Efficient Drying Processes of High-Quality Wood through Intelligent Desiccant Assisted Heat Pump System Innovations

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Abstract

Drying is an energy and carbon-intensive operation consuming 9–25% of national energy in the developed countries. For Kiln dying, commonly used heat sources include steam coils, hot water coils, and gas furnaces, which are energy intensive with high carbon density.

We will offer an innovative system solution that integrates dehumidification, low-cost Internet of Things (IoT) sensors, data assimilation, and model-free predictive controls to intelligently and safely operate the drying process through three modules:

1) *Kirigami*-based heat exchanger coated with regenerative desiccant channels;
2) Desiccant-assisted heat pump (DAHP) system; and
3) Intelligent deep-reinforcement learning (DRL)-based product-centric controller.

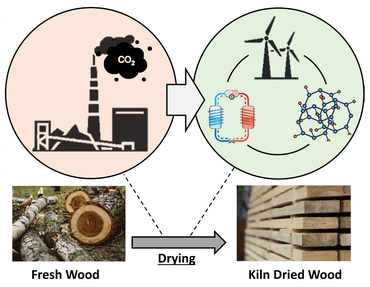
We envision to achieve improved energy efficiency, guaranteed product quality, reduced operating cost, and reduced fossil fuel use. The system will first be tested in a Hardware-in-the-loop (HIL) environment, and then in a Kiln chamber with our industry partners. Although the DAHP drying system will only be tested in a wood drying Kiln, the generic nature of the system can be applied to dry others (e.g., food, textile) with drying operation temperatures less than 120-160°F. Importantly, this project will offer the first example to apply the innovations in desiccant-assisted heat pump with *Kirigami*-based heat exchanger to an industrial drying process.

Alignment with Office Mission

- Achieve carbon pollution-free electricity by 2035.
- Achieve net-zero carbon emissions by 2050.
- Contribute to a clean and equitable energy economy.

Challenges and Impact

- Fuels with a lower carbon intensity such as electricity from renewable resources (e.g., wind and solar) are becoming prevalent in the era of electrification in U.S.
- Traditional heat pump technologies cannot effectively handle significant water removal, required by the drying process.
- To enhance drying process energy efficiencies, and reduce or eliminate the use of fossil fuel, we propose to research, develop, and demonstrate an intelligent desiccant-assisted heat pump drying system that will be applied to wood drying.



Project Outline

Innovations:
- Material innovations for heat pump application
- Artificial Intelligence and Machine Learning

Project Lead: Texas A&M Engineering Experiment Station

Project Partners: University of Pennsylvania, University of Virginia, Michigan Technological University, Lincoln University, Lawrence Livermore National Laboratory, Trane Technologies, Koppers Performance Chemicals, The Great Lakes Kiln Drying Association, InventWood, Great Southern Wood Preserving, and Lincoln Lumber LLC

Timeline: 10/01/2022 to 09/30/2025

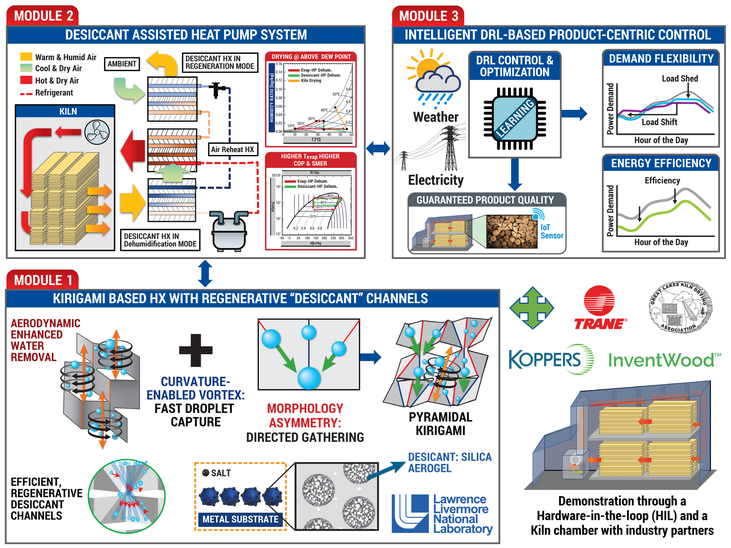
Budget:

	FY23 Costs	FY24 Costs	FY25 Costs	Total Planned Funding
DOE Funded	$830,586	$797,700	$577,998	$2,206,284
Project Cost Share	$207,647	$199,425	$144,499	$551,571

End Project Goal:
1) At least 25-30% energy consumption reduction.
2) 40-50% carbon intensity reduction.
3) 25% operation cost reduction for Kiln drying process.
4) Promote diversity, equity and inclusion.

