UNC CHARLOTTE
Energy Production and Infrastructure Center
LEHIGH UNIVERSITY
Worley
energy | chemicals | resources

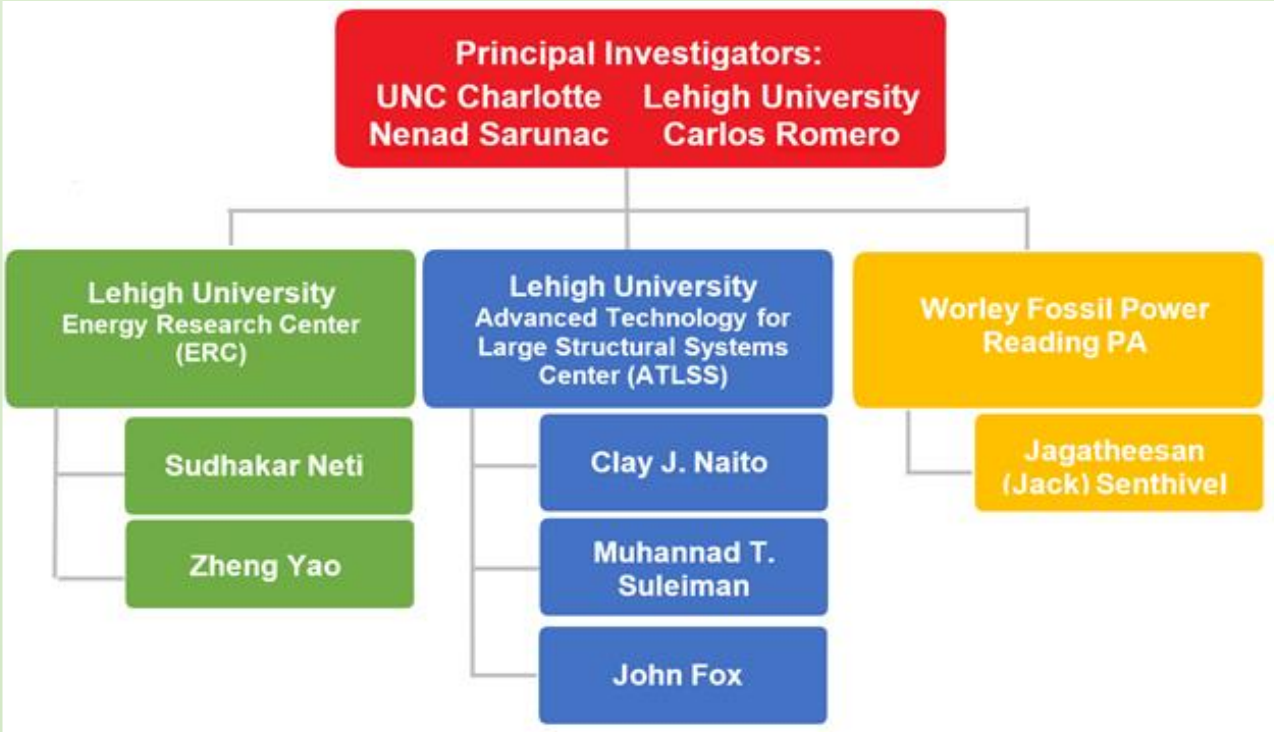
Improvement of Coal Power Plant Dry Cooling Technology through Application of Cold Thermal Energy Storage – Crosscutting Project Review Meeting

DE-FE0031886

May 17th, 2021

Project Team

- Nenad Sarunac, UNCC
- Carlos Romero, LU ERC
- Clay Naito, LU ATLSS
- Muhannad Suleiman, LU ATLSS
- Sudhakar Neti, LU ERC
- John Fox, LU ATLSS
- Zheng (James) Yao, LU ERC
- Senthivel Jagatheesan (Jack), Worley
- Graduate and postgraduate students from UNCC and Lehigh University



Industry Advisory Team
Yohann Rousselet, BAC
Yaroslav Chudnovsky, GTI

Background

- To produce power, thermal power plants (heat engines) **must** reject heat.
- U.S. power plant infrastructure is heavily reliant on water cooling
  - **51%** Evaporative Cooling Tower
  - **46%** Sensible Cooling (one-through)
  - **1.8%** Direct Dry Cooling (direct **ACC**, Air Cooled Condenser)
  - **0.5%** Hybrid cooling (**ACC** + wet cooling tower)
  - **0.7%** Other
- **Demand for dry cooling is increasing in water scarcity regions.**
- **More stringent EPA regulations on water intake and thermal discharge will render once-through cooling obsolete.**
- Wastewater treatment and reuse technologies need to be adopted.
- Water availability will continue to be an issue of increasing concern.

