Sorption Heat Pumps and Thermal Storage as Practical Pathways for Decarbonization, Frugal Water Use, and Food Preservation

Srinivas Garimella

Sustainable Thermal Systems Laboratory

GWW School of Mechanical Engineering

Sorption Friends III, Italy

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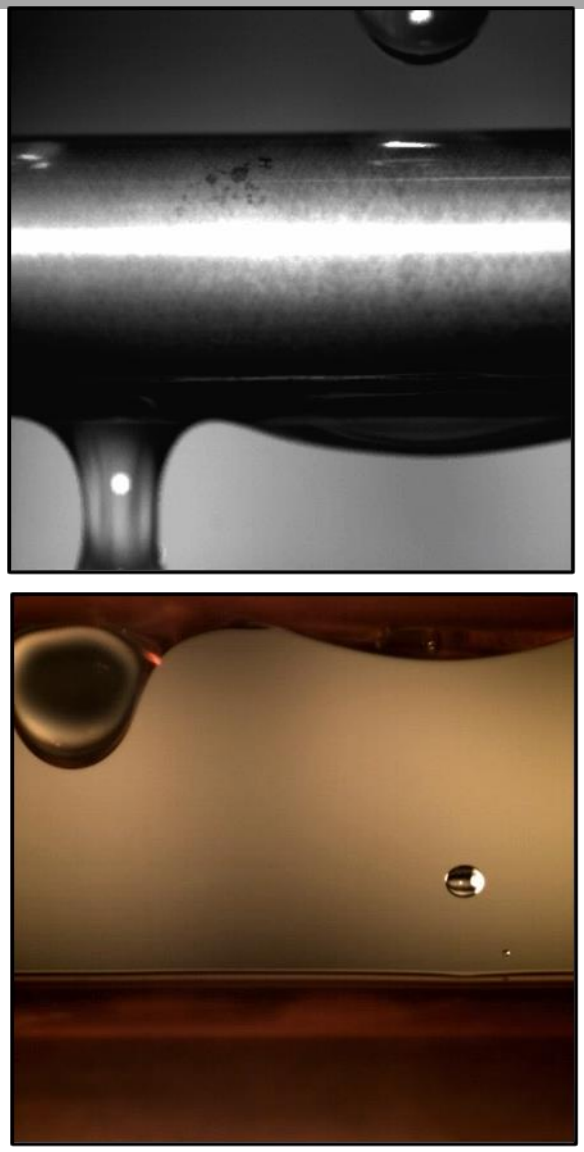
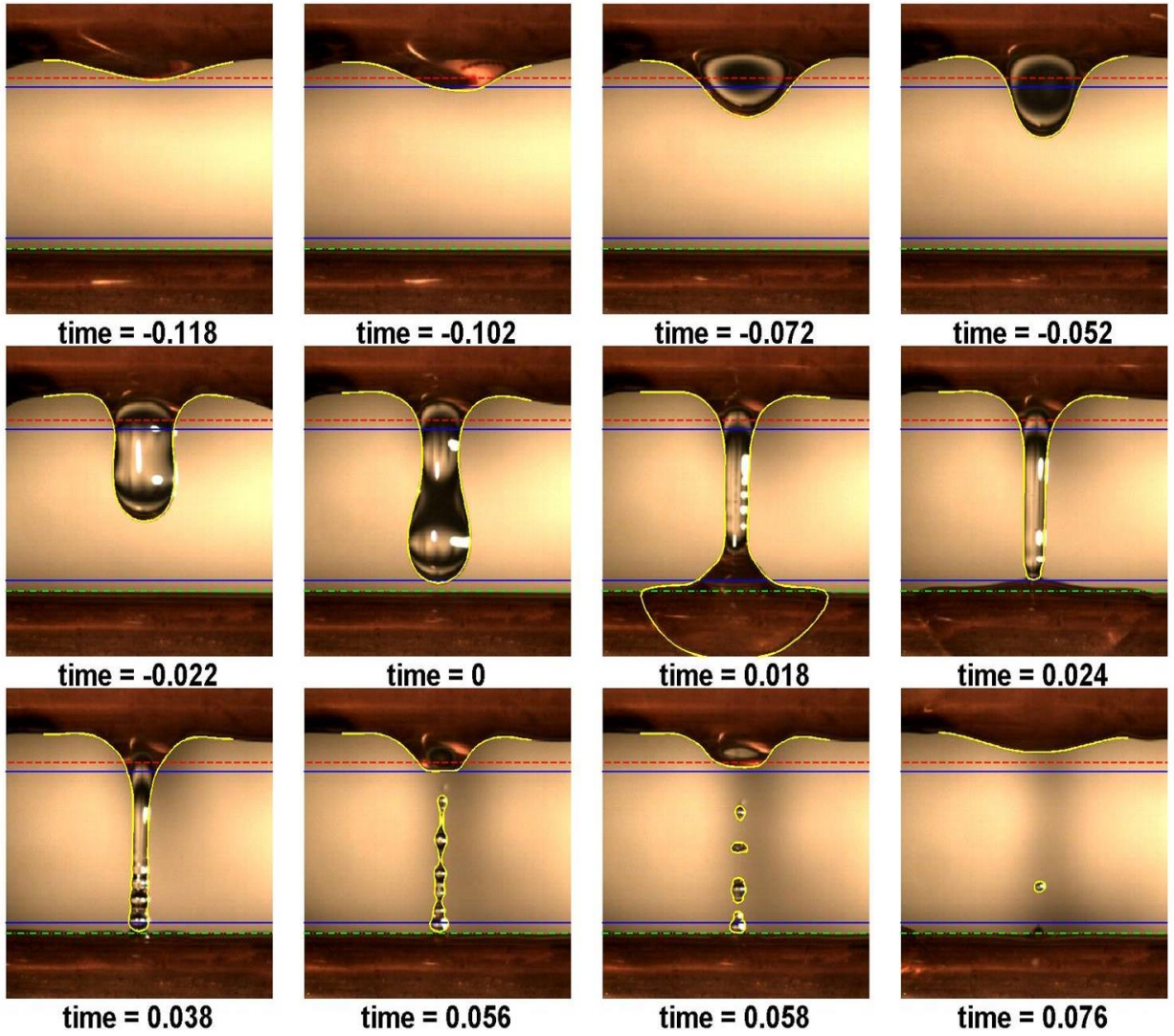
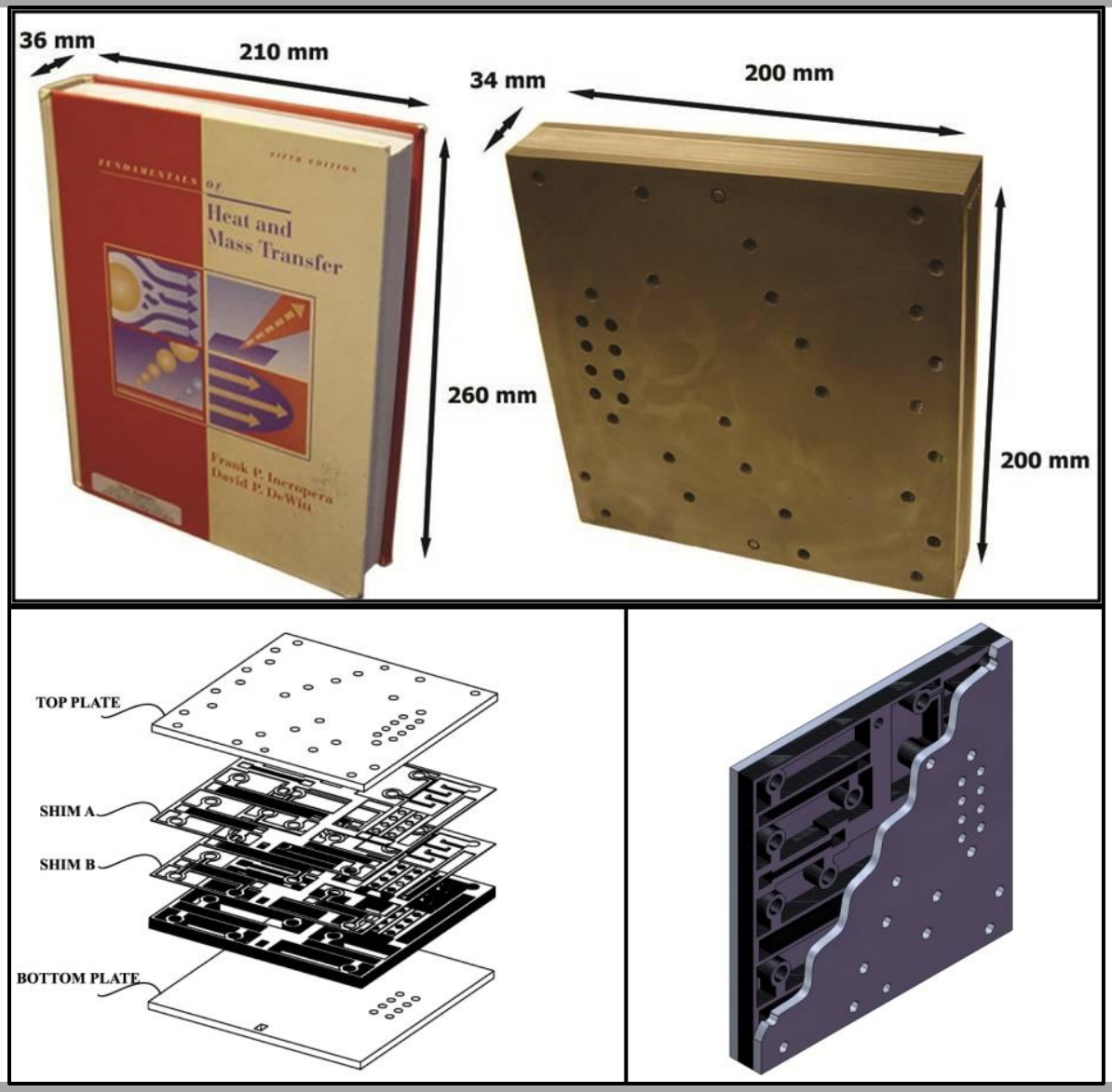
Past Work

