U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

May 16th-18th, 2023

Washington, D.C.

Integrated Radio Frequency and Ultrasonics (RFUS) with Conventional Processes for Efficient Water Removal in Pulp and Paper and Other Biomaterial Applications (IEDO)

PI: Ramaswamy, University of Minnesota;

Presenters: Ramaswamy, U of M, Jay Gaillard, Matthew Craps, SRNL, Ignasi Palou-Rivera, RAPID Institute

Contract Number: DE-EE0009395 | Project Period: 08/01/201 – 07/31/2024

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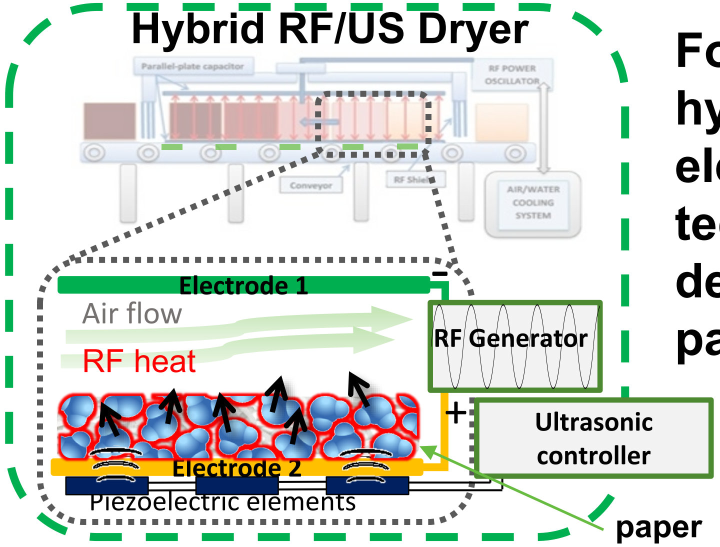
Project Overview

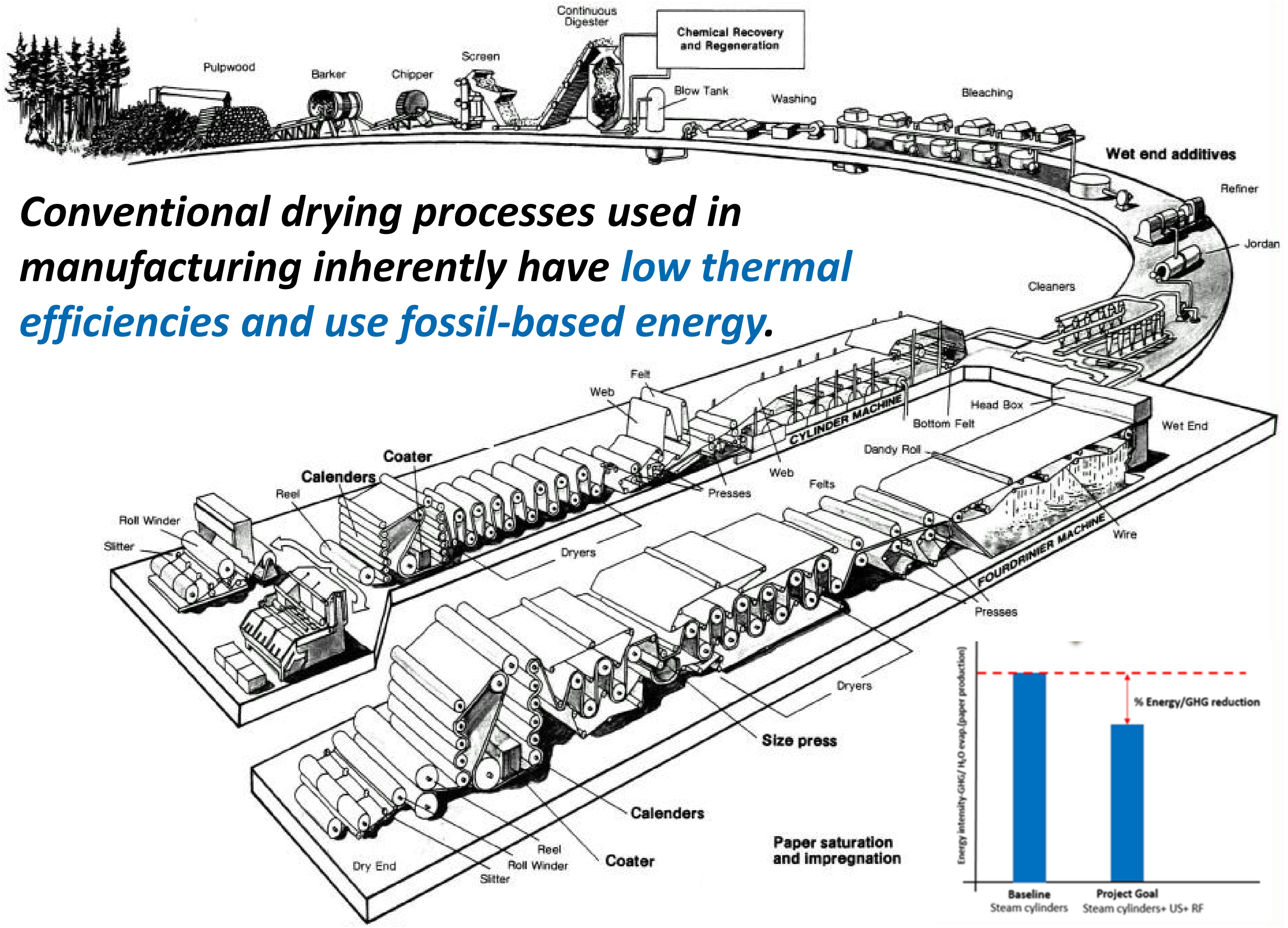
Pulp and paper industry - 13% of the manufacturing energy consumption mostly from process heating (DOE 2015 Bandwidth Study).