Background

Drying consumes 9–25% of national energy in the developed countries and are energy intensive with high carbon density. To effectively handle significant water removal required by the industrial drying process, we are developing an intelligent desiccant-assisted heat pump drying system for drying wood as a holistic integration of high-performance heat exchanger, hybrid desiccant dehumidification, and intelligent product-centric control. The project consists of **Module 1** *Kirigami*-based HX with regenerative desiccant channels; **Module 2** Desiccant-assisted heat pump system; **Module 3** Intelligent DRL-based product centric control.

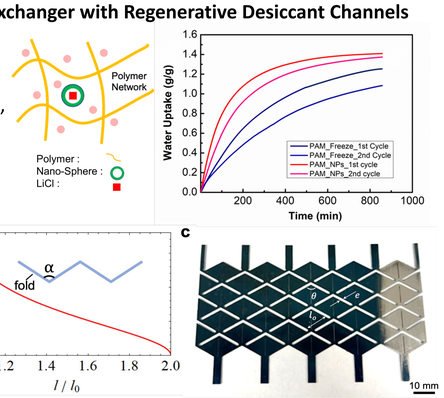


Key elements of the proposed Kiln drying system

Results

Module 1 – *Kirigami*-based Heat Exchanger with Regenerative Desiccant Channels

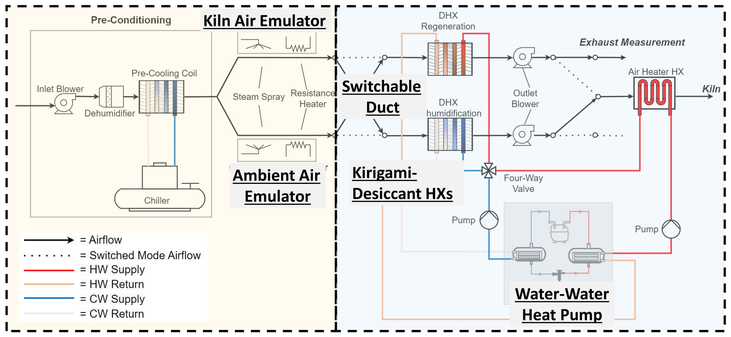
- Self-folding kirigami structure through uniaxial stretching
- Addition of Dow hollow spheres, ROPAQUE™ (~ 23 wt%), enhanced water uptake, speed and recyclability.



Folding and stress simulation of the Kirigami structure (left), laser-cut spring steel Kirigami sample (right)

Module 2 - Desiccant Assisted Heat Pump

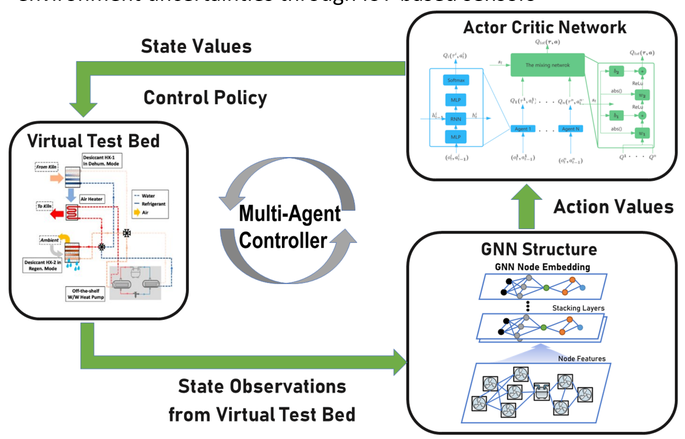
- Desiccant-coated exchanger integrated high performance heat pump system
- Design and operation evaluation based on Hardware-in-Loop facility



Hardware-in-the-loop (HIL) testbed for wood drying (left), Desiccant-assisted heat pump dryer (right)

Module 3 Intelligent DRL-based Product-centric Control

- Intelligent control scheme considering real-time operation status and environment uncertainties through IoT-based sensors



Graph neural network (GNN)-based DRL control for wood drying process

Conclusions

All milestones to date are completed. All proposed research development work including development of *Kirigami*-based heat exchanger with regenerative desiccant channels, design and modeling of desiccant-assisted heat pump system, implementation of intelligent DRL-based product centric control framework, HIL System level testing preparation are in progress as planned.

Technology Transfer

- Strategically pursued industrial partnership with Trane, a major heat pump manufacturer, and lumber industry (e.g., the Great Lakes Kiln Drying Association, Great Southern Wood Preserving, and Lincoln Lumber)
- Reach local lumber industry through TAMU DOE's Industrial Assessment Center.
- Work with TAMU Office of Commercialization and Entrepreneurship (TOCE) and Penn Center of Innovation (PCI)

Acknowledgements

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