Absorption Hydrodynamics, Heat and Mass Transfer

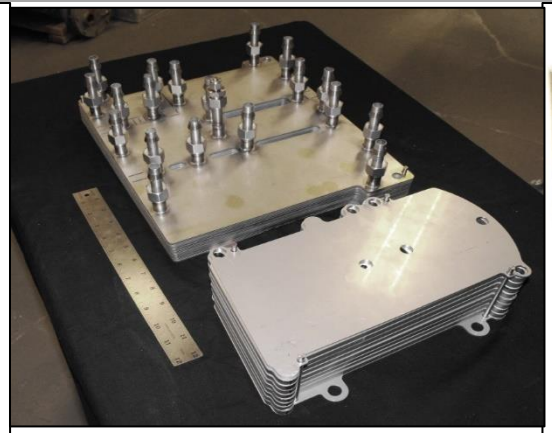


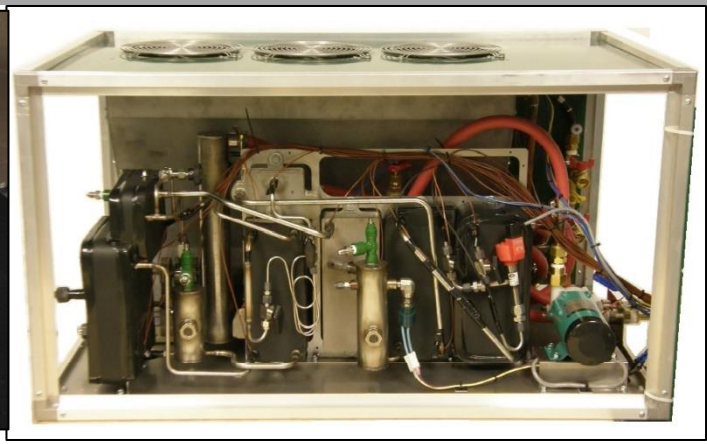


Microscale Monolithic Absorption System (300 W)



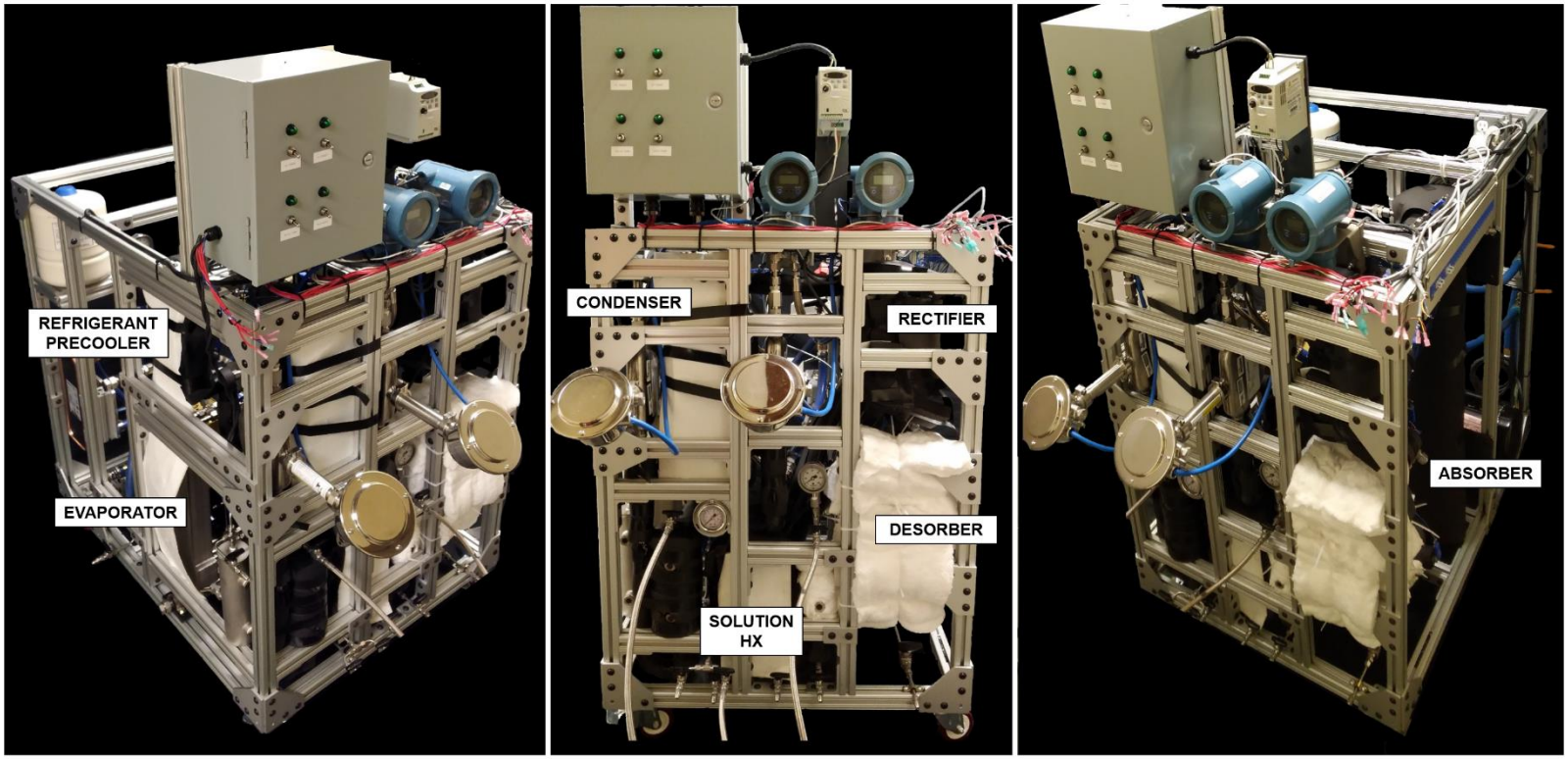
Scale-up, Versatile Applications





- Diesel-engine waste heat recovery (**2 kW_c**)
- Gas-fired heat pump water heater (**3 kW_h**)
- Residential Thermal Hub (**3.5 kW_C**, AC, heating, water heating)
- Residential gas-fired cooling (**7 kWc**)
- Forward operating base unit (**2.6 kWc @ 52°C** ambient)

Extreme Ambient, Residential Scale, Waste Heat Driven Absorption Heat Pump



Key specifications			
Size	1.0 × 0.8 × 1.0 m	T_{source}	165°C
Cooling duty	10.65 kW	$T_{ambient}$	44°C
COP	0.63	$T_{chilled}$	12°C