US paper drying uses 36% of the total energy required for manufacturing to produce 83 million tons of paper and paperboard.



Focused on a hybrid electrification technology to decarbonize paper drying

Conventional drying processes used in manufacturing inherently have low thermal efficiencies and use fossil-based energy.



The integrated advanced process intensification technology has the potential to revolutionize drying in manufacturing process industries including pulp and paper and biomaterials

Project Outline

Innovation: Integrated hybrid volumetric drying technology using Radio Frequency (RF) and Ultrasonics (US)

Project Lead: University of Minnesota

Project Partners: Savannah River National Lab, Electric Power Research Institute, RAPID Institute, PSC Inc, Alliance for Pulp and Paper Technology Innovation, Liberty Paper, SIEMENS, Asten Johnson

Timeline: 08/01/201 – 07/31/2024, 55 %

Budget: BP1: 08/01/21 – 01/31/23; $337,078 cost share; BP2: 02/01023 – 07/31/24; $340,612 cost share

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$23,847	$831,004	$877,507	$2,364,209
Project Cost Share	$166,102	$161,803	$263,481	$677,690

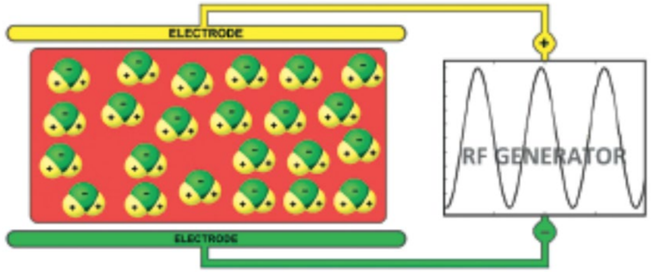
FY21 and FY22 costs include actual amount spent; FY 23 costs include planned FY23 funding

End Project Goal: With optimal integration of the hybrid process intensification technology, based on laboratory experiments on paper drying and TEA/LCA analysis, project goal is to meet/exceed the following minimum targets in paper manufacturing: increase the drying rate and production/throughput rate by 20%; decrease the drying energy consumption 20%; reduce the carbon intensity by 25%; and reduce the operating costs including energy costs by 20%.

Background

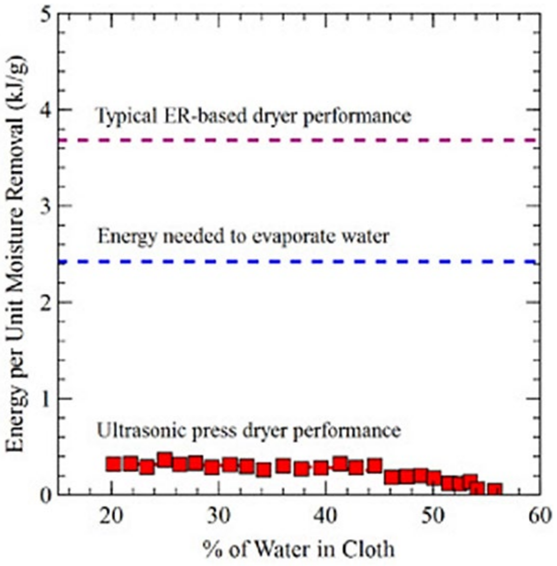
Conventional drying processes primarily involve slow, inefficient, multi-cylinder steam-heated conductive drying with longer drying times, low drying rates, low thermal efficiencies ranging from 20-60% and use fossil-based energy.

