Advanced Dry-cooling with Integrated Enhanced Air-Cooled Condenser and Daytime Load-shifting Thermal Energy Storage for Improved Power-Plant Efficiency

DE-FOA-0002001

Raj M. Manglik

University of Cincinnati

U.S. Department of Energy

National Energy Technology Laboratory

Resource Sustainability Project Review Meeting

April 2-4, 2024

Project Overview

Funding (DOE and Cost Share): Total: $1,857,330

Federal - $1,485,086 and Cost Share - $372,244

Overall Project Performance Period:

February 01, 2021 – July 31, 2024

University of Cincinnati

EPRI Electric Power Research Institute

evapco

Maulbetsch Consulting

Southern Company

Raj M. Manglik (Principal Investigator)
Milind A. Jog (Co-PI)

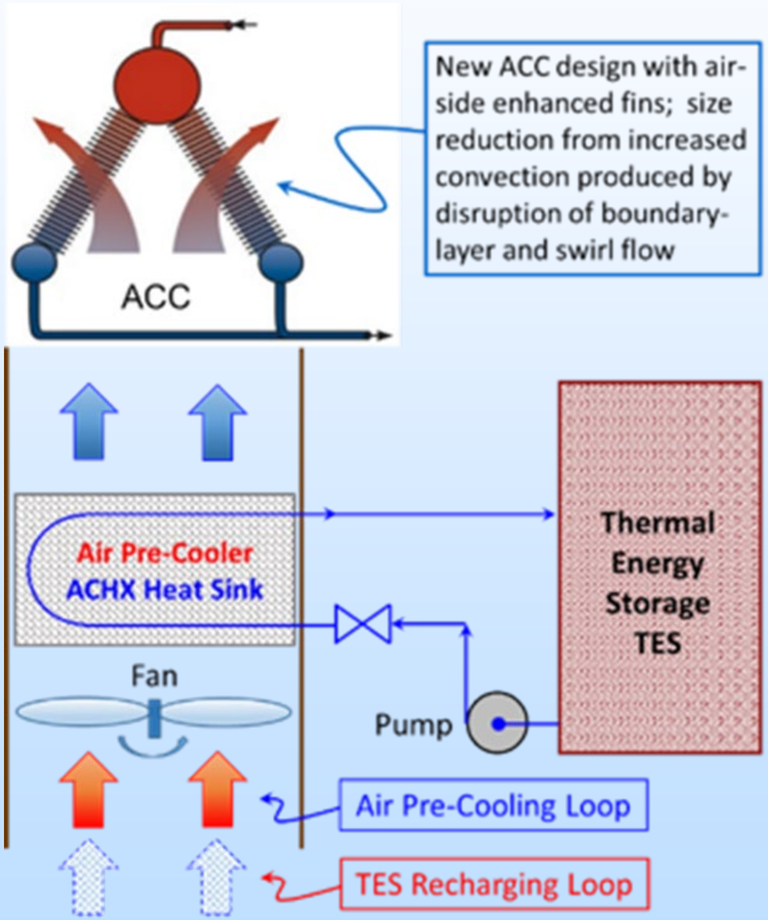
Andrew Howell (Industry Partner)

Jean-Pierre Libert (Industry Consultant)

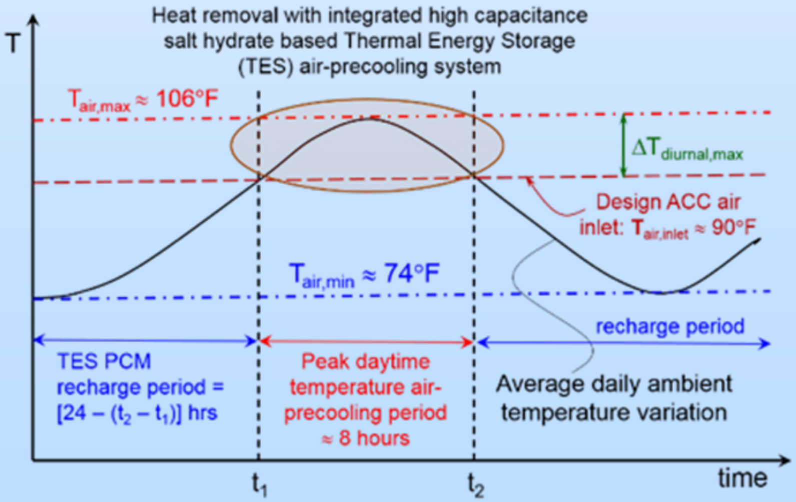
John S. Maulbetsch (Consultant)

Project Participants

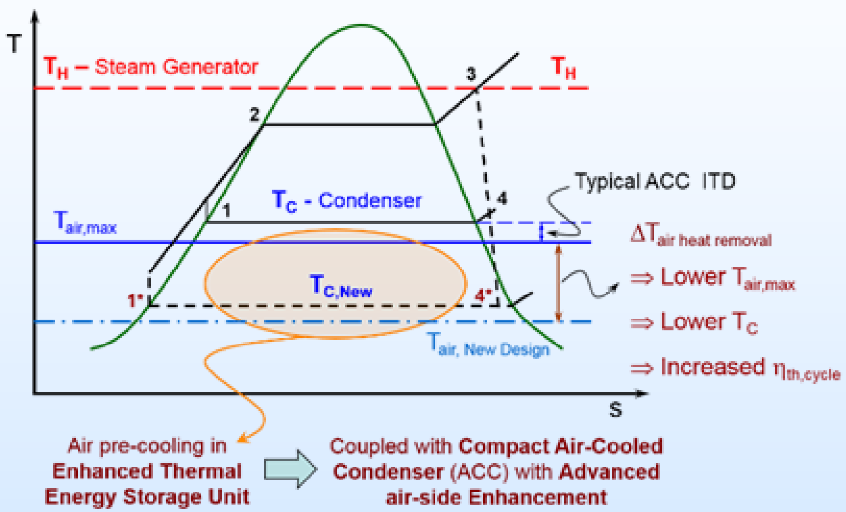
Project Overview (Overall Objectives)



Develop a novel and transformative dry-cooling system that integrates daytime peak air-load shifting thermal energy storage (TES), with an enhanced, highly compact and optimized air-cooled condenser (ACC), to significantly increase power plant efficiency. The TES system, a phase-change-material (PCM) based heat exchanger, is integrated in the inlet air-stream of the ACC via an air pre-cooler (ACHX).

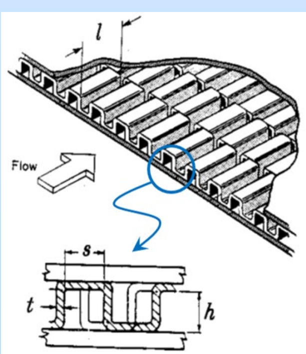


Technology Background

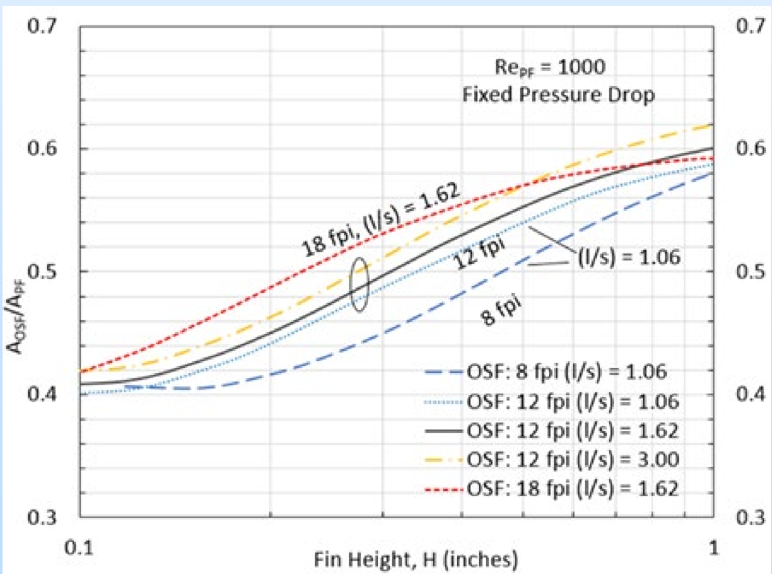


Integrated PCM-TES in air-flow path of air-cooled steam condenser (ACC)

- Reduces T_C operating constraint, and increases Rankine cycle output and efficiency.
- Reduced $T_{air,\ Design}$ increases ACC's ΔT_{lm} thereby increasing both q and effectiveness (reliable steady operation) of ACC.