Recent and Ongoing Work

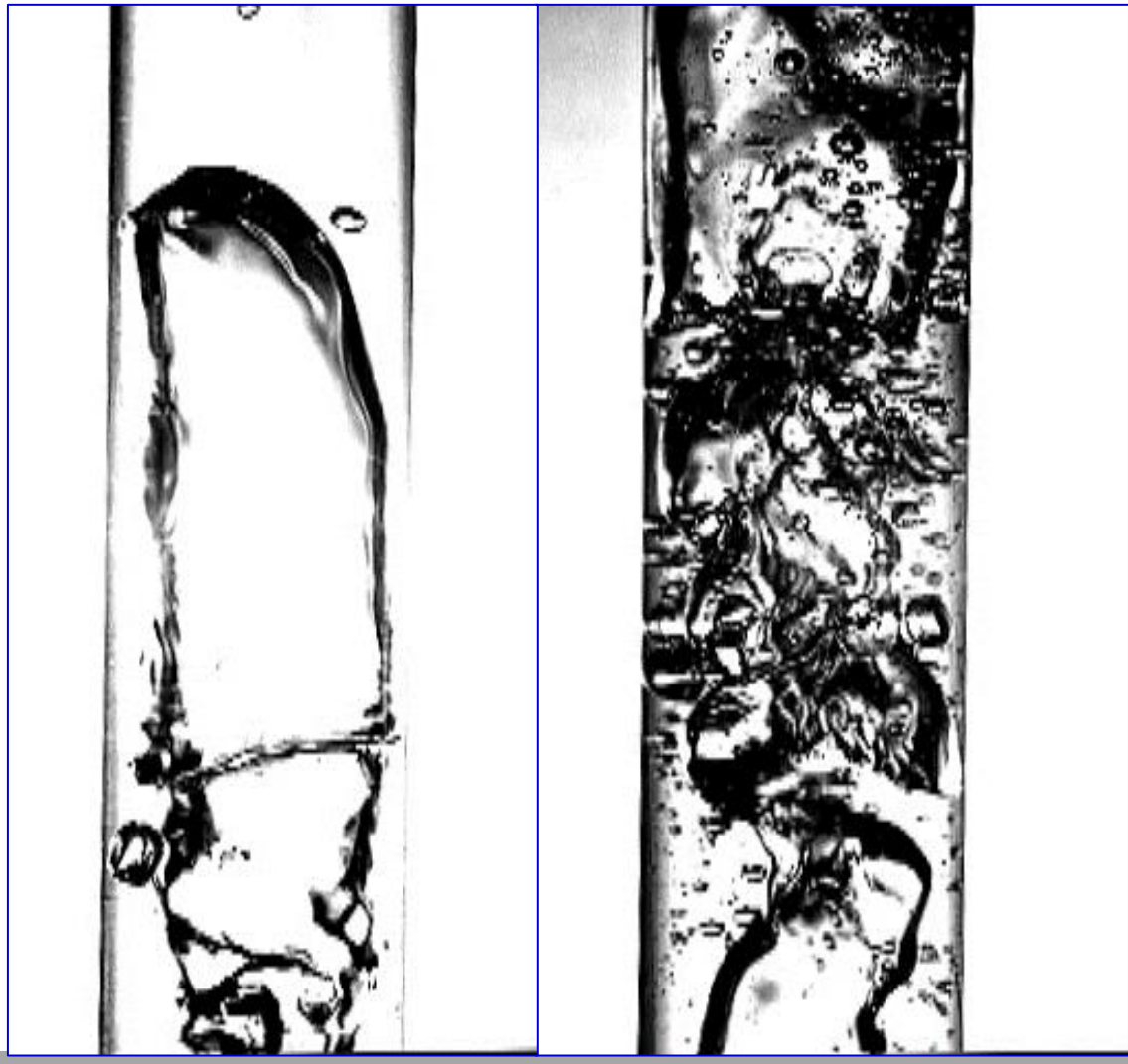
Surfactant Enhanced Absorption

Ammonia-water absorption

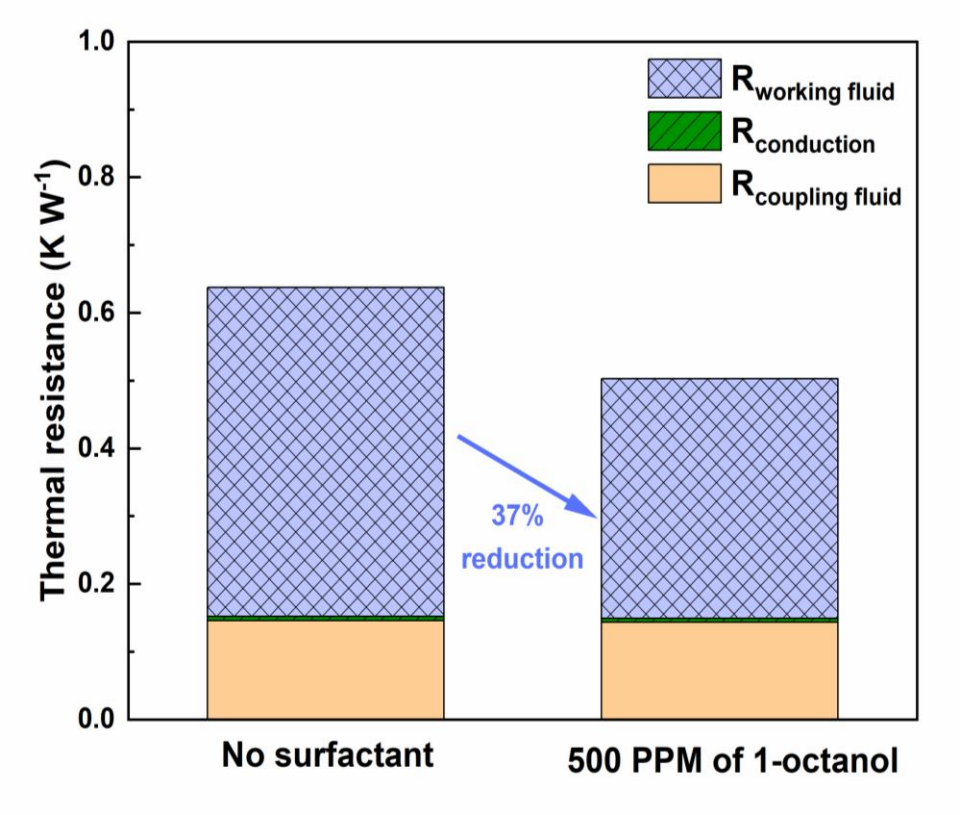
- High solution-side thermal resistance

With surfactants

- Enhancement in transport coefficients by Marangoni convection
- Increase in interfacial area



Surfactant Enhanced Absorption



Component level

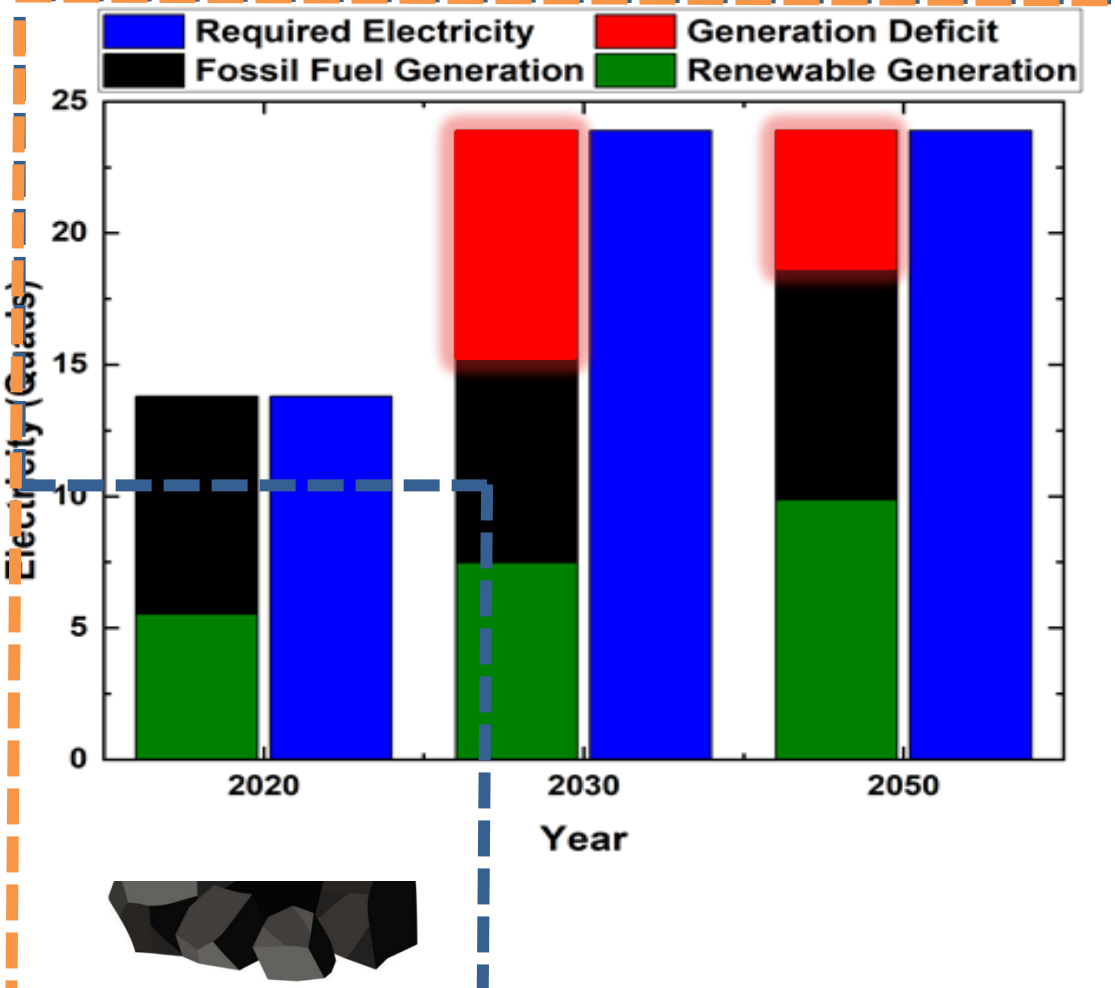
- Overall thermal resistance reduction > 35%
- **Compact absorbers**

