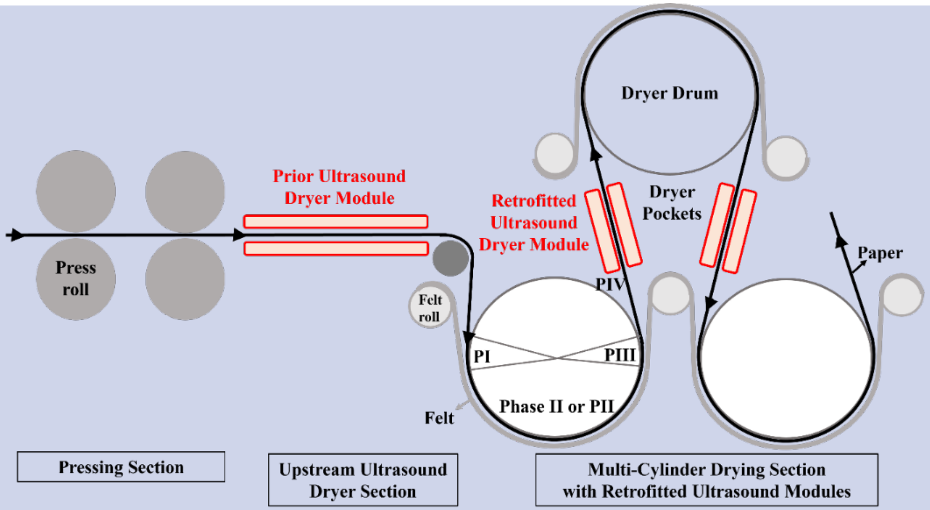




Results and Achievements: Ultrasonic (US) Drying

At UIUC (food):
- 20-40% reduction in energy use (Compared with Traditional Tray Dryers)
- Reduction in drying time 25-70% (Increase in production rate)
- Improvement in the final quality of the product.
- ✓ No protein denaturation due to non-thermal heating.
- ✓ Improve the texture, total phenolic content, and color of the final product.

At WPI (paper):
- A detailed predictive correlation developed for contact-US drying of paper under various conditions.
- The correlation incorporated into our existing paper machine drying section numerical simulation software.
- Enhancements of 7% might be achieved if installed throughout dryer.
- Non-contact US will have less impact.

Plan forward	Multi-frequency, Multimode, and Modulated US Testbed at UIUC & Direct Contact US Setup at WPI
• Tests to be conducted w SJR at UIUC testbed • Non-contact US to be installed in WPI testbed for system level tests	

Future Work, Technology Transfer, & Impact

Future Work:

- Install the airborne US transducer and DEP electrodes into the novel testbed at WPI to investigate the integrated performance of these technologies along with SJR nozzle technology (for food and paper). Validate the physics-based model with the experimental data. Use the model and the data to develop AI for real time process optimization minimizing energy consumption and improving product quality.
- Conduct the tests with SJR assisted US drying on the testbed at UIUC and develop AI for real time process optimization minimizing energy consumption and improving product quality.
- Complete the remaining development tasks for sensors.

Technology Transfer:

- SJR technology successfully being transferred to food industry. Testbed at WPI being regularly used by CARD members for development of fully electric baking ovens using our novel technologies (including IR emitters as well).
- A commercial licensing venture using technology developed from this DOE and several of CARD's research projects. This deal was signed in December 2022 and allows the licensing company (a CARD member company) to leverage the unique drying technology for its business purposes.
- 12 journal papers published in highly ranked journals. The 22^{nd} International Drying Symposium was held at WPI in June 2022.

Impact:

- Three novel technologies pursued to deliver up to 25% energy efficiency increase and integrate advanced sensors and AI for optimal process optimization and up to 10% additional energy efficiency.
- Use the testbeds to assist industry partners toward zero carbon footprint. Make U.S.A. industries more competitive.

Questions?

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