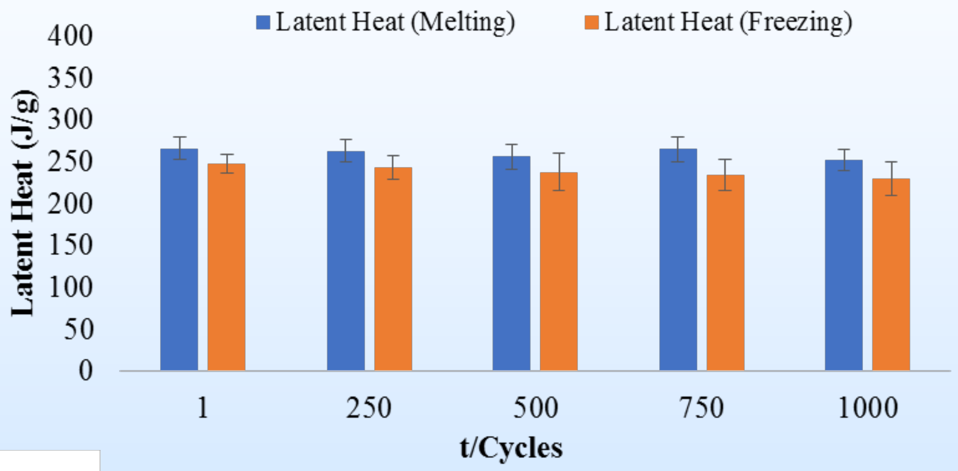


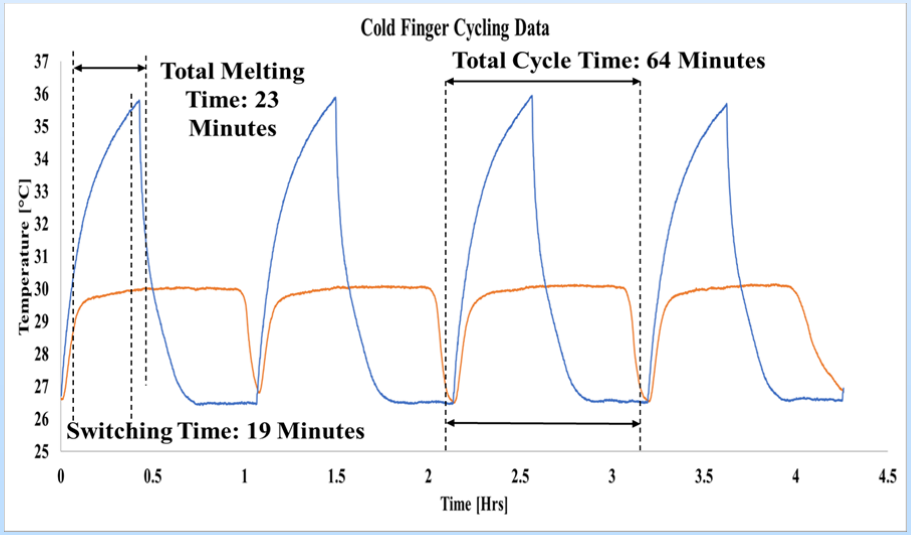
The new Air-Cooled Condenser design with enhanced-fin cores for improvement of air-side heat transfer can yield significant reduction in the surface-area requirement and hence the size of the ACC



Technology Background

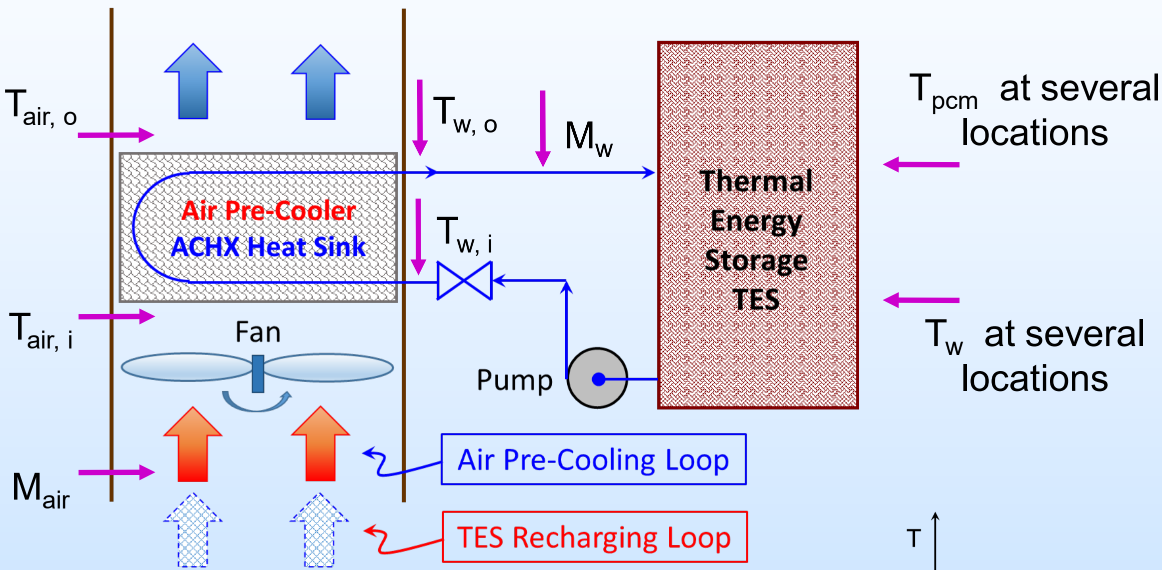
Selection of PCM ($LiNO_3 \cdot 3H_2O$) and Stable Thermal-Cycling Performance – thermal capacity of $LiNO_3 \cdot 3H_2O$ over 1000 heating (melting) and cooling (re-crystalization) cycles





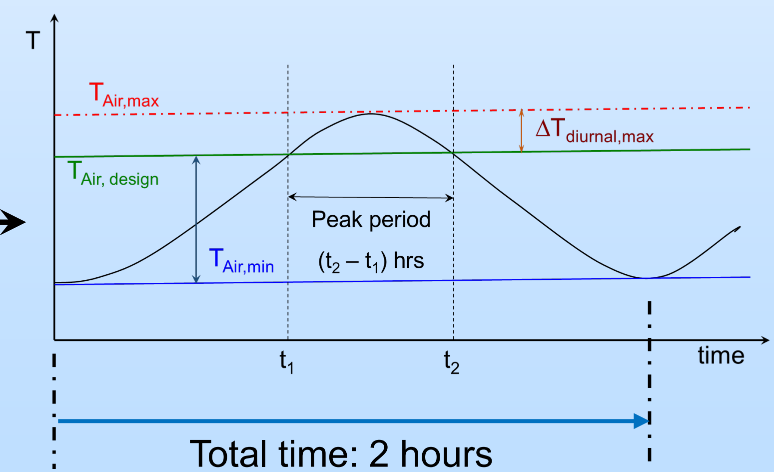
Self-seeded nucleation (or "cold-fingering") and phase-transition stability of $LiNO_3 \cdot 3H_2O$ during thermal cycling