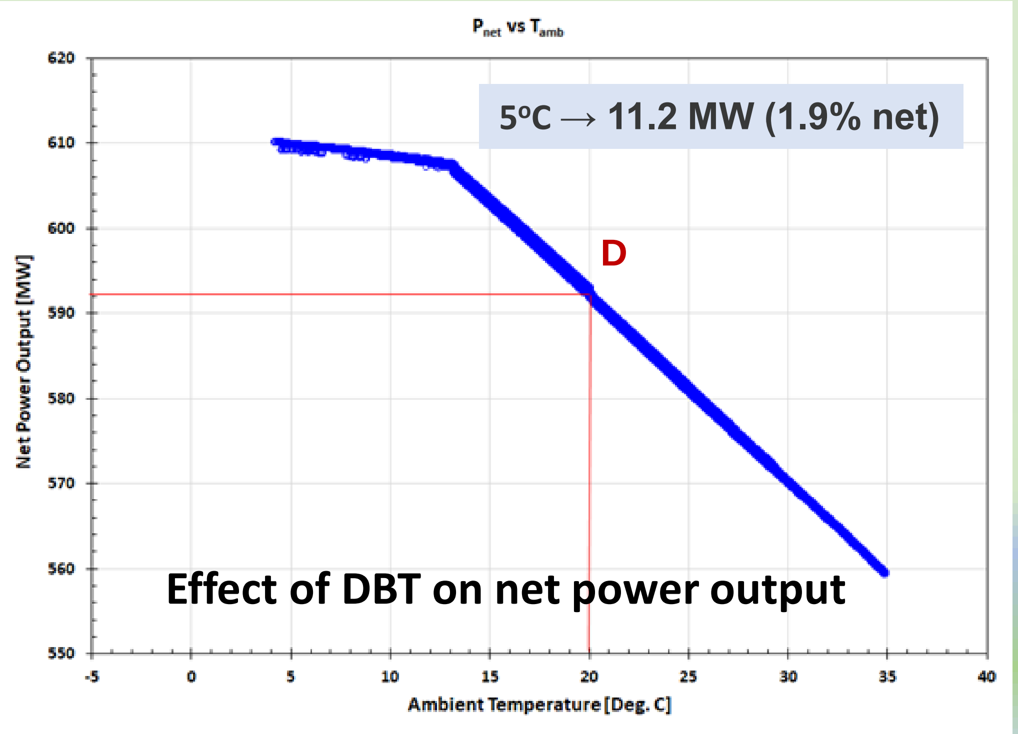
- A. Howell, “Performance Enhancement for Air-Cooled Condensers”, 2019
- Report of Department of Energy, National Energy Technology Laboratory, “Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirement:, DOE/NETL-400/2008/1339, 2008
- EPRI Report, “Water Use for Electric Power Generation:, No. 1014026, 2008

Background - ACC

Dry Bulb
Wet Bulb

Source: B&W SPIG

- ACC performance is governed by the dry bulb temperature (DBT).
- DBT varies considerably during the day.
- **+3ºC → 1% decrease in net power output** (depends on ACC rating)