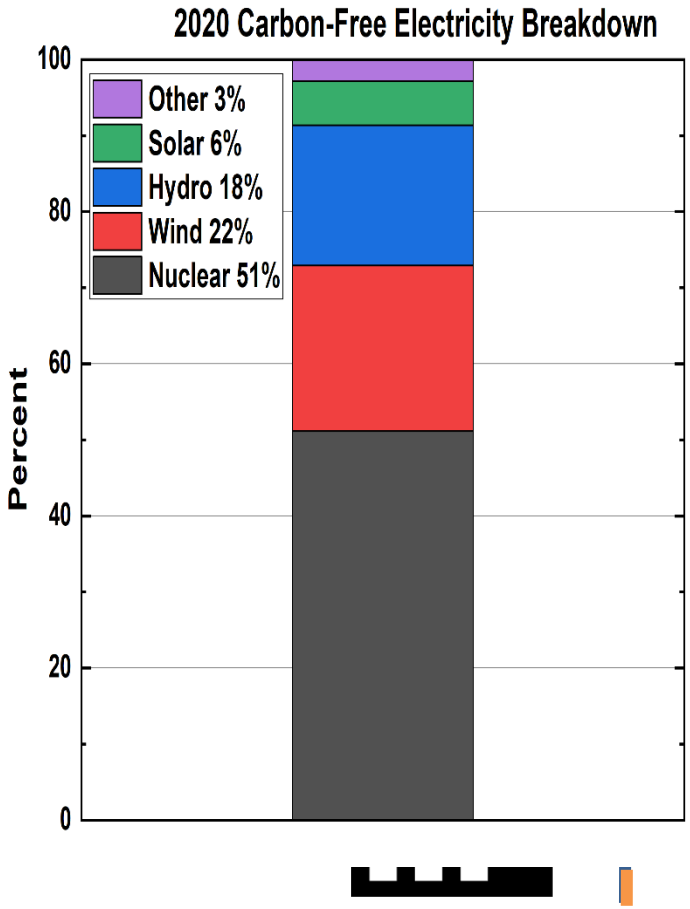
System level

- Reduction in absorber pressure, no change in desorber input
- Improvement in **COP and Q_{evap}**

Decarbonization: What and where exactly is the challenge?

Energy sources **Transmission** **End-use**

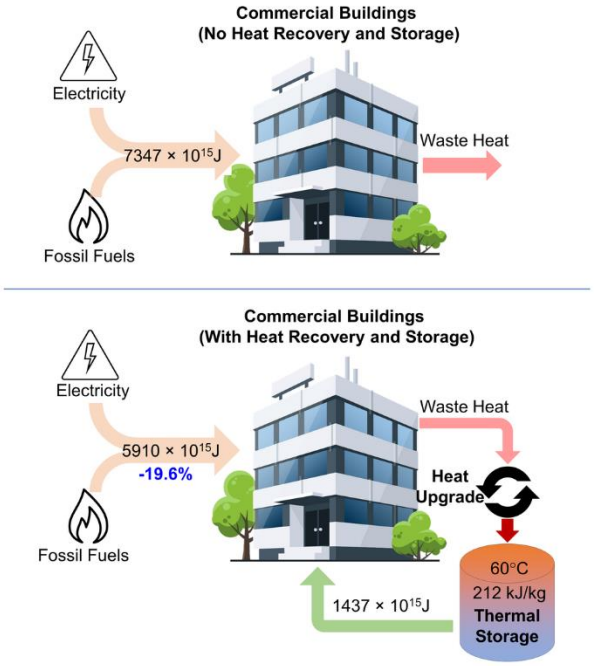




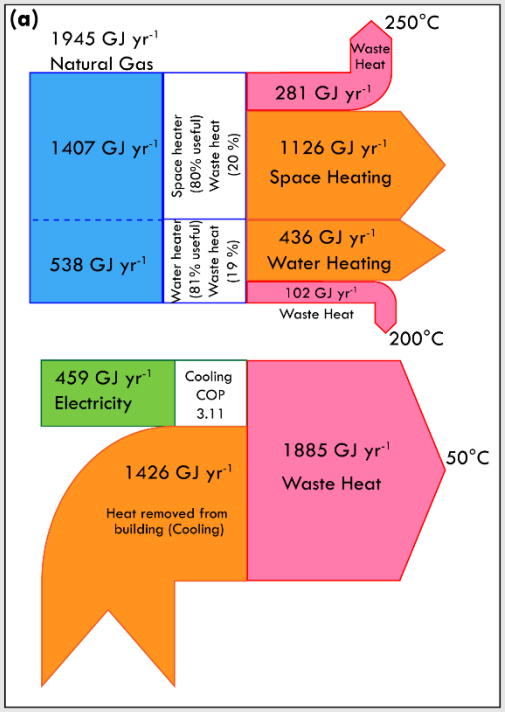
[EIA, 2021]

The Need for Thermal Storage

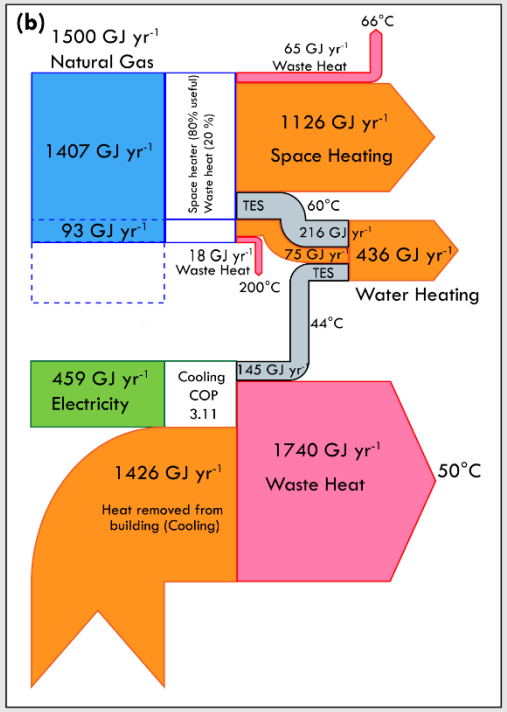
Waste Heat Recovery and Storage in Buildings