Technical Approach/Project Scope

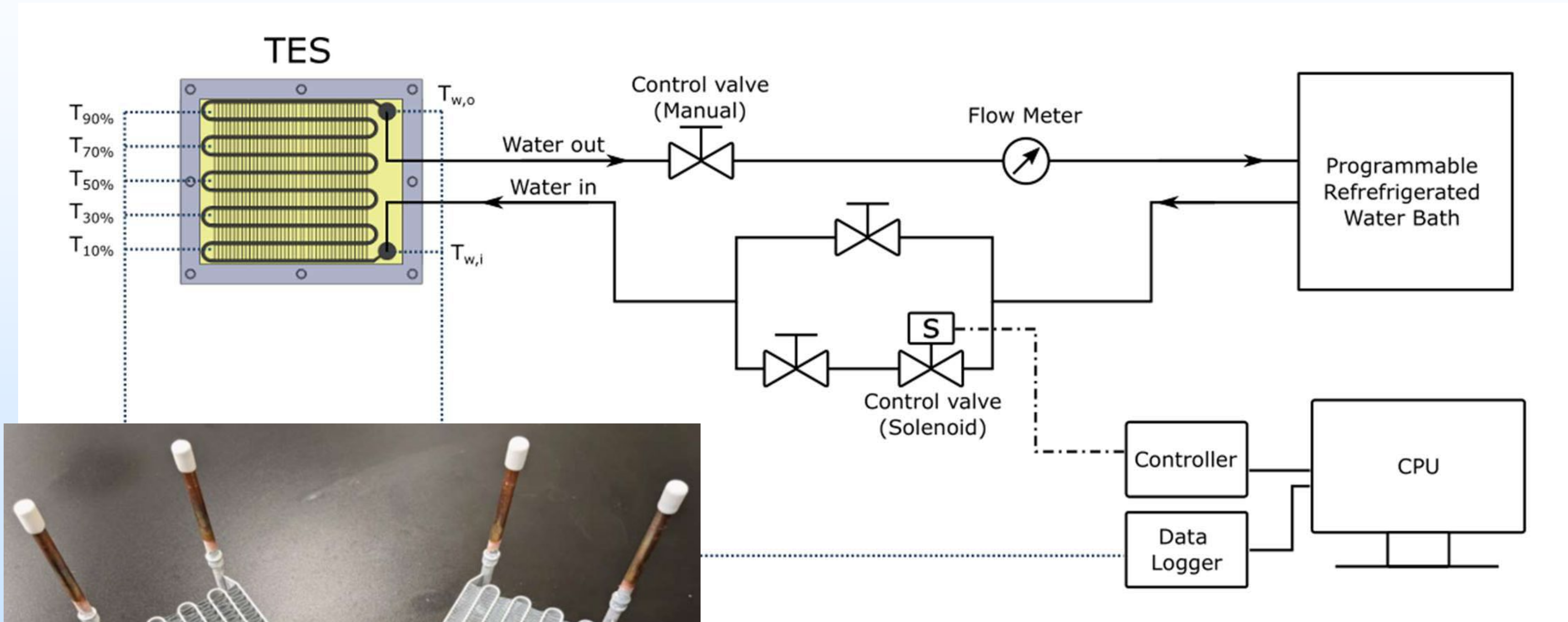


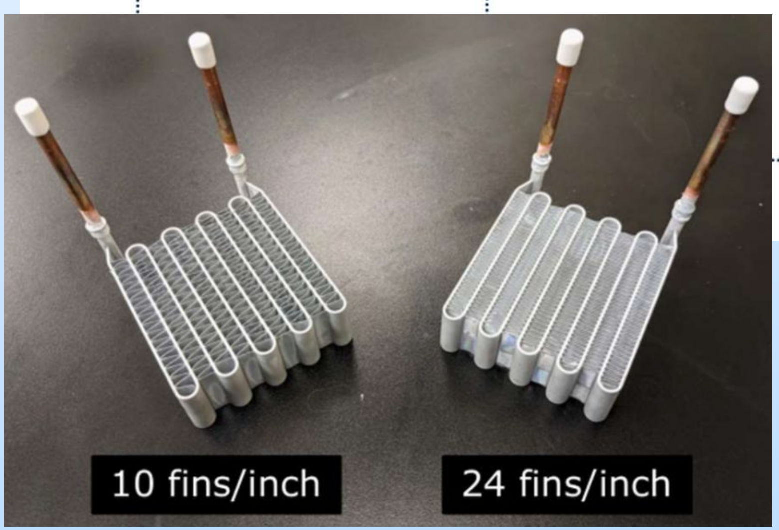
- TES scale-up (10× scale-up; 100 kJ → 1.0 MJ → 10 MJ) and performance testing
  - Performance with diurnal air-side temperature variations (system-level prototype performance)

Inlet air – models diurnal temperature variation (Max 106°F, Min 74°F over a two-hour cycle)
Heating: 1 MJ over 40 min period; Cooling: 1 MJ over 80 min period; Air Pre-Cooler tube-fin heat exchanger size: ~ 420 W (or ~ 450 W, or can be overdesigned for testing purposes)