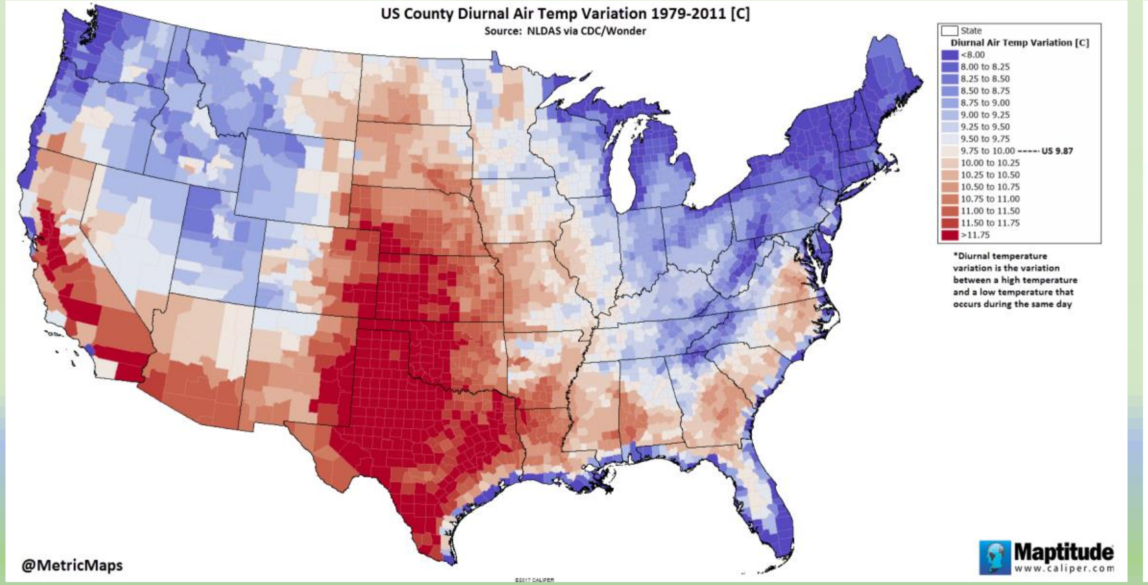


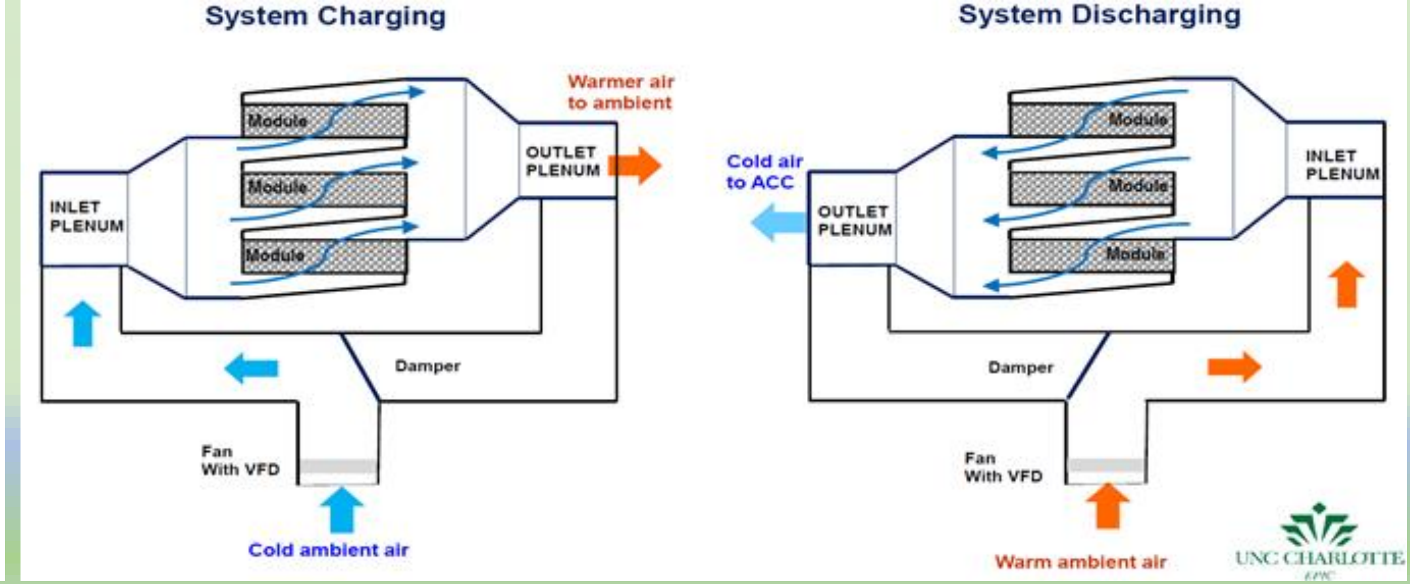
Project Objectives

- **Main Objective**: Develop and **demonstrate a new technology** for improving performance of dry cooling.
- The proposed system is based on the concept of **"Cold Thermal Energy" Storage (CTES)**, which involves storing low-temperature heat during nighttime, when temperature of the ambient air is low, and using it to pre-cool air entering a Dry Cooling Tower (DCT) or Air-Cooled Condenser (ACC) during the hot period of the day.
  - The proposed concept is also applicable to simple and combined Brayton cycle, industrial, commercial, and residential applications, as well as concentrated solar power (CSP).
- The heat storage medium is an integration of **Pervious Concrete (PC)** and **Phase Change Material (PCM)**. Integration of a PCM into a porous structure of PC is an innovative method for increasing media heat storage capacity in an efficient direct contact heat exchanger.
  - The PCM selected for this demonstration project is commercially available low-cost hydrated salt, calcium chloride ($CaCl_2 \cdot 6H_2O$, or CC6).
- **Increase TRL from 3 to 5.**

Principle of Operation

- The CTES technology for improving performance of dry cooling systems is based on the natural diurnal temperature difference where low-temperature heat stored during nighttime is discharged during the hottest period of the day to pre-cool the DCT/ACC inlet air.
  - Lower temperature of the inlet cooling air would improve performance of dry cooling systems and increase power output and net generation of power plants during periods of highest load demand and prices.