RF heating and how it works

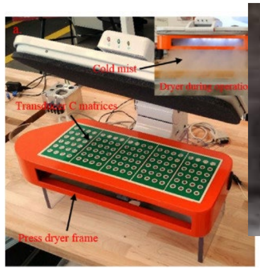


PSC RF drying system

Low-energy drying using ultrasonics (US)



C. Peng, S. Ravi, V. K. Patel, A. M. Momen, S. Moghaddam, Physics of direct-contact ultrasonic cloth drying process, Energy, Volume 125, 2017, Pages 498-508

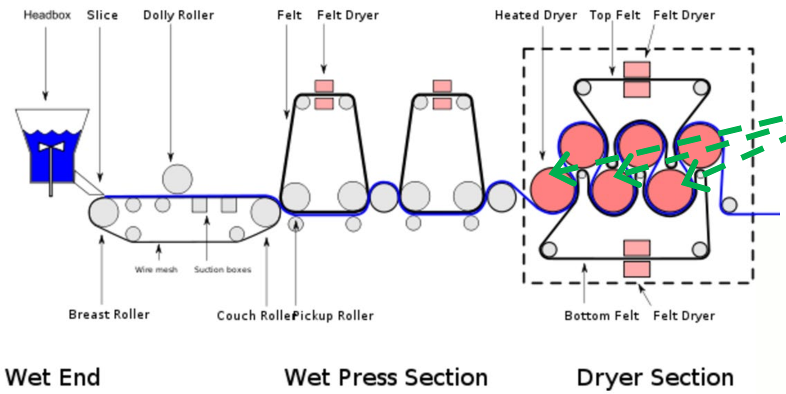


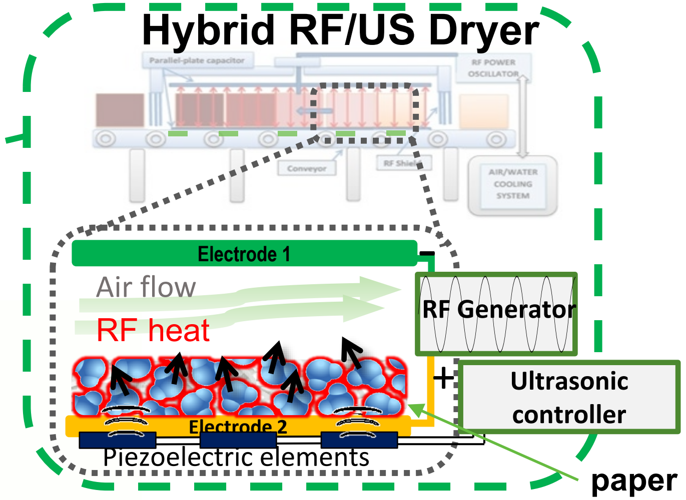
These electrification approaches could save 80 trillion BTU/yr and a 20% reduction in energy intensity.

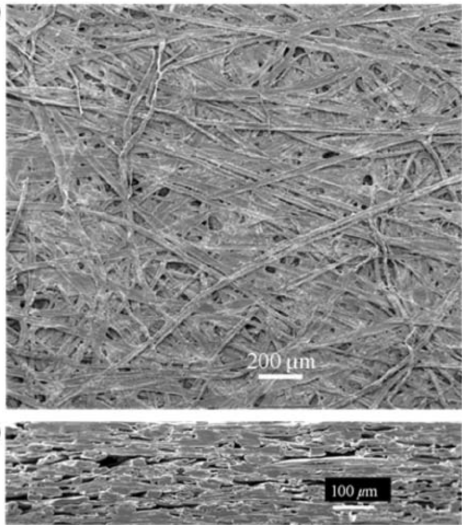
Strategic Approach

Proposed Solutions and Approach:

- ❖ Develop innovative hybrid volumetric drying technology using Radio Frequency (RF) and Ultrasonics (US)
- ❖ Effective removal of free and bound water by leveraging the synergies of RF and US
- ❖ Acoustic energy (US) to loosen the bound water and push the liquid water to drying front
- ❖ RF to augment liquid water supply to the drying front, supply energy where needed
- ❖ **Integrated hybrid RFUS drying technology** in conventional drying processes to achieve maximum efficiency



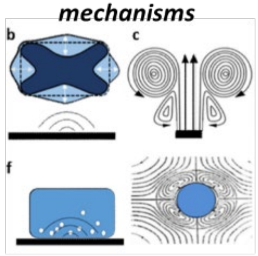




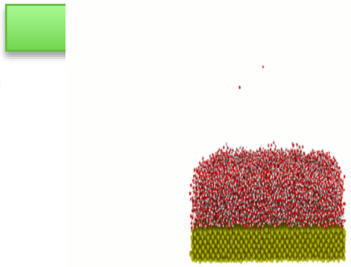
SEM image of linerboard (surface and cross section)