Progress and Current Status of Project



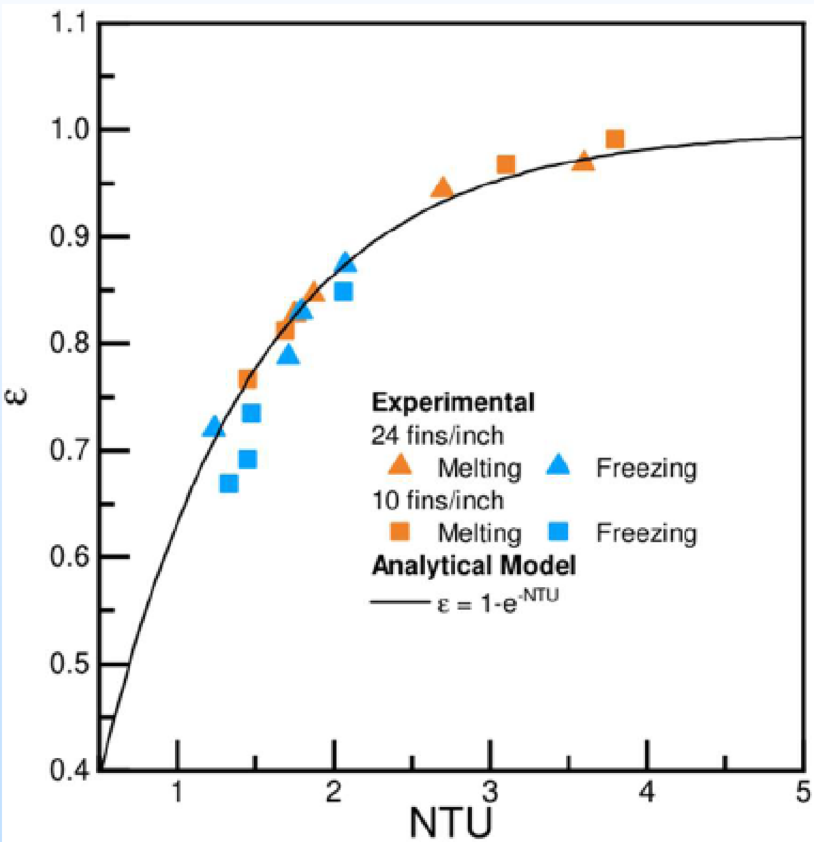


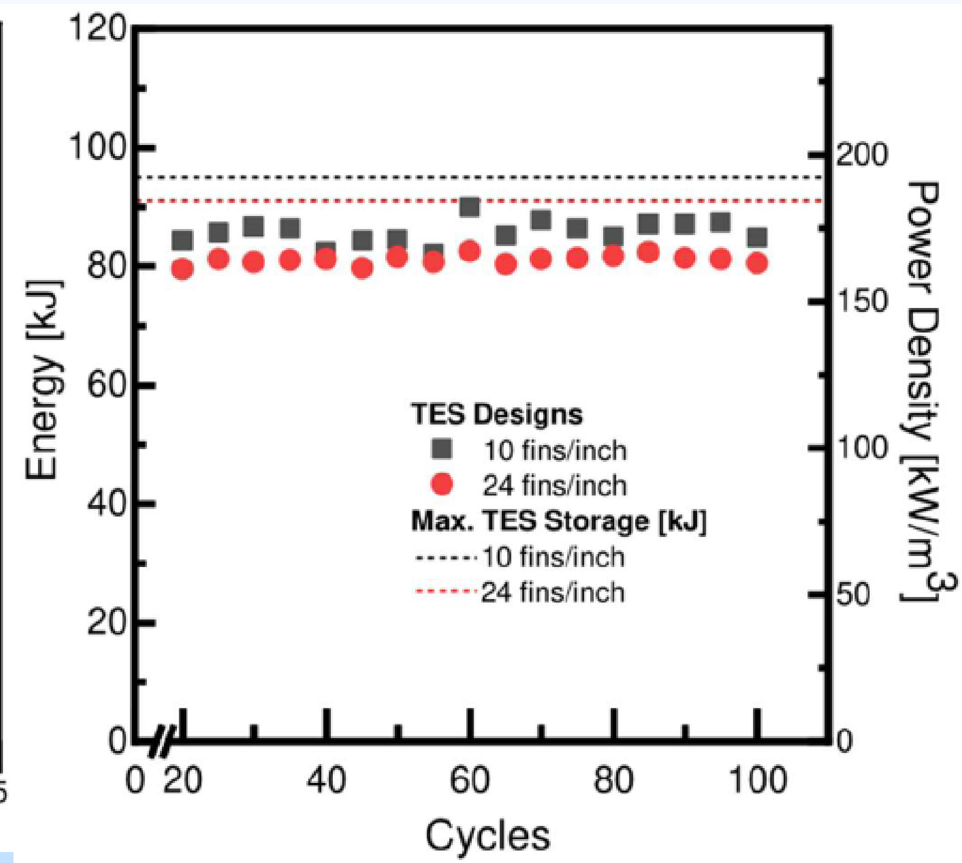
Micro-Channel Finned Heat Exchanger

Experimental set up and testing of 100 kJ Lab-scale system

Progress and Current Status of Project

e-NTU characteristics for scale-up of HX and energy / power density of TES under thermal cycling