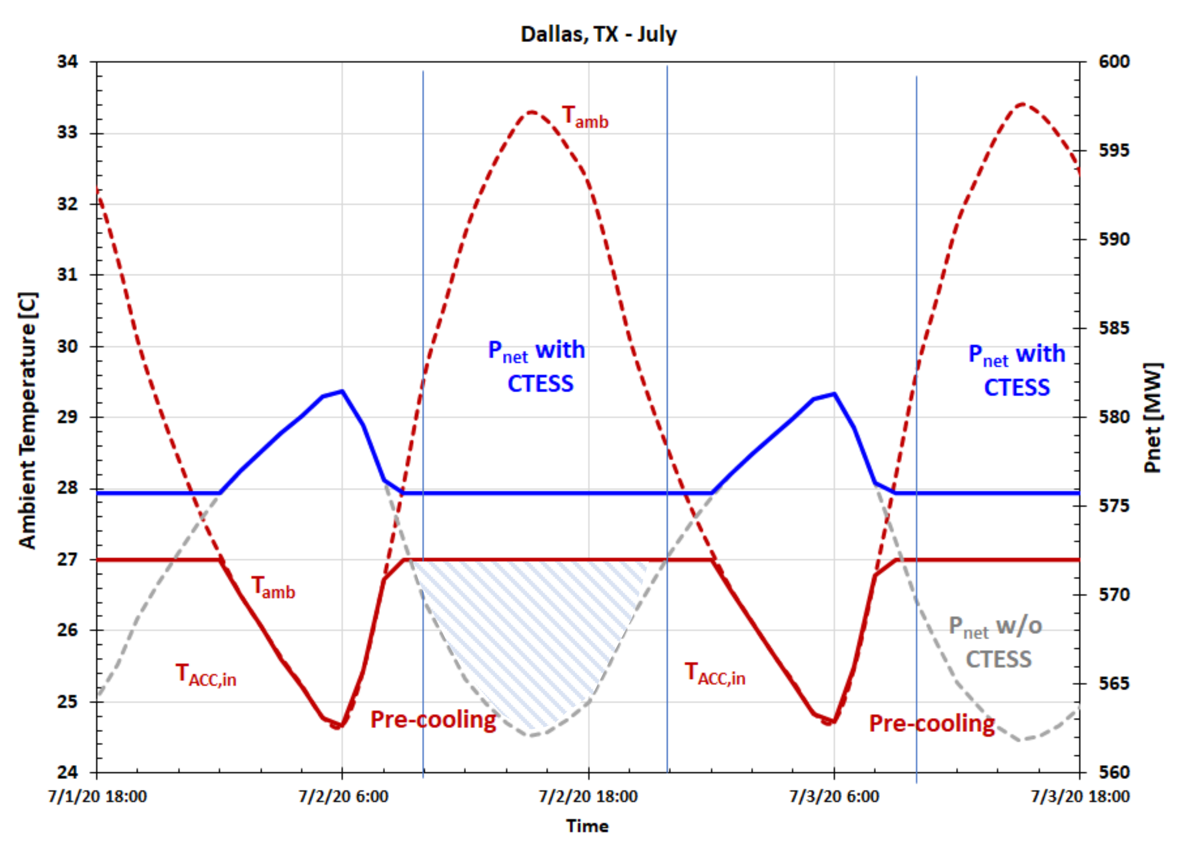


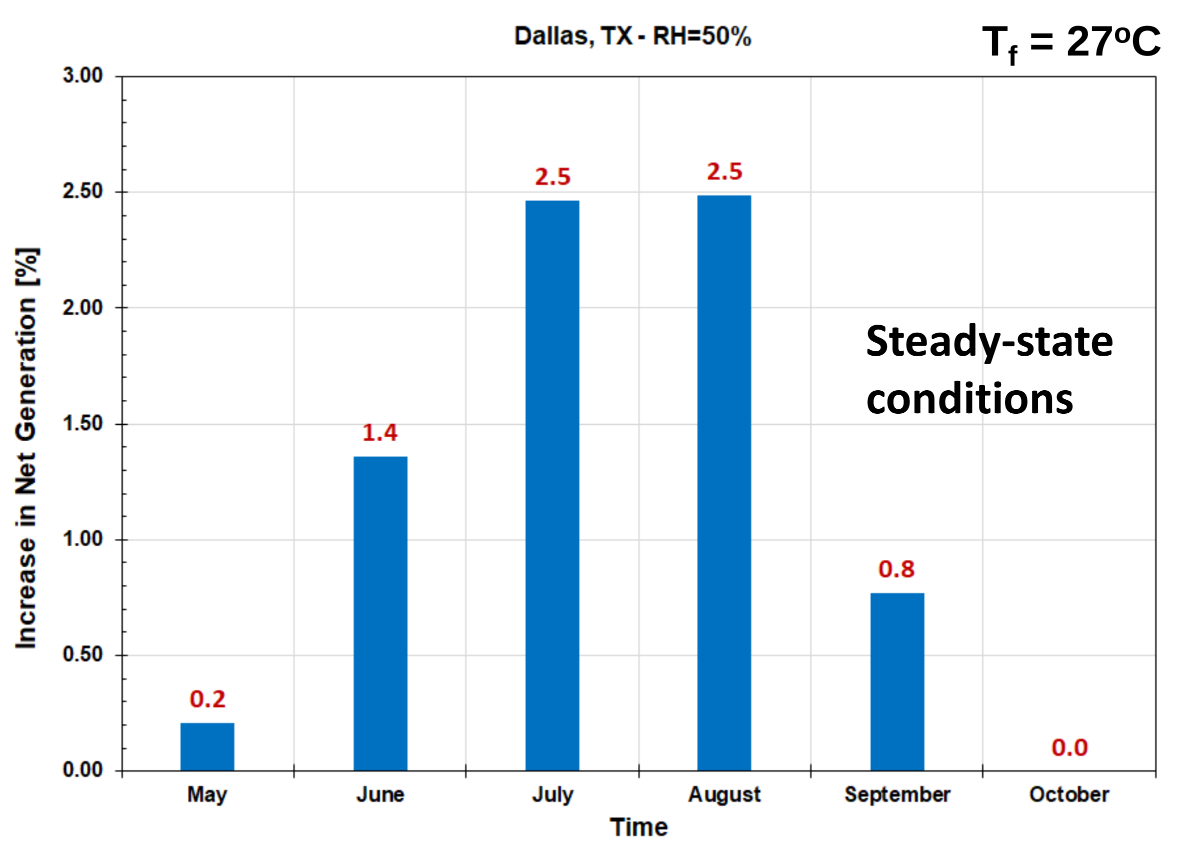


Benefits – Plant Performance Improvement

- Lower temperature of the inlet cooling air increases power output and net generation of dry cooled power plants during periods of highest load demand.

Increase in net generation





Technical Approach

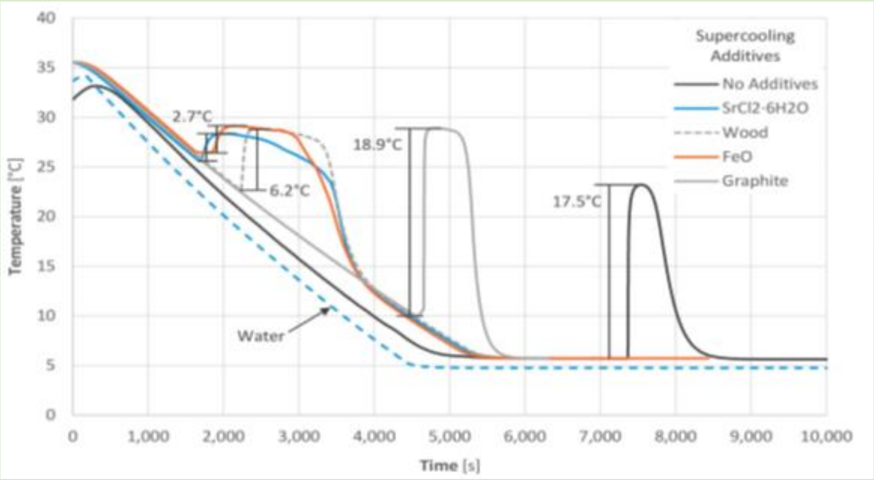
- Engineer and test heat storage medium and modules.
  - The heat storage material, a mix of pervious concrete (PC) and phase changing material (PCM) is a novel concept being developed by the project team.
  - Several designs, involving micro- and macro-encapsulation of PCM in PC matrix are being developed.
  - Engineer and characterize PCM and develop optimal PC and PC-PCM mixes.
- Test heat storage modules using a lab-scale test setup.
- Develop and demonstrate the CTES concept, using previous development in PCM and PC technology, to a 10 kWh-scale prototype.
  - Design, fabricate, and test the prototype
- Determine economic viability (perform TEA)
- Prepare for the next phase scale-up.
  - 100 kWh-scale prototype for side-stream or full-steam testing at a power plant
- The ultimate goal is **TRL 9**.
  - Large-scale prototype
  - Full-scale prototype (commercial)

Technical Approach

- PCM engineering and characterization
  - Commercially available low-cost hydrated salt, **CC6**
  - Chemical composition (impurities in commercial CC6)
  - Phase change temperature, $\mathbf{T_f}$
  - Latent heat of fusion, $\mathbf{h_f}$
  - Supercooling
  - Phase separation due to temperature cycling
  - Variability in $\mathbf{h_f}$ under repeated temperature cycling
  - Corrosion rate
- Additives were identified to suppress supercooling
- Corrosion rate was determined
  - Carbon steel is a suitable encapsulation material
- Long-term temperature cycling tests were performed
  - Variability in $\mathbf{h_f}$ under temperature cycling was determined
  - Additives were identified to mitigate phase separation.