US drying via atomization

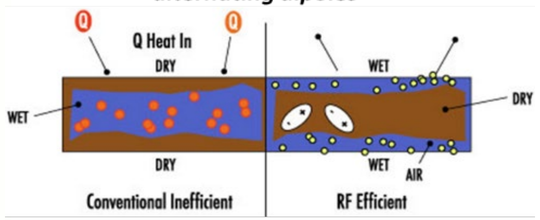
US drying via internal mechanisms



Simulation of US atomization



RF dries from inside out from alternating dipoles



https://fyfluiddynamics.com/2018/10/ultrasonic-vibrations-can-boil-nanoscale-liquid/

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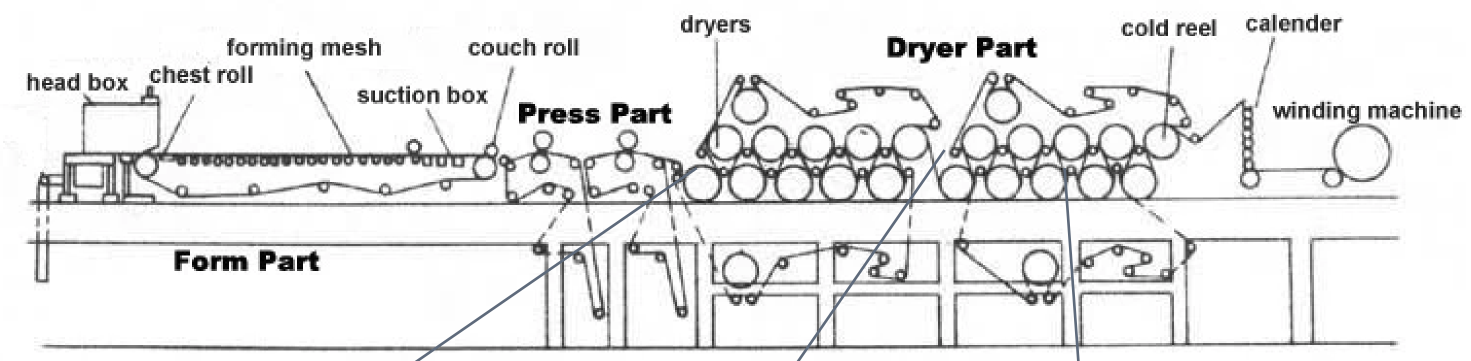
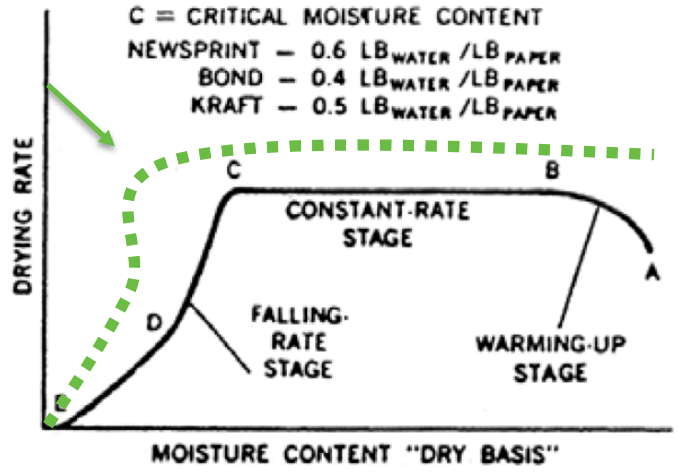
Hybrid RFUS drying technology integrated with conventional drying processes to achieve maximum efficiency.