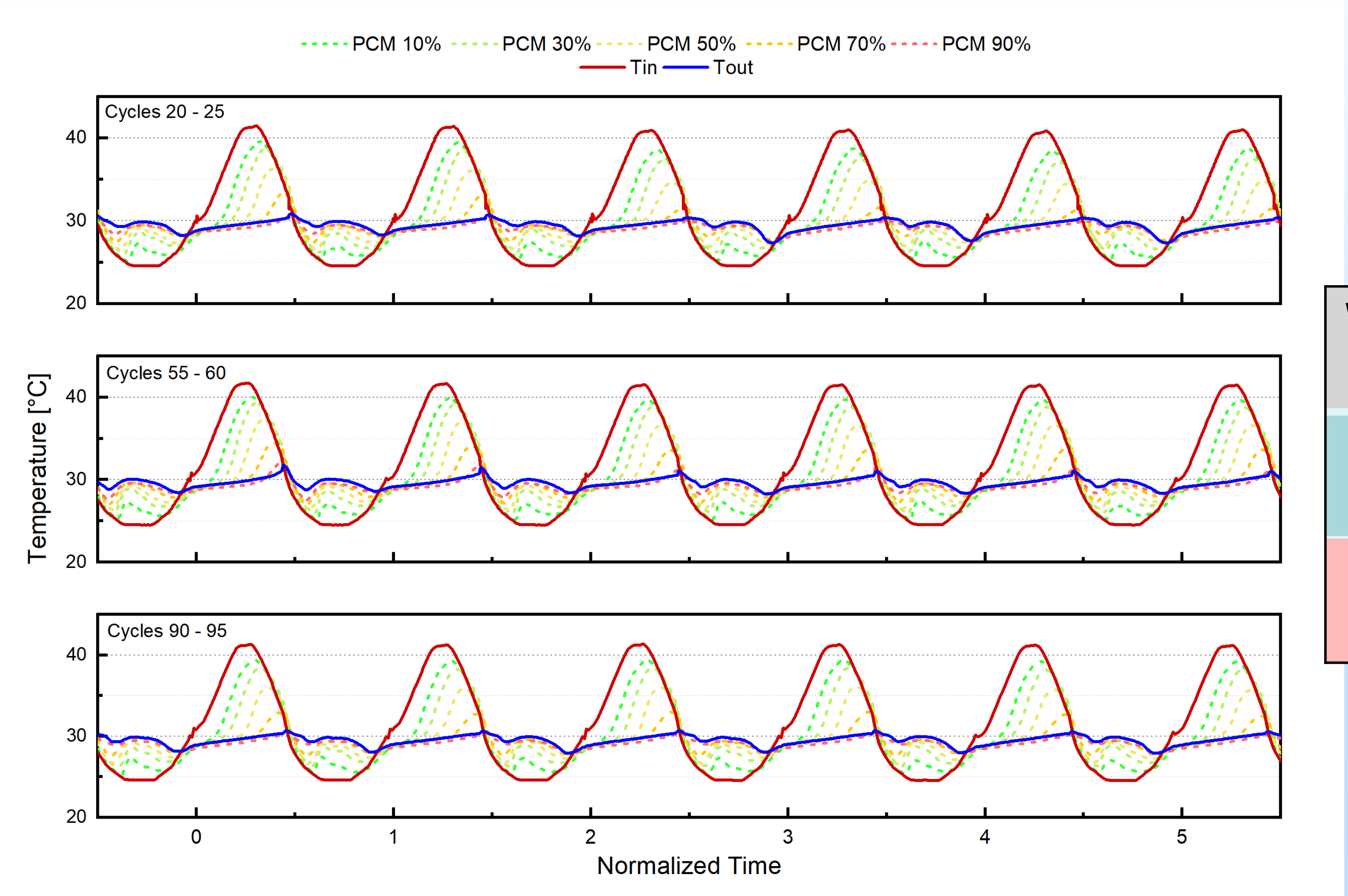




$$e = 1 - e^{-NTU}$$

Progress and Current Status of Project

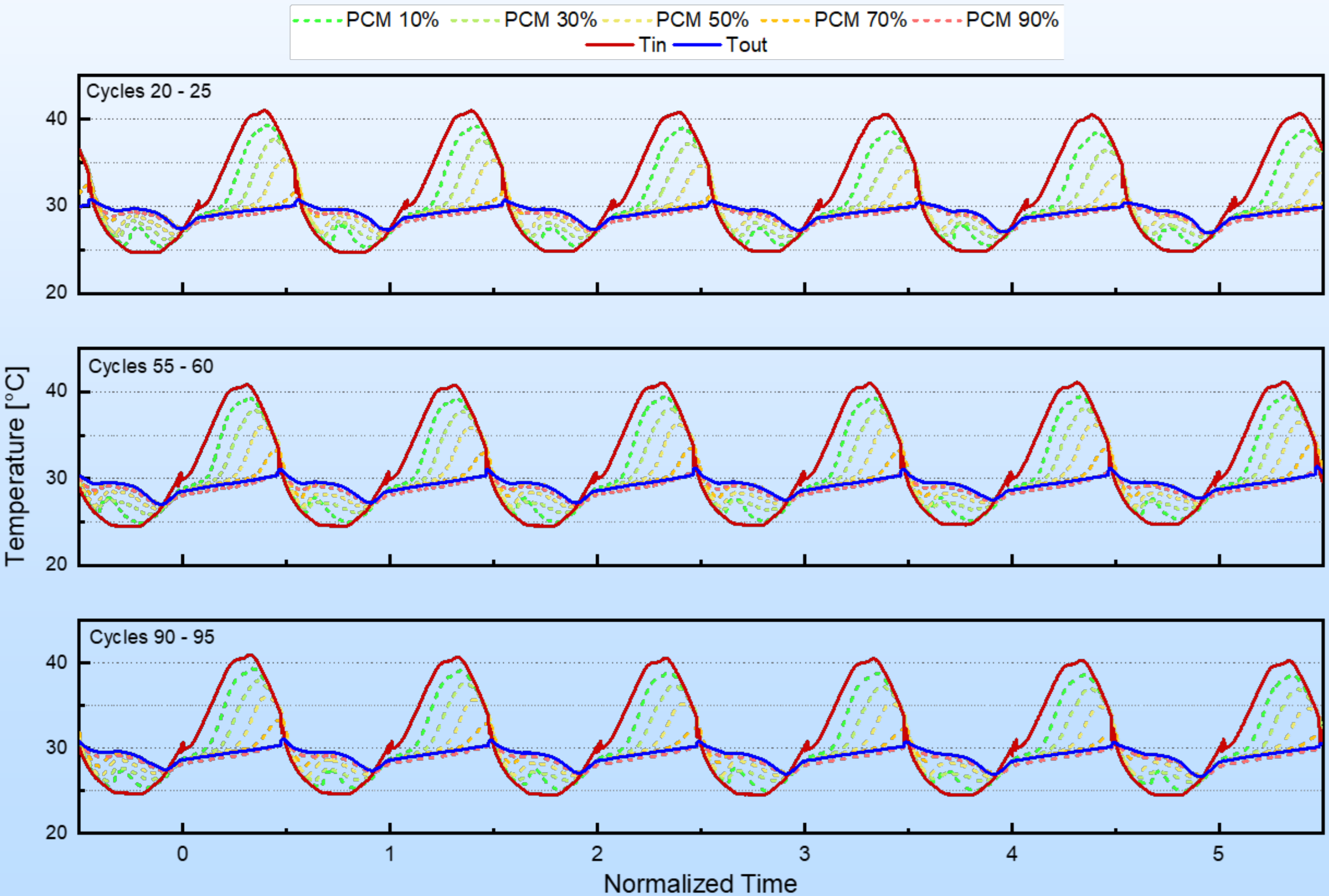
TES with 24 FPI – Performance testing results for 100 heating/ cooling cycles with self-seeding of PCM (Lithium Nitrate Trihydrate)



Water Inlet Temperature Flow Rate Time
25 - 30°C 155 ml/min ~ 30 min
30 - 41°C 56 ml/min ~ 30 min

Progress and Current Status of Project

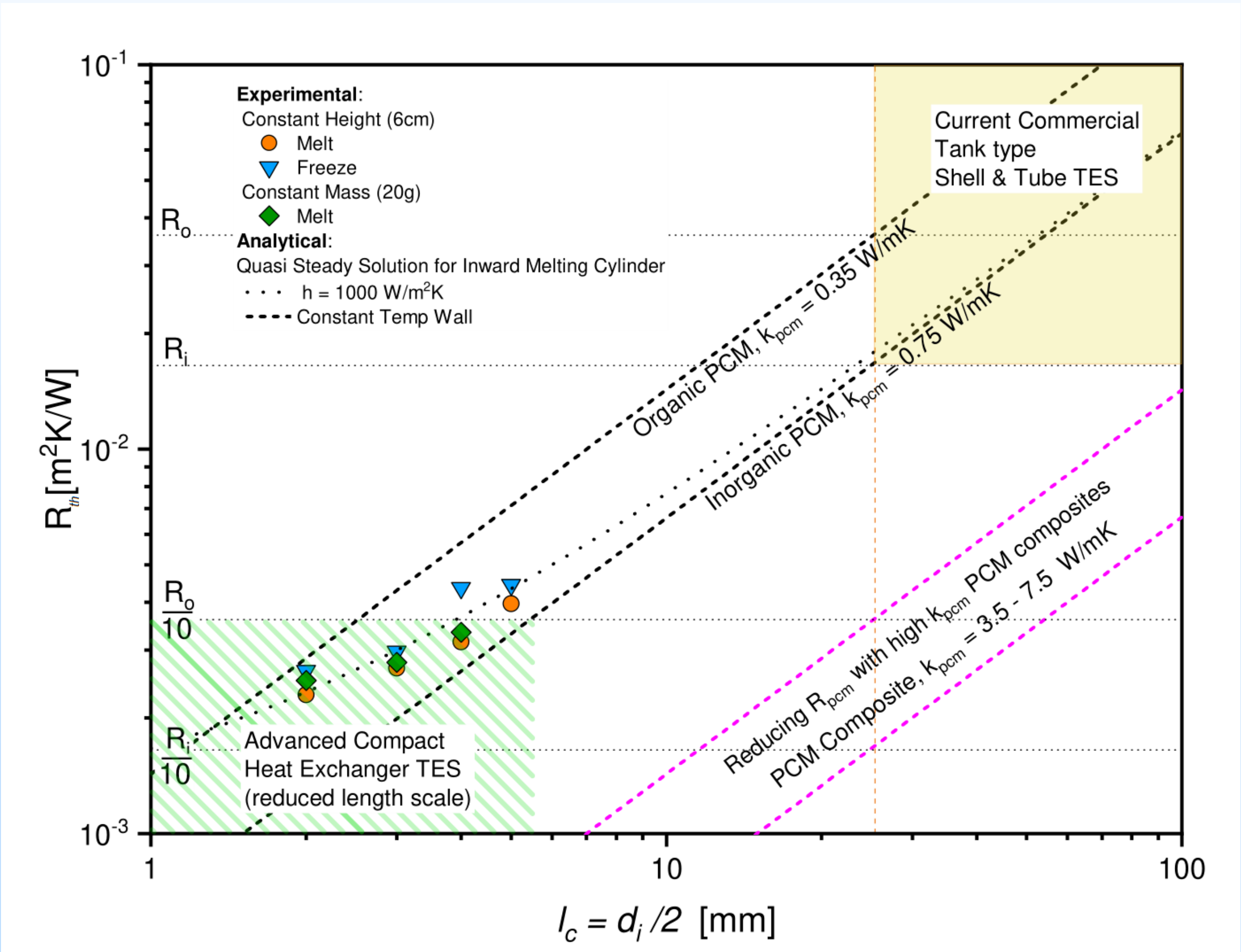
TES with 10 FPI – Performance testing results for 100 heating/ cooling cycles with self-seeding of PCM (Lithium Nitrate Trihydrate)

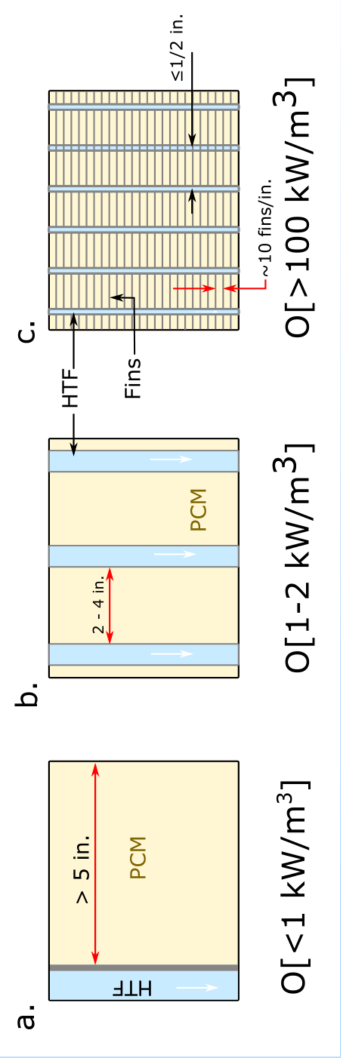


Water Inlet Temperature Flow Rate Time
25 - 30°C 170 ml/min ~ 30 min
30 - 41°C 65 ml/min ~ 30 min