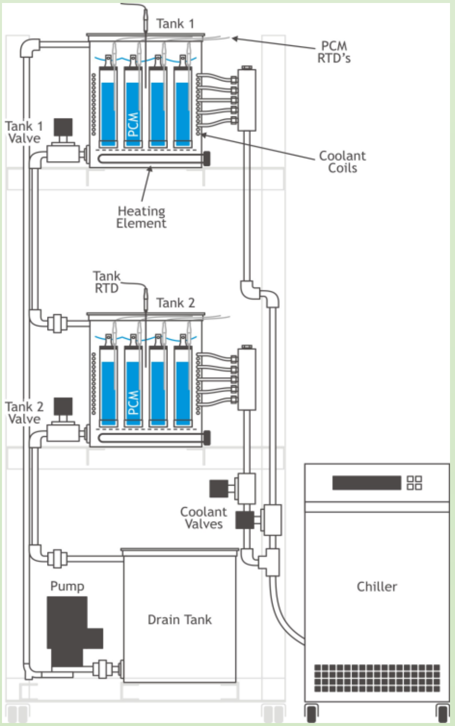
Affected by impurities

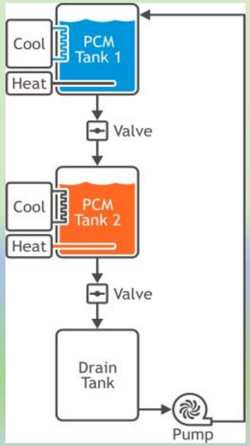
Supercooling



Technical Approach

- PCM engineering and characterization

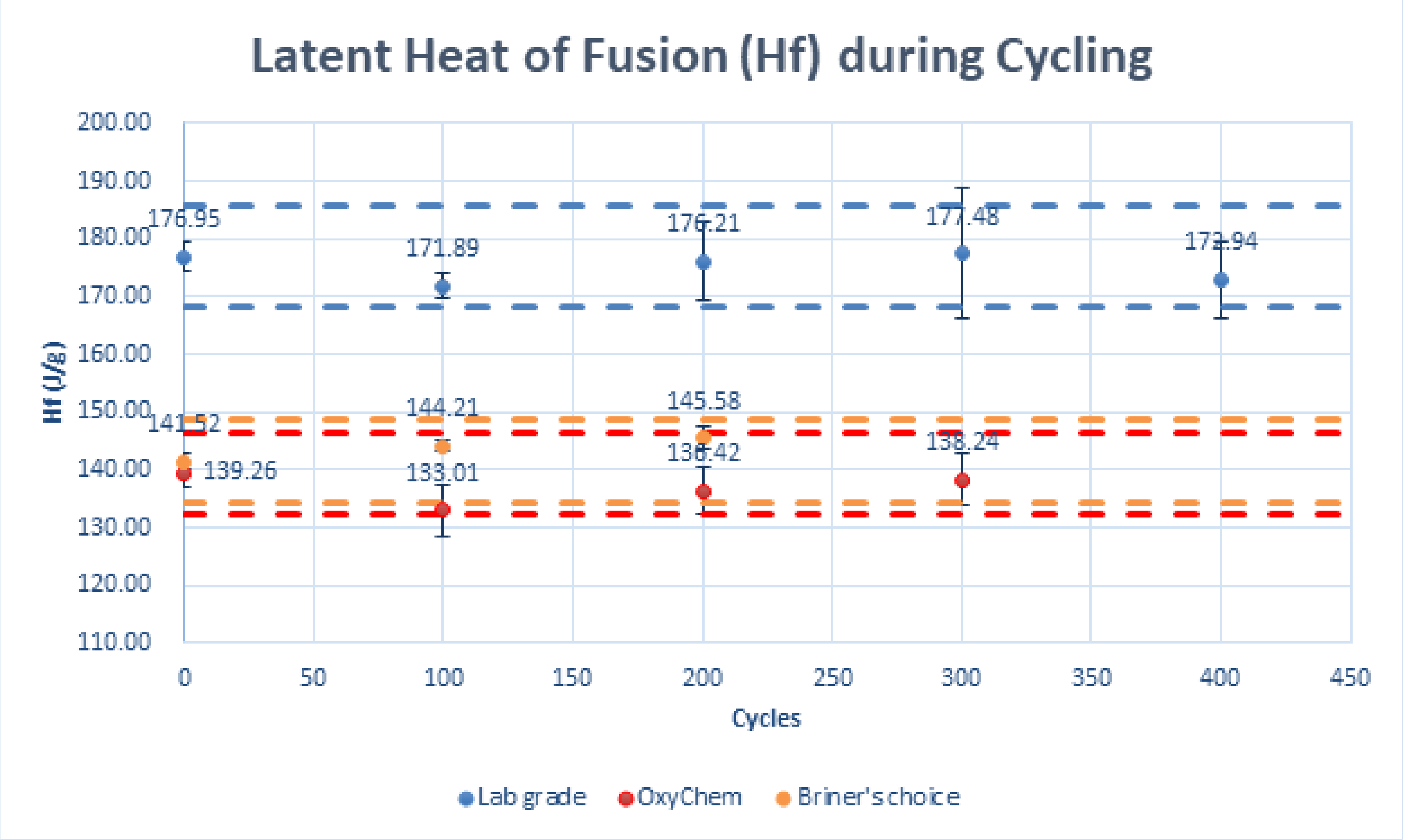




A temperature cycling machine for PCM testing.