No Heat Recovery and Storage



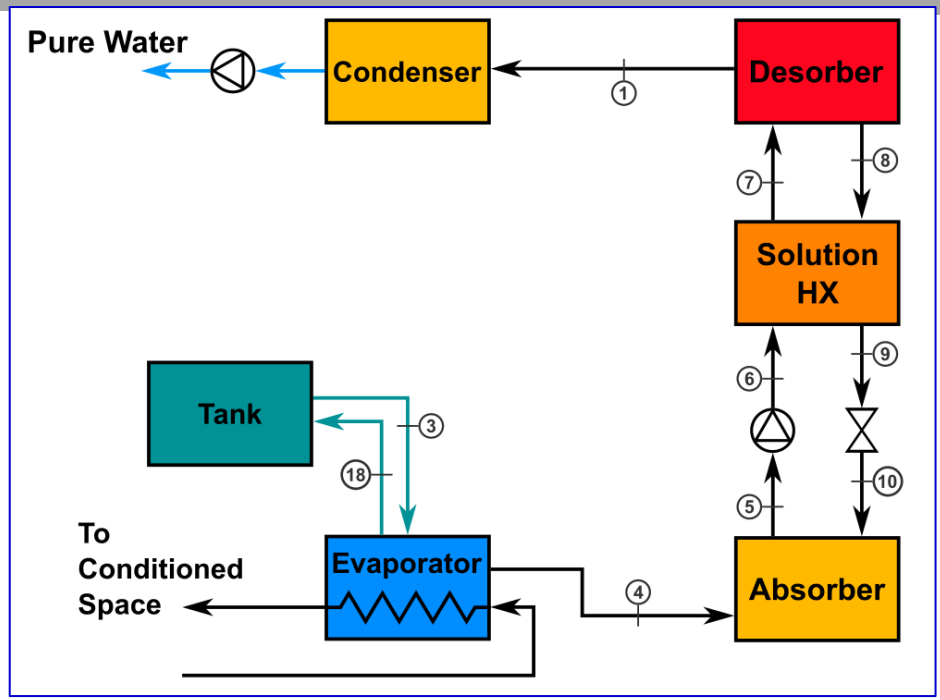
With Heat Recovery and Storage



- Waste heat recovery and storage can reduce **19% of primary energy consumption in buildings**
- **Compact, low-cost** TES systems will play a key role reducing energy and emissions

Simultaneous Space Conditioning and Water Purification

- Open-loop absorption heat pump
- Modified to provide water purification with minimal additional energy cost
  - Partial evaporation of feedwater
  - Pure water collected in condenser
  - Feedwater used for cooling



- Synthetic graywater used as feed solution
- Reduced conductivity from 106 µS/cm to 27 µS/cm
- Demonstrates simultaneous water purification and cooling

Sorption for Textile Drying

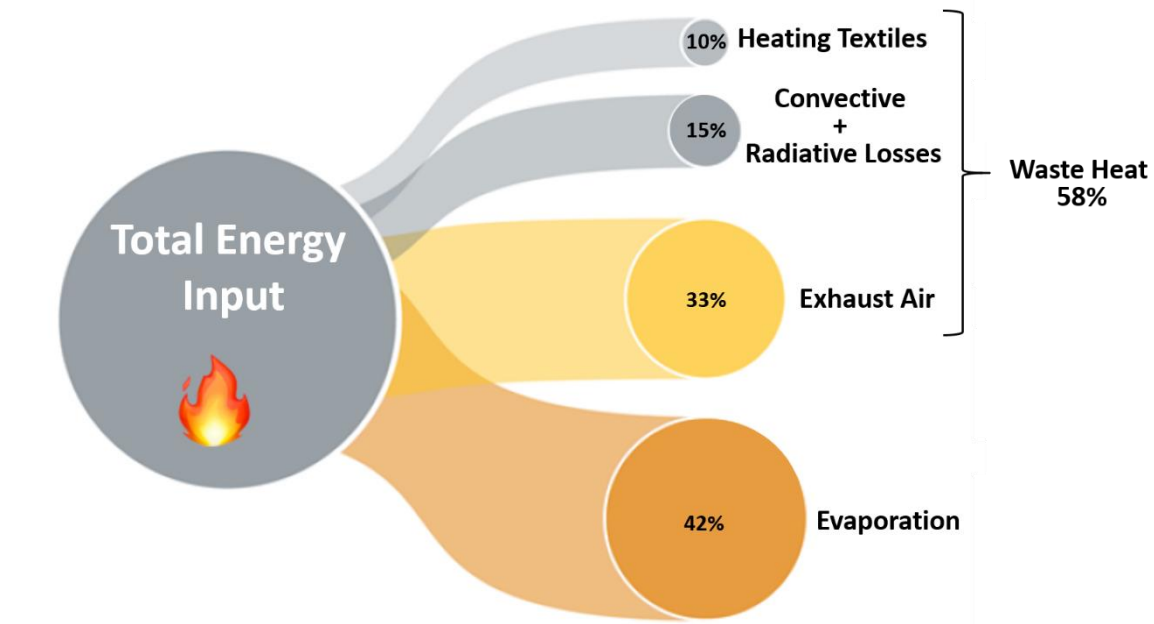
Motivation

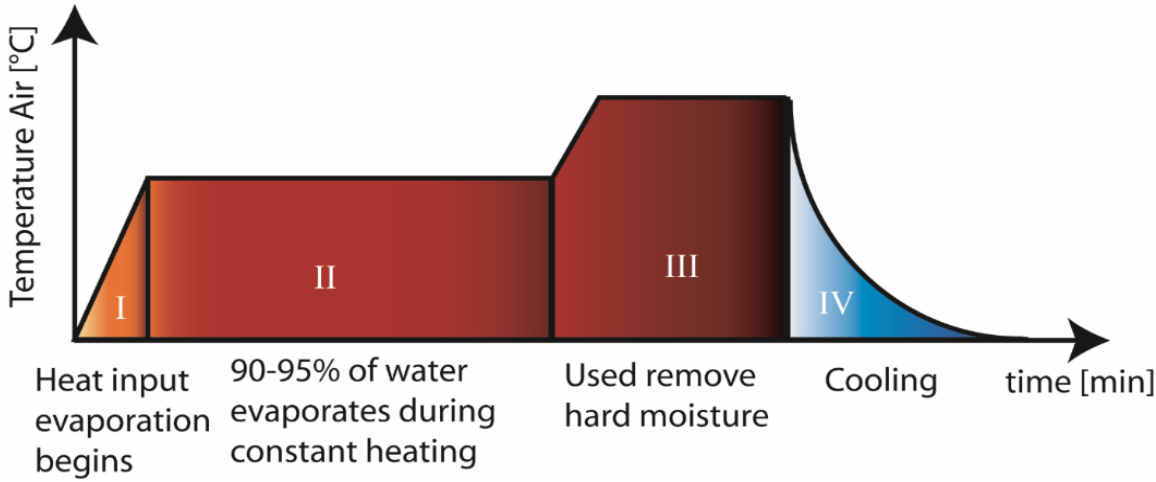
- Drying: energy intensive
- Tumble drying: **~ 2%** of US energy consumption

Typical energy flows

- **> 55%** of the energy input to the dryer wasted

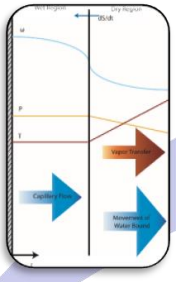
Commercial gas-fired tumble dryer innovations



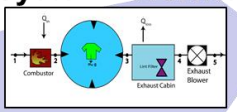


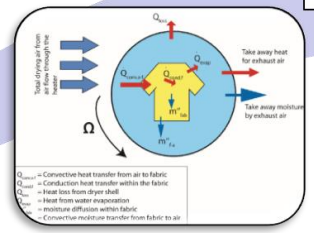
First Principles Modeling and Validation