Structure of Fourdrinier Paper Machine

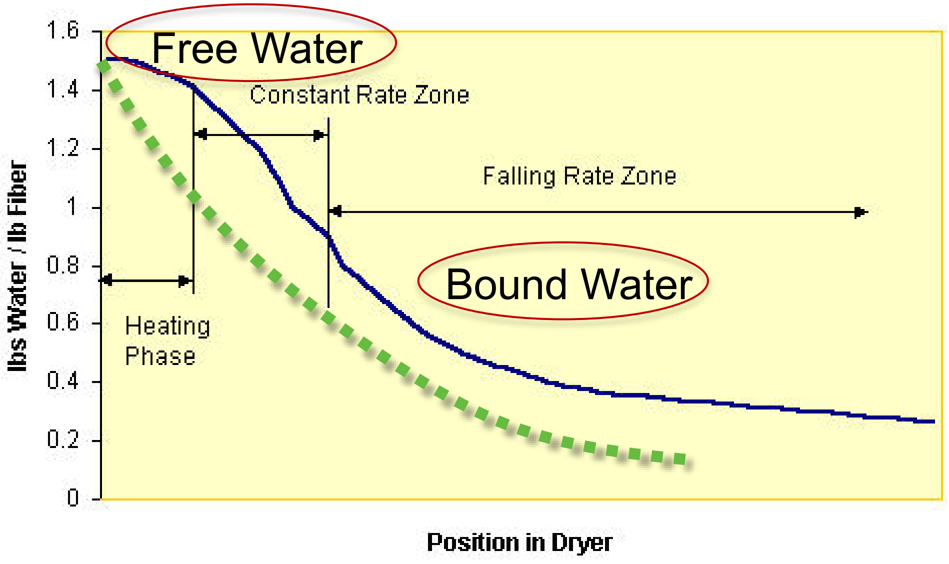
our go



~50% wet
RF: Rapid heating
US: Atomization
Intensified atomization

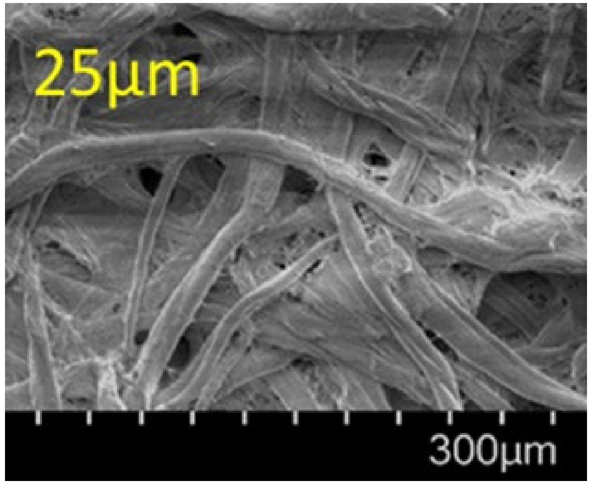
~20% wet
RF: RF "boost"
US: Disruption of bound water and separation of fluid boundary layer
Increased evaporation

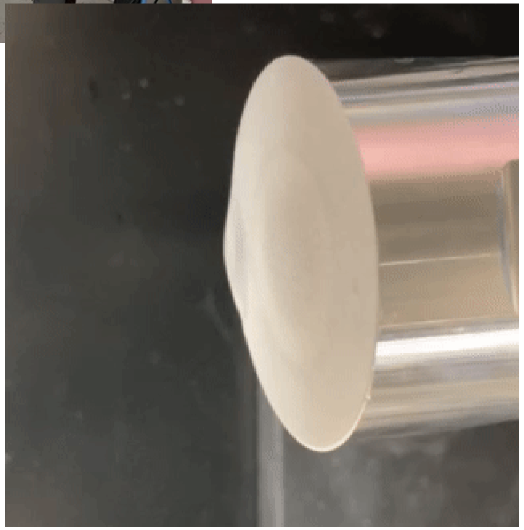
~10% wet
RF: Targeted heating and even drying of final product
US: Continued disruption of bound water
Enhanced diffusion, evaporation