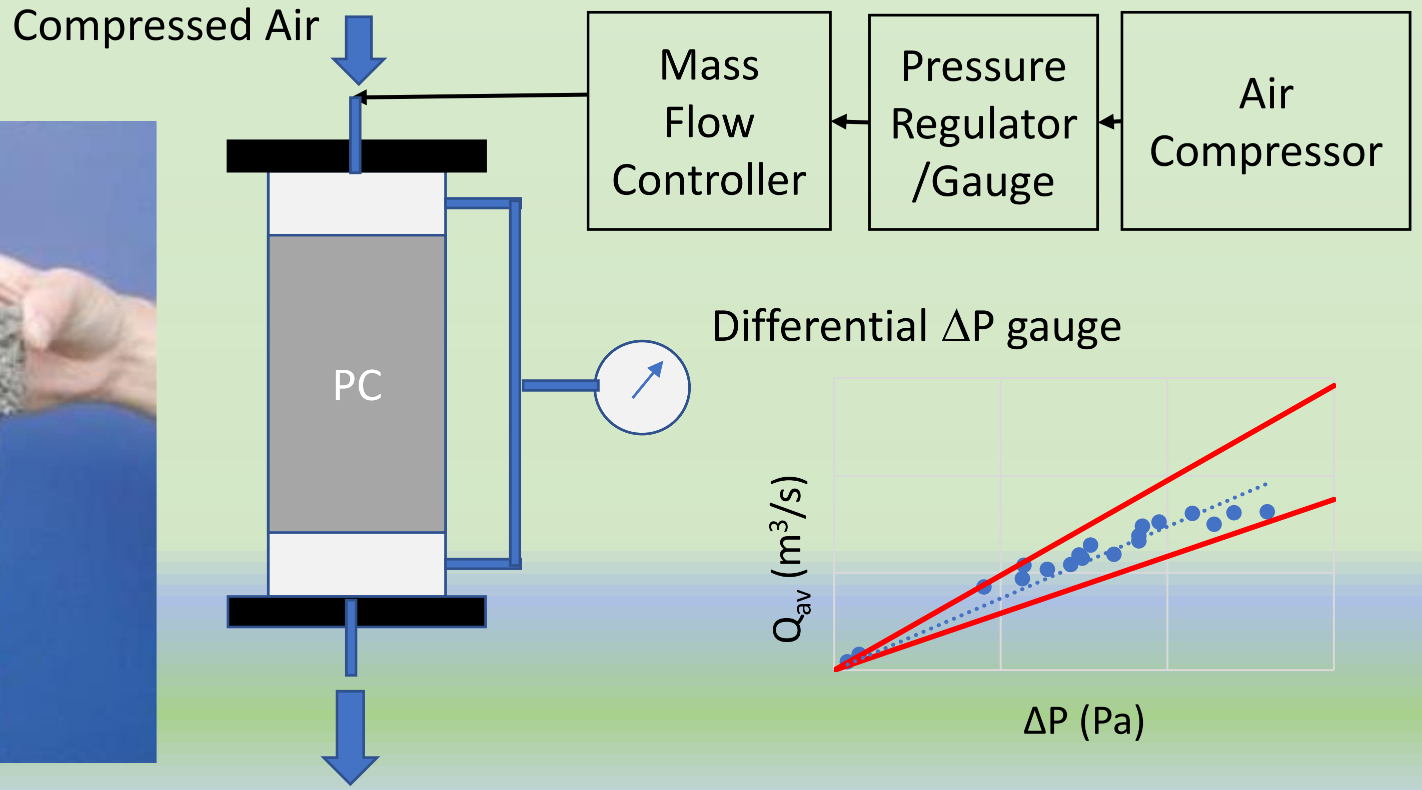
Cycle parameters: 5-30°C, 150 min cycles.

h_f variability under repeated temperature cycling



Technical Approach

- PC engineering and characterization
  - PC characterization was performed for a variety of concrete and aggregate mix proportions.
  - Air and water permeability, and strength were determined as functions of porosity (PC mix).
  - Thermal characterization is in progress (thermal conductivity, specific heat, etc.)



Technical Approach

- Engineer and test heat storage medium and modules.
  - Engineer and characterize PCM and develop optimal PC and PC-PCM mixes.
  - Micro-encapsulation of PCM achieved by infusing PCM into a porous PC aggregate.
  - Vacuum infusion
  - Macro-encapsulation involves embedding PCM-filled spheres or tubes into PC mix.