Moisture transfer in textile

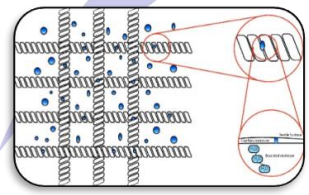


System-level models

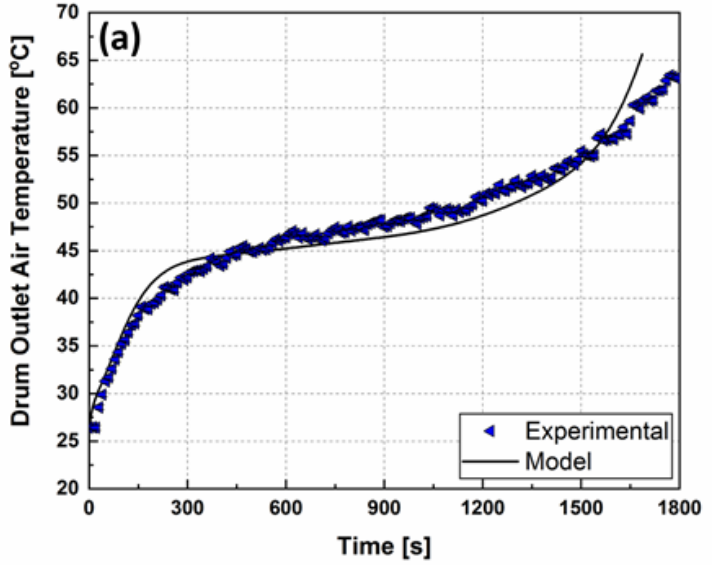


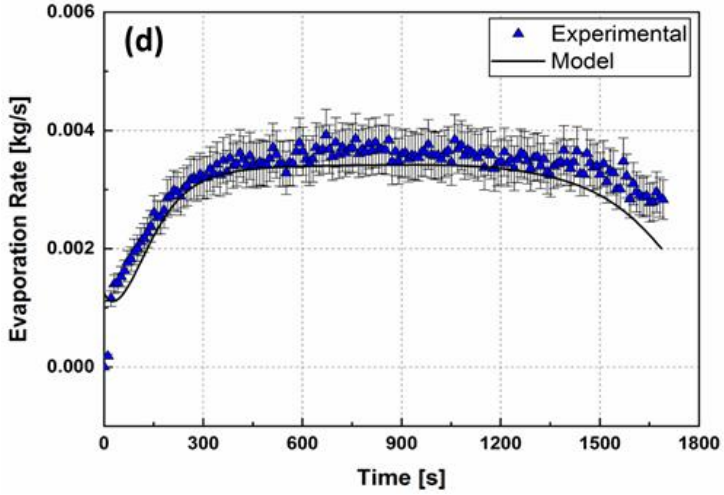


Detailed heat and mass transfer models

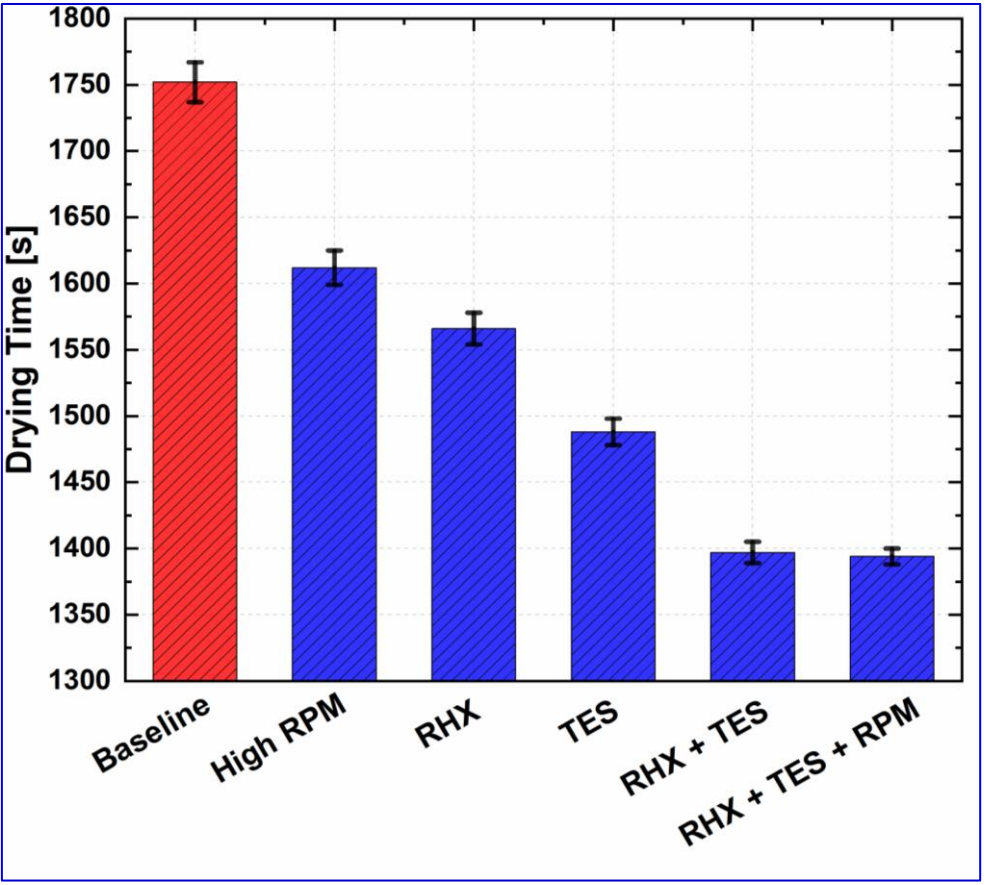


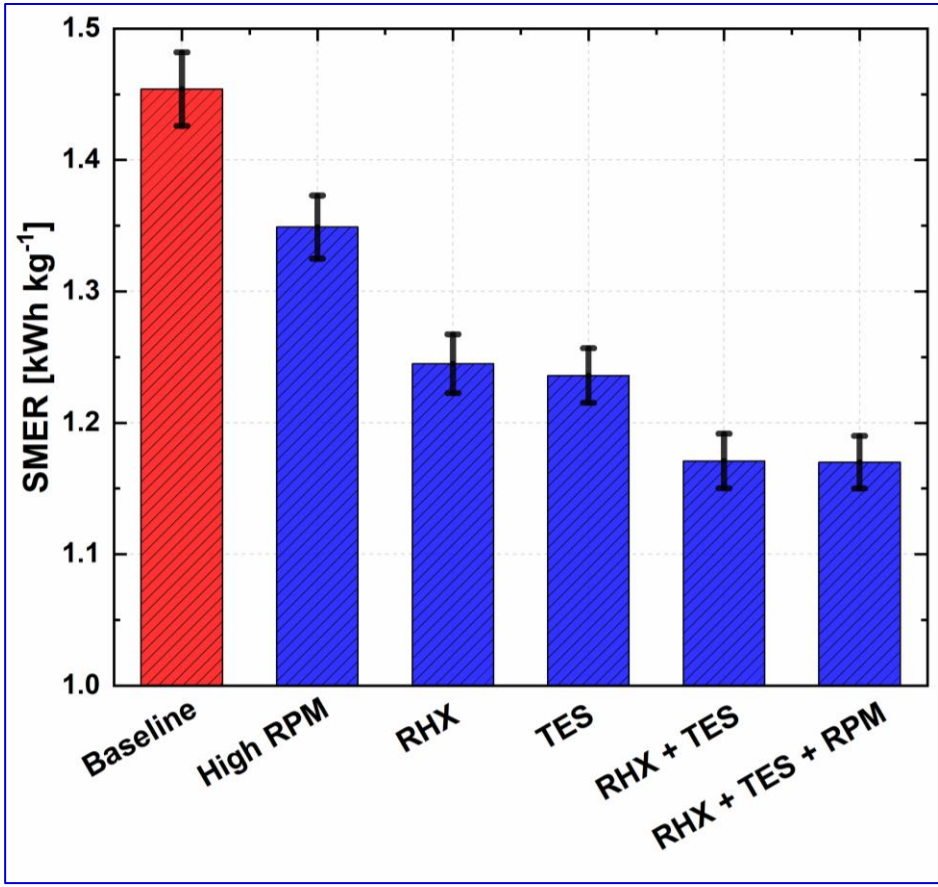
Pore-size level modeling





Simultaneous energy use and drying time reduction

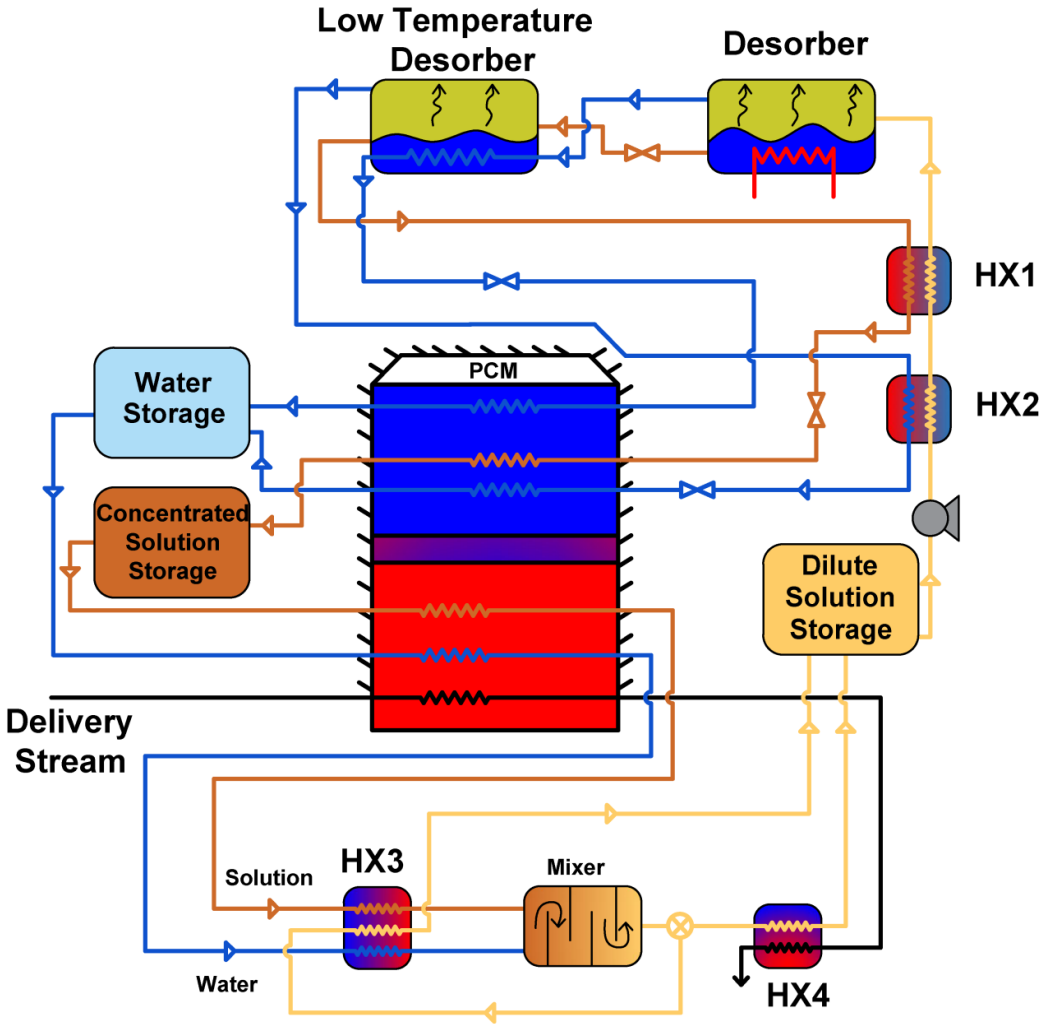




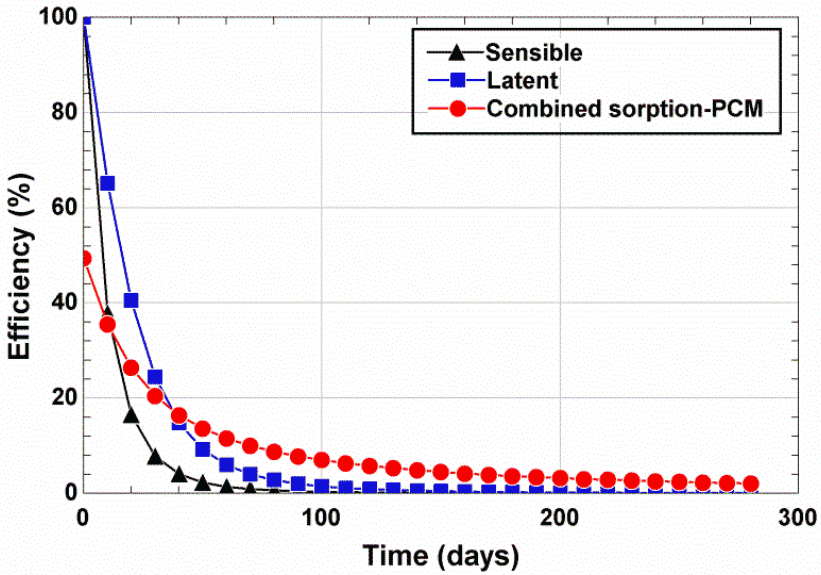
Parameter Optimization, Recirculation, Recuperation, Adsorption Thermal Storage, Heat Pumping

Combined PCM Sorption

Cycle configuration



Results (for 1 GJ)

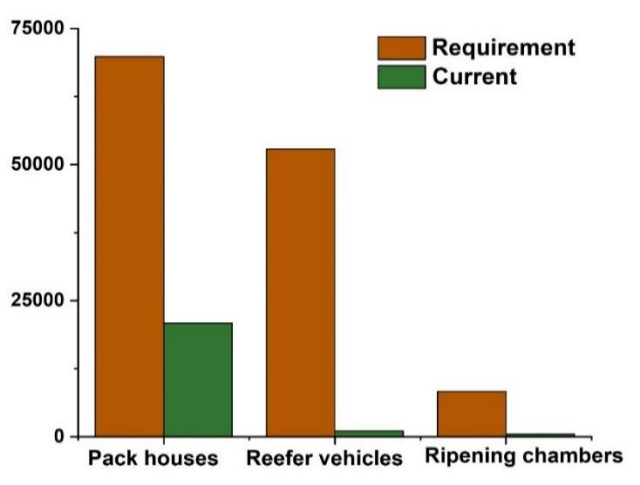