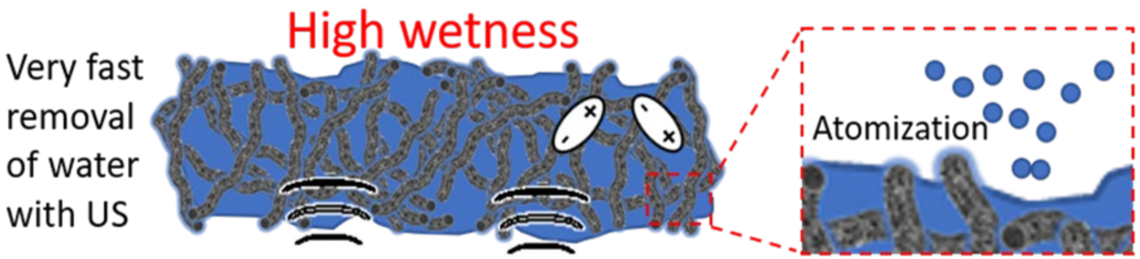


Results and Achievements

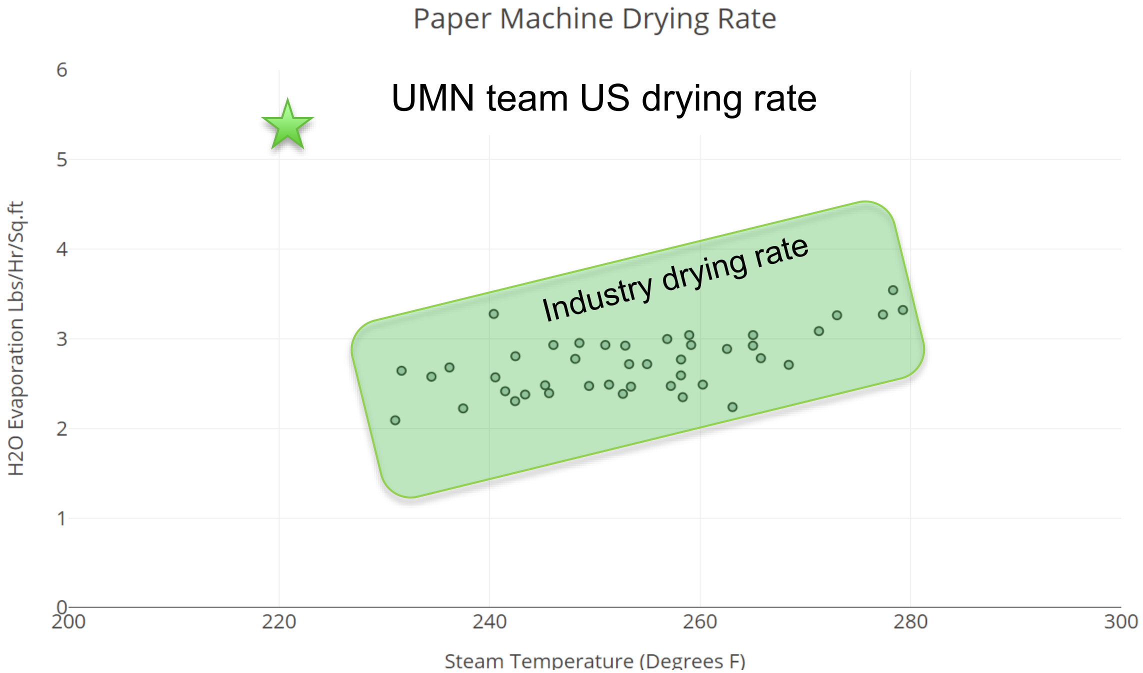
RF/US/ Convection drying experimental setup







Ultrasonic experiments with Whatman filter paper (25 micron pore size)



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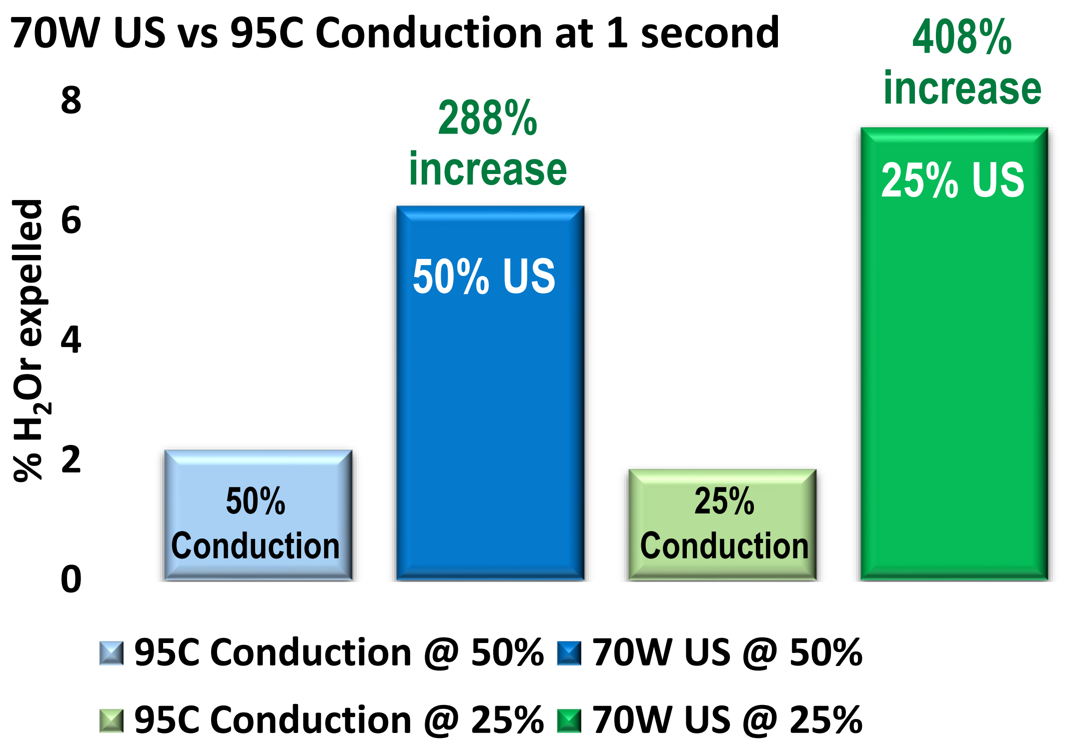
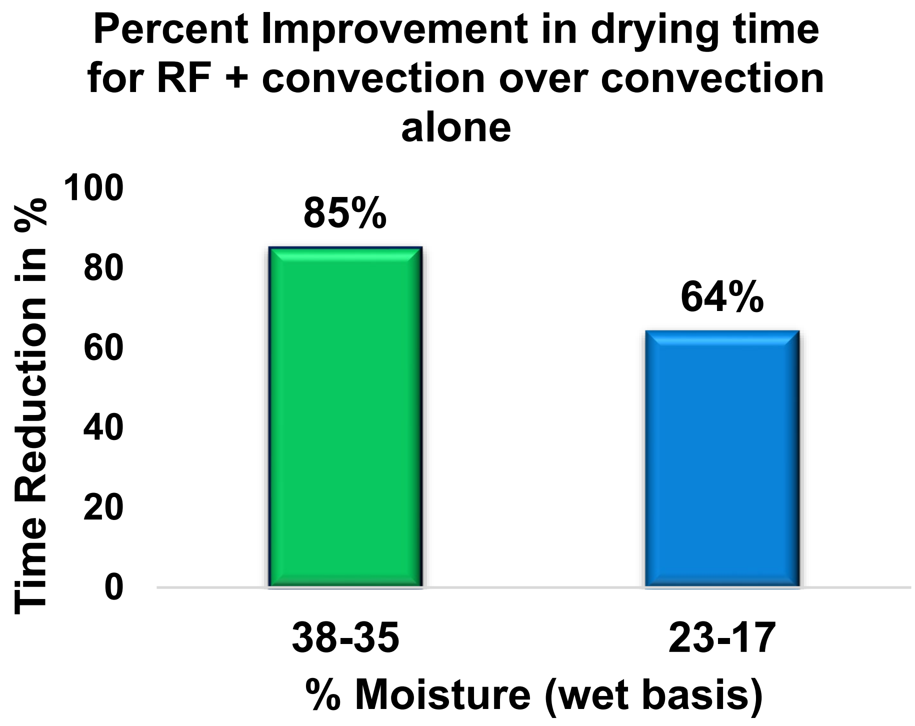