Progress and Current Status of Project

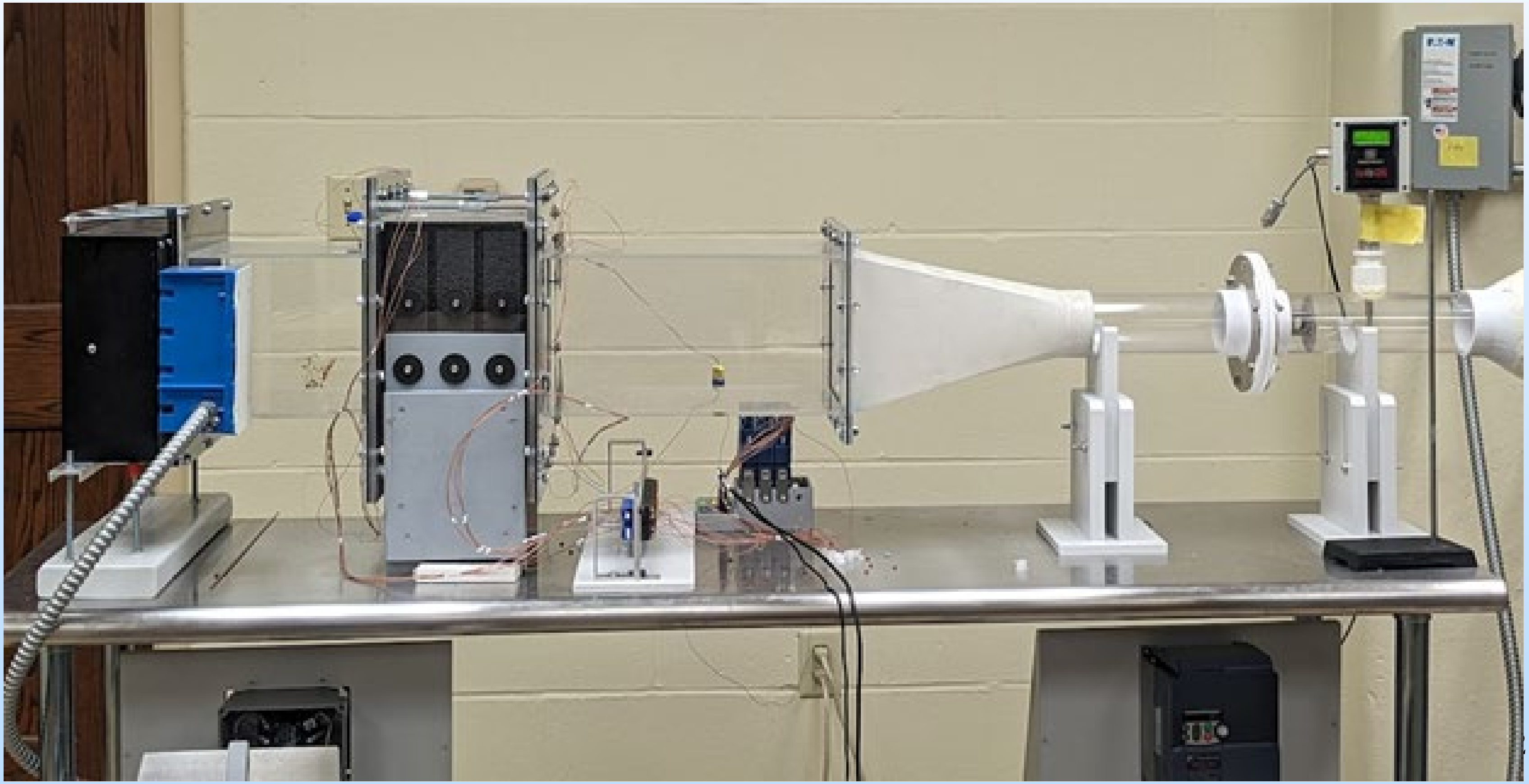
Compact HX PCM Encasement Length-Scale and Scale Up –
Reduced thermal resistance and enhanced TES performance





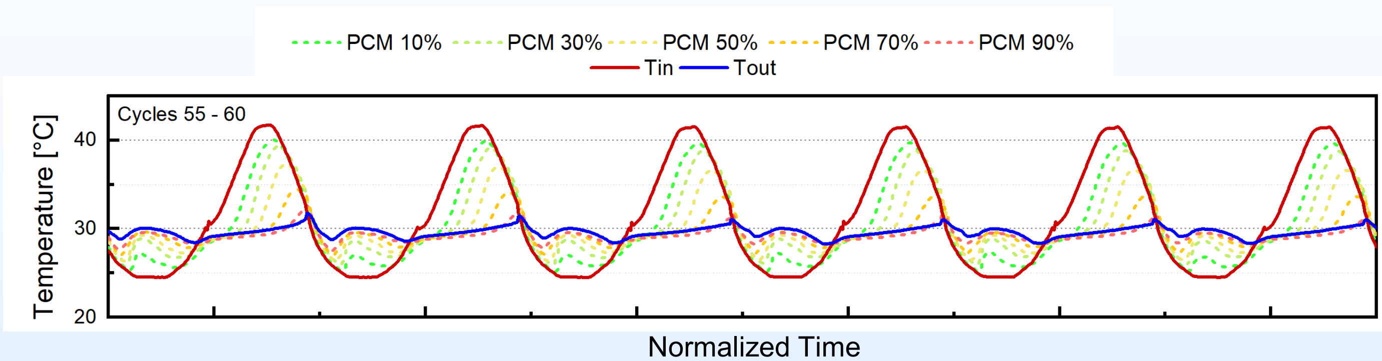
Progress and Current Status of Project

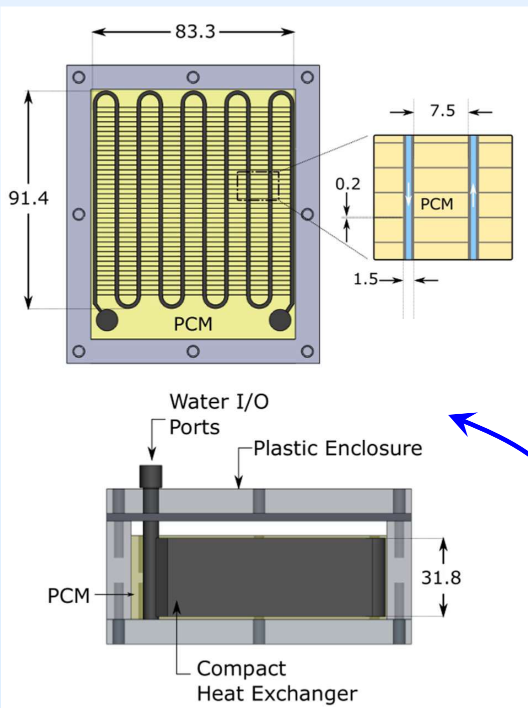
Coupled TES and air pre-cooler heat exchanger performance test system (1.0 MJ) with simulated diurnal temperature variation of inlet air