- For long periods of storage time, combined sorption-PCM cycle is the **most efficient**
- **Future work :** Working fluid with high enthalpy of dilution and low enthalpy of evaporation

Cold Chain in Developing Countries: Adsorption Chillers

Problem

- 360 million tons of horticulture produced annually
- Massive gaps in cold chain infrastructure



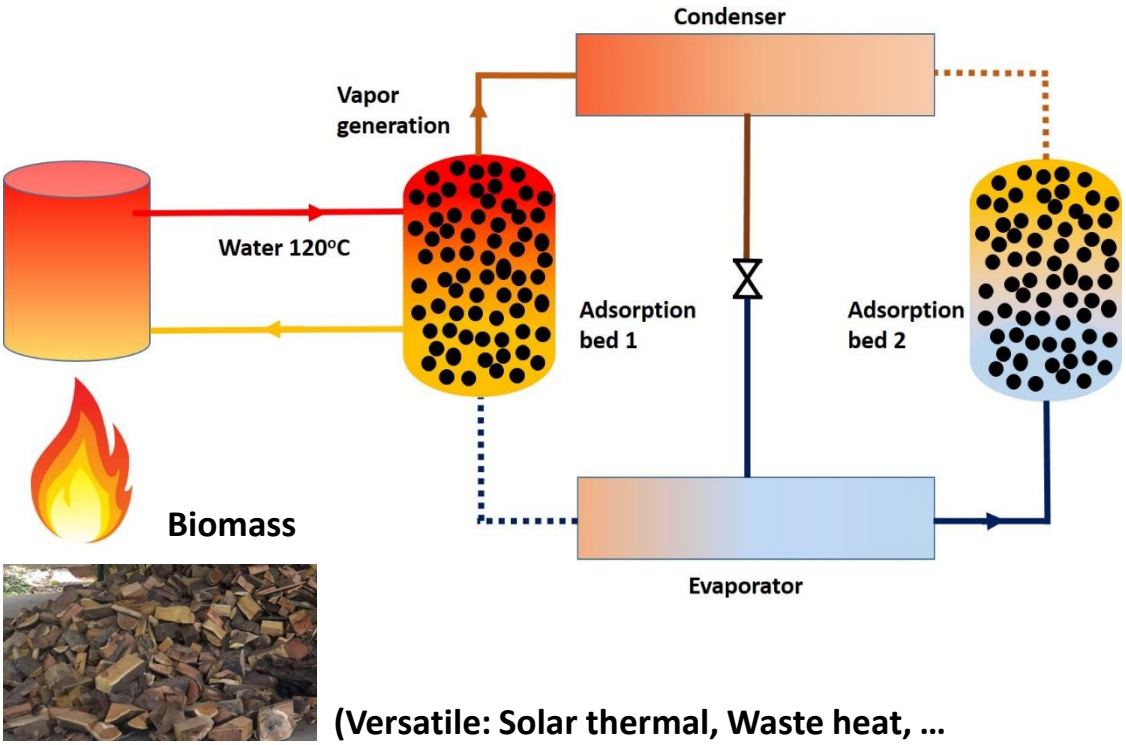
- Post-harvest losses ~**$13 billion** annually

- 15 tons food storage
- Biomass driven, Green refrigerant **(GWP = 0)**
  - Ammonia/salt composite working pair
- Automatic operation, humidity & temperature control
- **Off-grid, compressor-free, affordable, reliable cold storage: food security**