0.07-0.08 kg H_2O expelled/kg paper/s



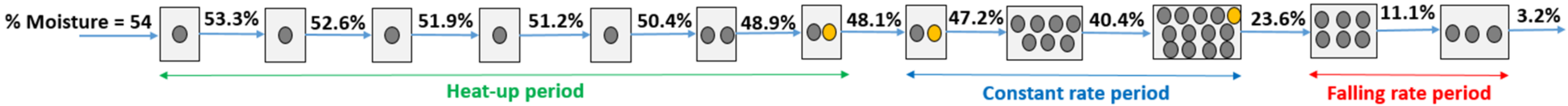
>200% improvement in % water expelled with high frequency ultrasonics

>60% improvement in drying rate and >15% reduction in energy

Results and Achievements pg. 3

Techno-Economic Analysis of the Hybrid RFUS system

- Experiments on US and RF with **fine paper**. 37 heated cans, basis weight 13 pounds/1000 sq ft, line speed ~3700 ft/min.
- Preliminary mass and energy balance calculations performed and validated against data from industrial report (basis weight 52 pounds/1000 sq ft).



<u>19.8 % Energy Intensity Reduction</u> from the entire drying section using (**Steam Cylinders + US+ RF**):

- Steam cylinders remain in place for subsections 8, 9, and 10 of constant rate period and subsection 12 of falling rate period . Residence time ~0.2 seconds for individual cans in the heat up period. Paper contact area ~70% of dryer surface area.
- *Ultrasonic drying in experimental work compared to conduction for equivalent area.*
- *Testing of US at 36W to 55W, various frequencies and up to contact time of 1 sec.*
- Radio frequency drying applied at 800W and lower levels for up to 10 seconds including below 23% Moisture.

Results and Achievements pg. 4

Life Cycle Analysis of a Hybrid RFUS system

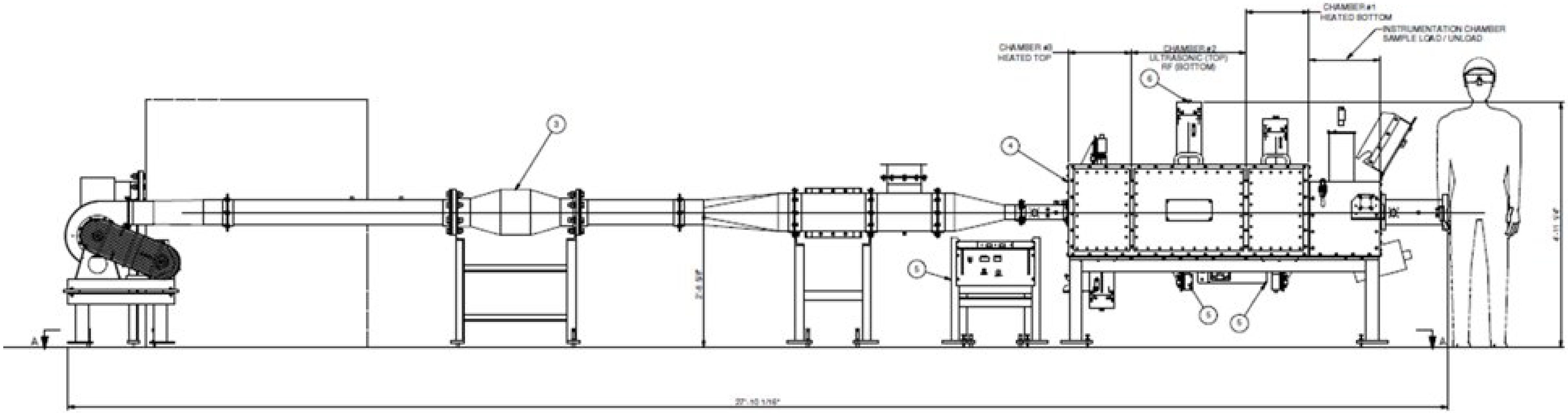
- **All steam requirement met by onsite generation. Steam production from fuel oil and natural gas reduced to meet lower steam requirement. Steam production from other fuels remains same as base-case. Additional electricity requirement met by purchased electricity.**
- **Scenario with experimental data showing 2 to 4 times better drying rates with ultrasound. RF synergy under review.**
  - Scope 1 reductions at the mill are over 80%. CO_2 emission of biomass-based fuels such as waste pulping liquor and wood/bark assumed as zero.
  - Scope 2 emissions change over time as the electricity grid becomes greener in line with AEO 2021 projections: MMT of CO_2/Quad decreases 33% from 120 in 2021 to 80 by 2040.