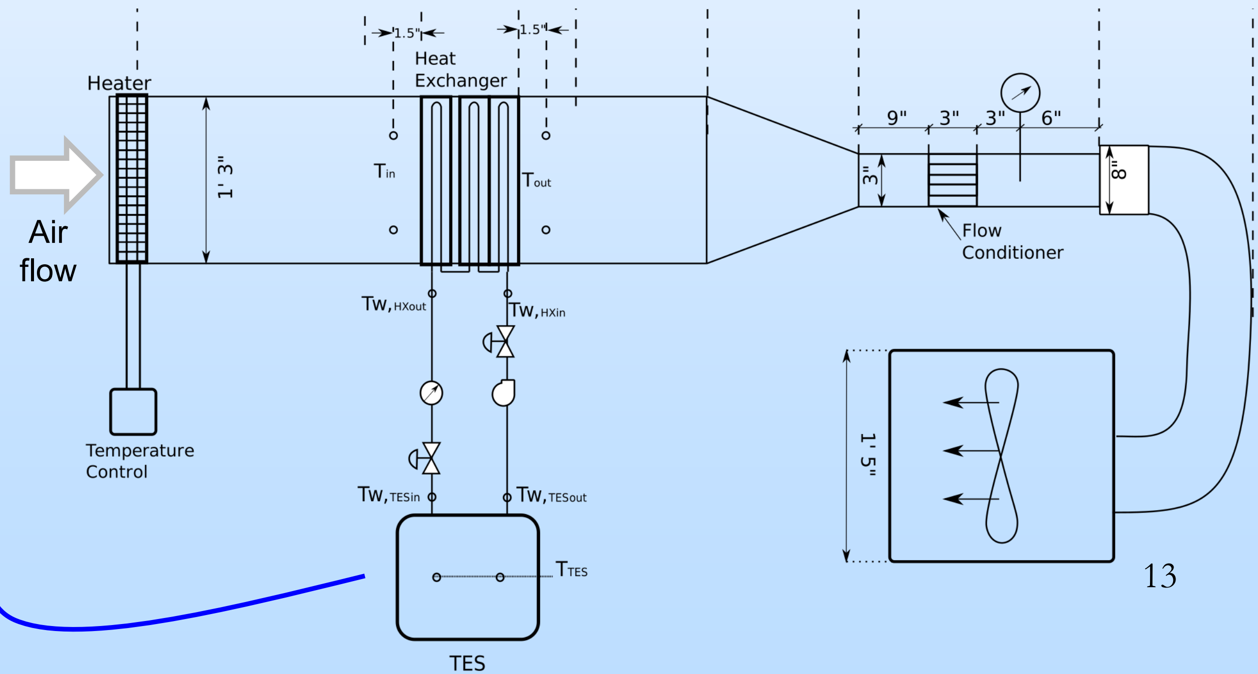


Progress and Current Status of Project

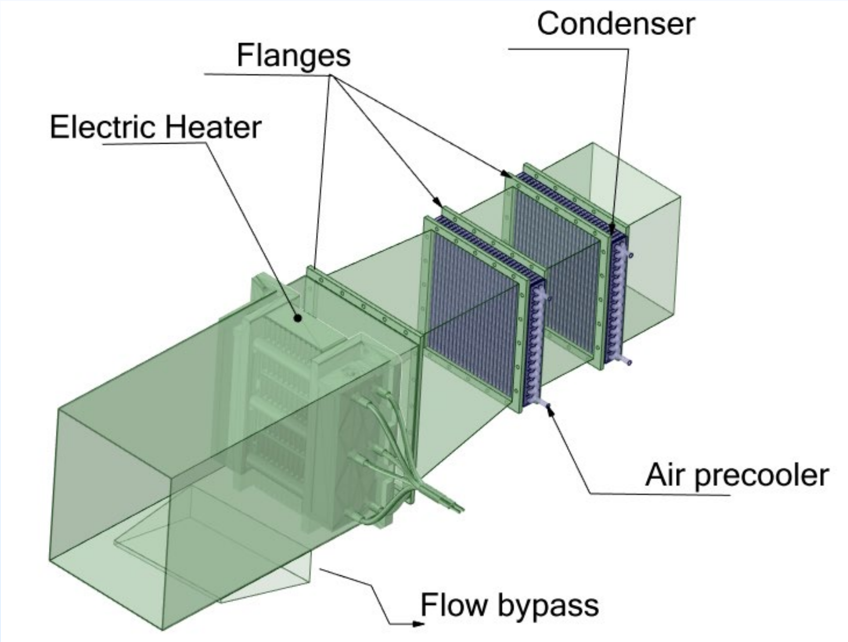
Performance (steady temperature control of air inlet to ACC) of a scaled-up lab-scale **1.0 MJ** TES over multiple heating/ cooling cycles







Progress and Current Status of Project



System Design for Scaled-up (10 MJ unit) Pilot-Scale Testing at EPRI-Georgia Southern WCC

Plans for future testing/development/ commercialization

- Complete pilot-plant testing of the 10 MJ system at WRCC, Southern Company, Smyrna, GA, over sustained heating-cooling cycles so as to establish the set-up as a demonstrator unit for potential commercialization
- Pitch the pilot-scale results and project success to air-cooled (and water-cooled) condenser manufacturers
  - Evapco; SPX; Holtec; SPG
- Pitch the pilot-scale results and project success to utilities and power-plant companies (EPRI partners, and more)
- Translate to large-scale commercial HVAC applications and pitch to the associated air-cooled condenser manufacturers

Outreach and Workforce Development Efforts or Achievements

- Workforce Development –
  - Trained and graduate two PhD and one MS students, including one woman PhD engineer.
  - Current training of two PhD students and one female MS student.

Summary

- Successfully completed stability re-evaluation of PCM ($LiNO_3 \cdot 3H_2O$) with results for 1000 heating/cooling cycle
  - Results establish efficacy of self-seeding nucleation of PCM (cold finger operation), thereby obviating need for nucleating agent additives
- Successfully tested 100 kJ capacity design of TES (10 fpi and 24 fpi micro-channel heat exchanger) under cyclical heating and cooling conditions for 100 continuous cycles
  - Stable phase-transition and storage behavior of TES design
- Successfully tested 1.0 MJ capacity system (TES coupled with air pre-cooler heat exchanger) to establish stable predicted performance.
- Construction of scaled-up pilot-plant system (10 MJ) nearly complete at the WRCC facility of Southern Company, Smyrna, GA. Testing expected to begin in May 2024

Appendix

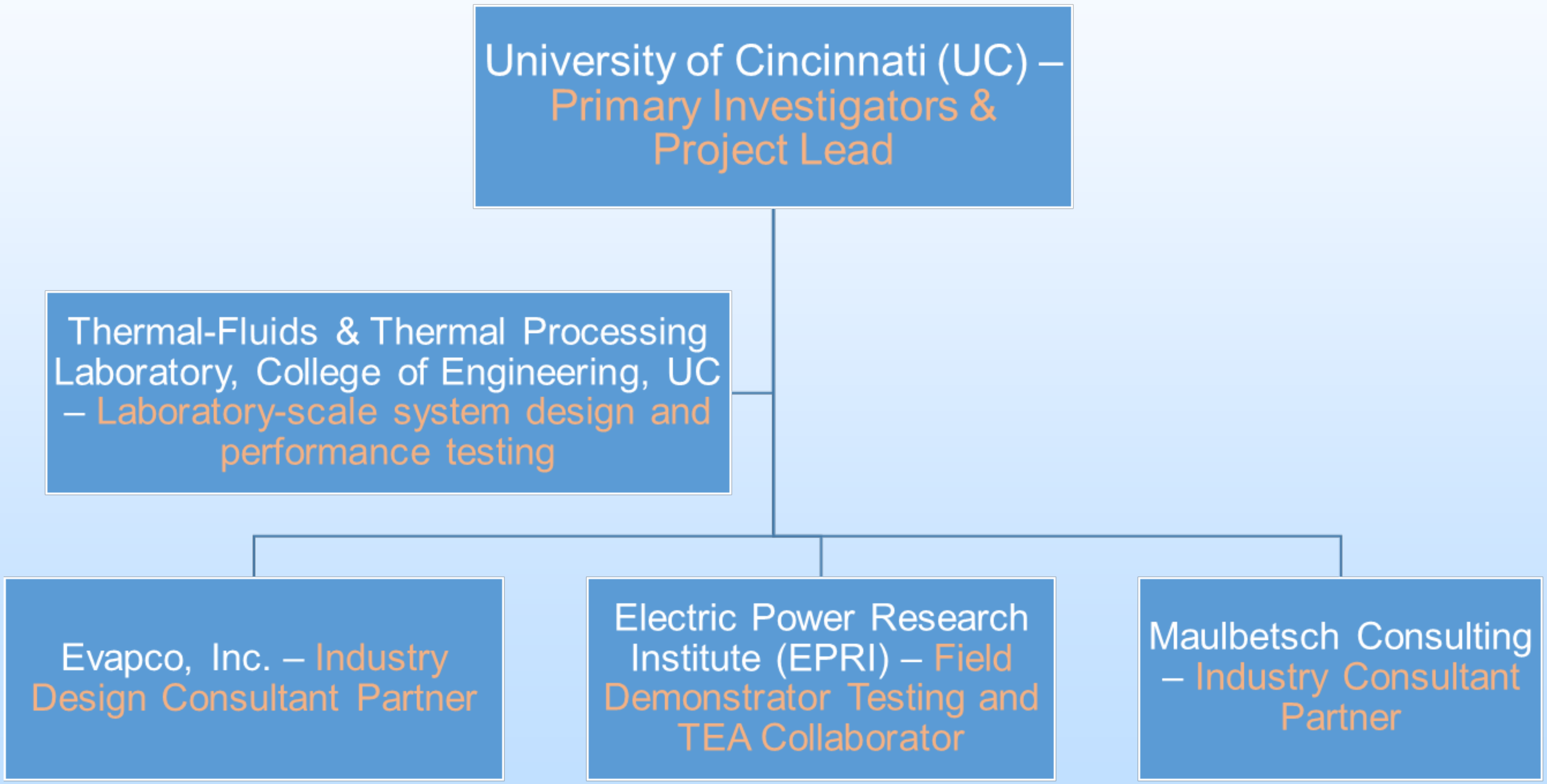
– These slides will not be discussed during the presentation but are mandatory.