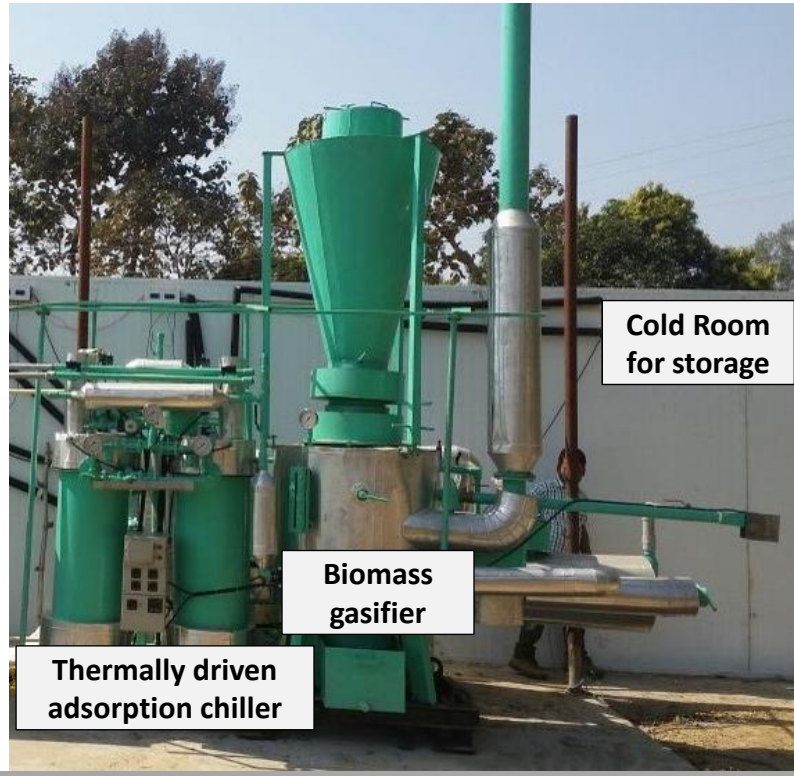
Cold Chain in Developing Countries: Adsorption Chillers

Operating Process

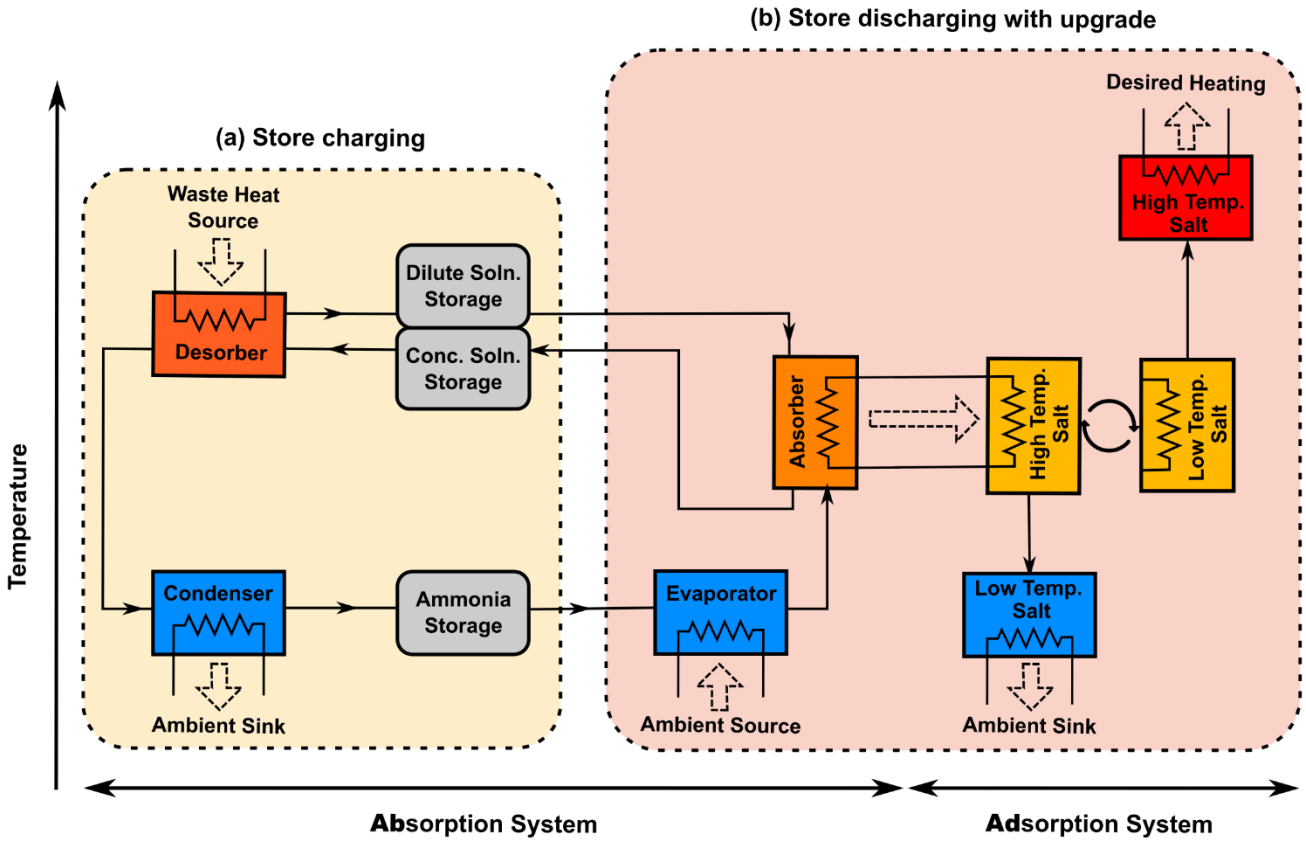
Clean combustion of biomass → Producer gas heats water to 120° C → Hot water drives GreenCHILL (NH_3 + Salt Composite) → GreenCHILL cools stored produce



(Versatile: Solar thermal, Waste heat, …

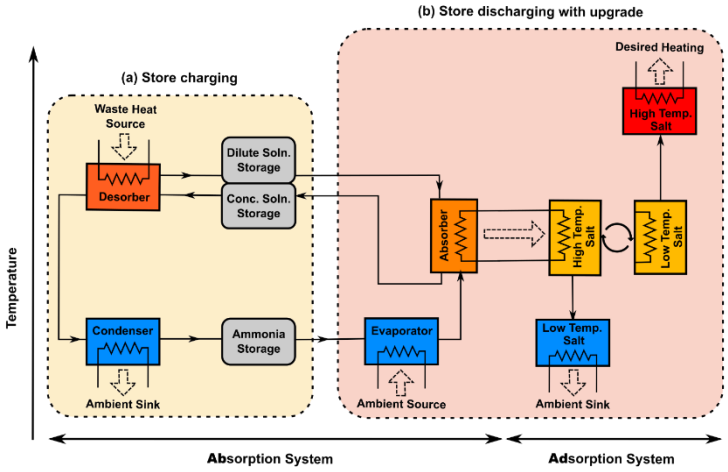


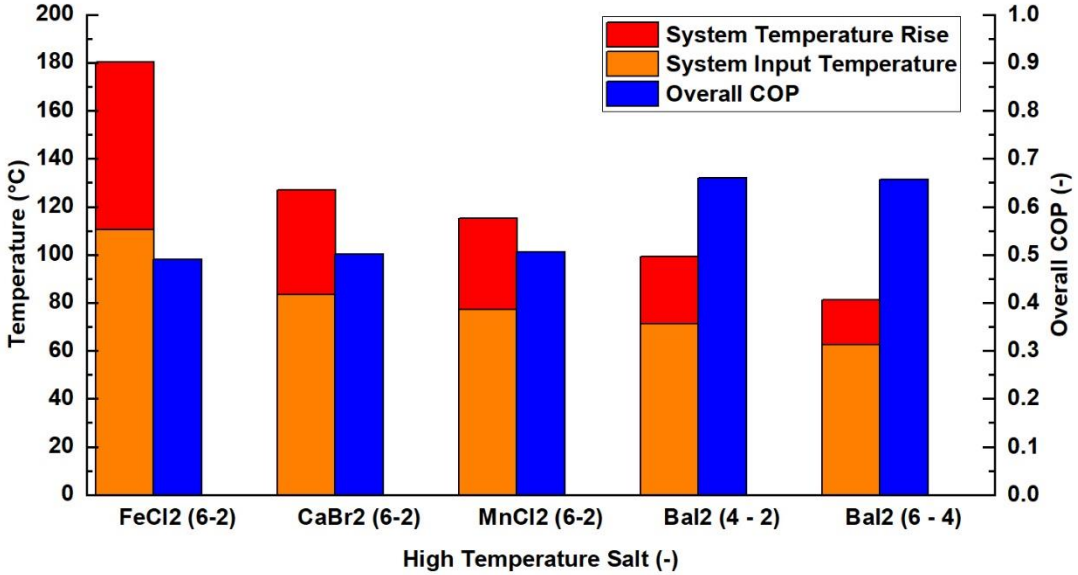
Combined Absorption and Adsorption



- Liquid-gas absorption system for **thermal energy storage** of intermittent heat sources
- Solid-gas adsorption system for **thermal energy upgrade**

Combined Absorption and Adsorption





Motivation

- Solid-gas sorption has a wider range of working pairs and **temperature ranges**
- Liquid-gas sorption requires **less HEX surface area**