Future Work, Technology Transfer, & Impact

Future Work: Continue development & optimization of the integrated hybrid RFUS Drying System in the lab/pre-pilot scale drying setup along with modeling and simulations. (under development)

Technology Transfer: Working with industry partners and Office of Technology Commercialization for licensing and technology commercialization policies and procedures facilitating the transfer of technology.

Impact: Accelerated innovation and adoption of RF & US integration at key locations will maximize efficiency, reduce energy intensity, and eliminate GHG emissions. This helps advance the IEDO mission.



Questions?

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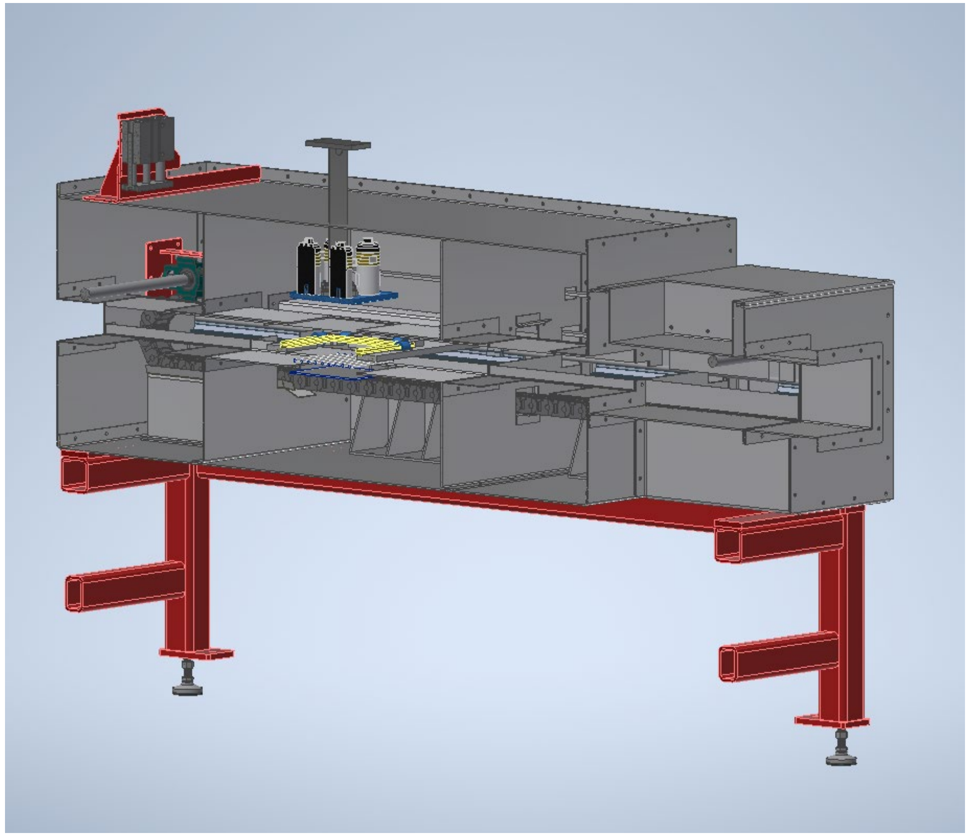
shri@umn.edu;

Jay.Gaillard@srnl.doe.gov

Matthew.Craps@srnl.doe.gov;

ignap@aiche.org



3D model of the drying experimental setup with the 3 chambers (alternating conduction and convection and RF/US) (side view)