Organization Chart

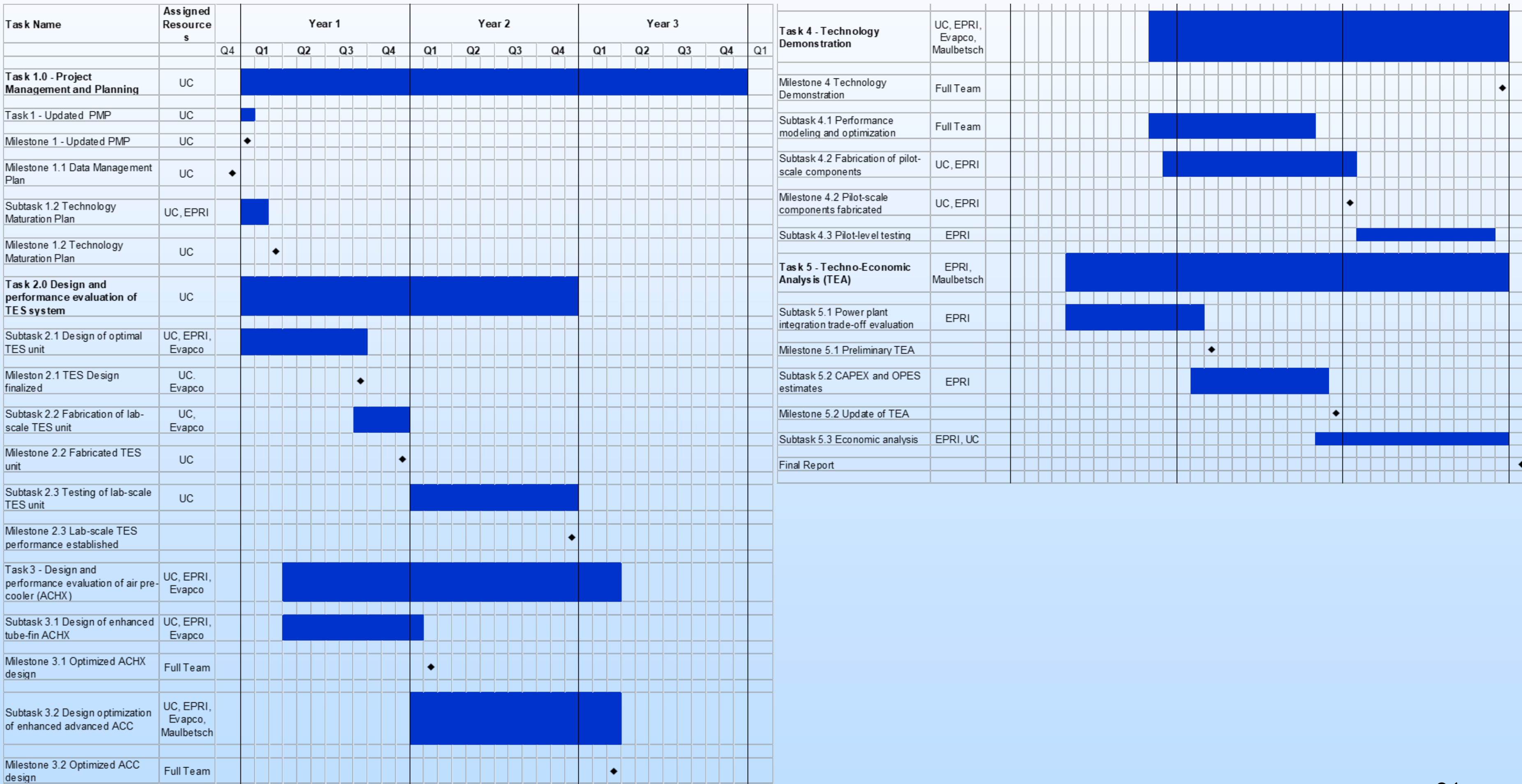
- Describe project team, organization, and participants.
  - Link organizations, if more than one, to general project efforts (i.e., materials development, design, systems analysis, pilot unit operation, management, risk/cost analysis, etc.).

- Please limit company specific information to that relevant to achieving project goals and objectives.

Organization Chart



Gantt Chart



Task Name
Assigned Resources
Year 1
Year 2
Year 3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Task 1.0 - Project Management and Planning
UC
Task 1 - Updated PMP
UC
Milestone 1 - Updated PMP
UC
Milestone 1.1 Data Management Plan
UC
Subtask 1.2 Technology Maturation Plan
UC, EPRI
Milestone 1.2 Technology Maturation Plan
UC
Task 2.0 Design and performance evaluation of TES system
UC
Subtask 2.1 Design of optimal TES unit
UC, EPRI, Evapco
Mileston 2.1 TES Design finalized
UC. Evapco
Subtask 2.2 Fabrication of lab-scale TES unit
UC, Evapco
Milestone 2.2 Fabricated TES unit
UC
Subtask 2.3 Testing of lab-scale TES unit
UC
Milestone 2.3 Lab-scale TES performance established
Task 3 - Design and performance evaluation of air pre-cooler (ACHX)
UC, EPRI, Evapco
Subtask 3.1 Design of enhanced tube-fin ACHX
UC, EPRI, Evapco
Milestone 3.1 Optimized ACHX design
Full Team
Subtask 3.2 Design optimization of enhanced advanced ACC
UC, EPRI, Evapco, Maulbetsch
Milestone 3.2 Optimized ACC design
Full Team
Task 4 - Technology Demonstration
UC, EPRI, Evapco, Maulbetsch
Milestone 4 Technology Demonstration
Full Team
Subtask 4.1 Performance modeling and optimization
Full Team
Subtask 4.2 Fabrication of pilot-scale components
UC, EPRI
Milestone 4.2 Pilot-scale components fabricated
UC, EPRI
Subtask 4.3 Pilot-level testing
EPRI
Task 5 - Techno-Economic Analysis (TEA)
EPRI, Maulbetsch
Subtask 5.1 Power plant integration trade-off evaluation
EPRI
Milestone 5.1 Preliminary TEA
Subtask 5.2 CAPEX and OPES estimates
EPRI
Milestone 5.2 Update of TEA
Subtask 5.3 Economic analysis
EPRI, UC
Final Report