PC-PCM mix designs: **Designs a to d**

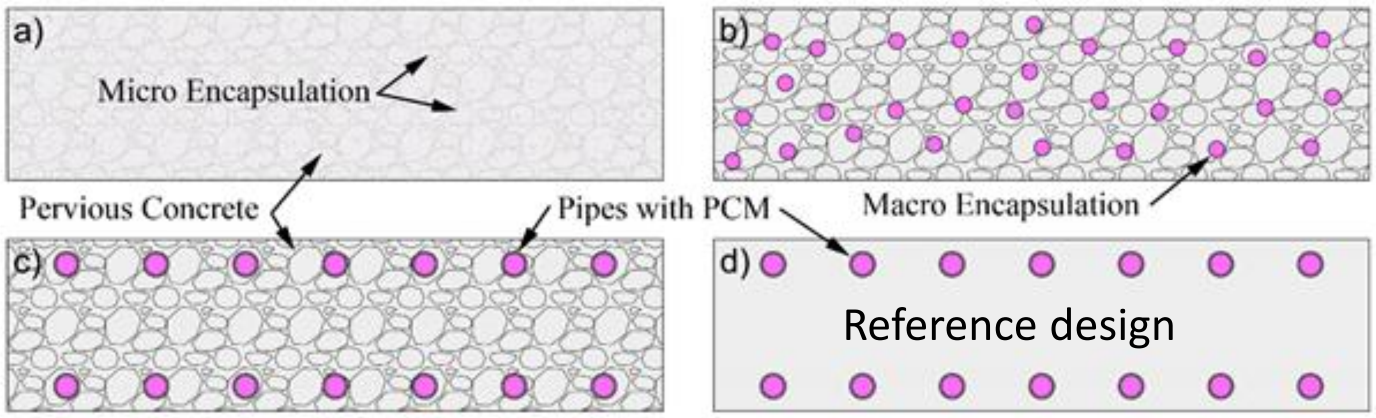
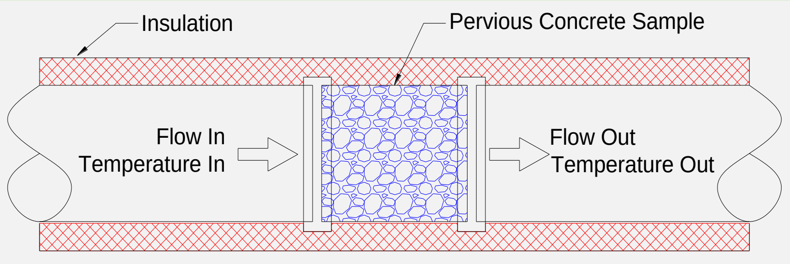


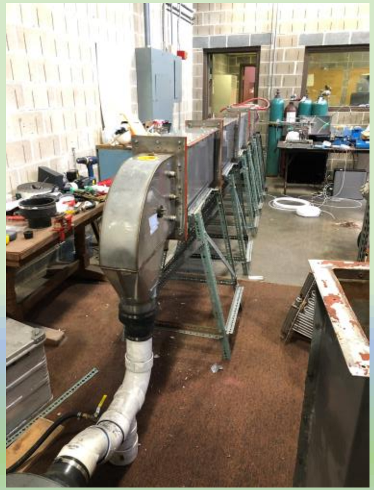
Figure 3. Module designs: (a) PC/micro-encapsulated PCM, (b) PC/macro-encapsulated PCM, (c) PC-PCM tubes, (d) PCM tube array.

Vacuum Infusion

Technical Approach

- Testing of heat storage modules
  - Heat storage modules of four different designs will be fabricated and tested using a lab-scale facility under realistic temperature and flow conditions.
  - Tests will be performed to characterize thermo-hydraulic performance of heat storage modules during charging and discharging.
  - Module fabrication and test setup are in progress.
  - Results will be used for design of a 10 kWh-scale prototype.

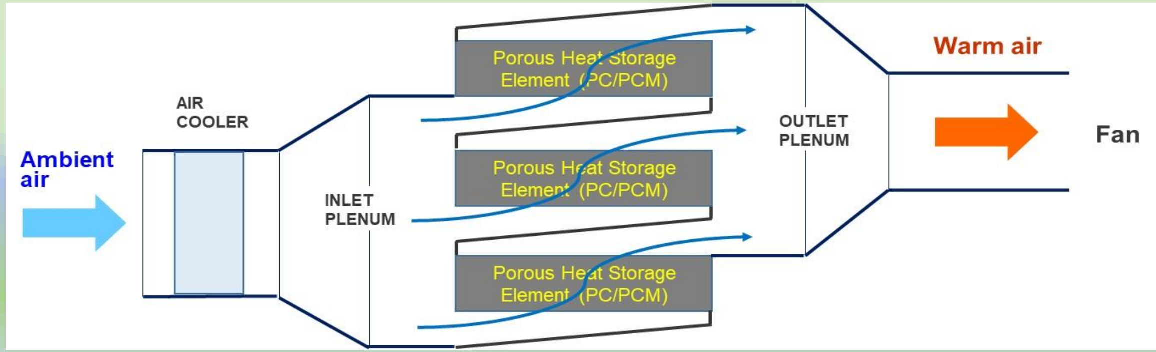




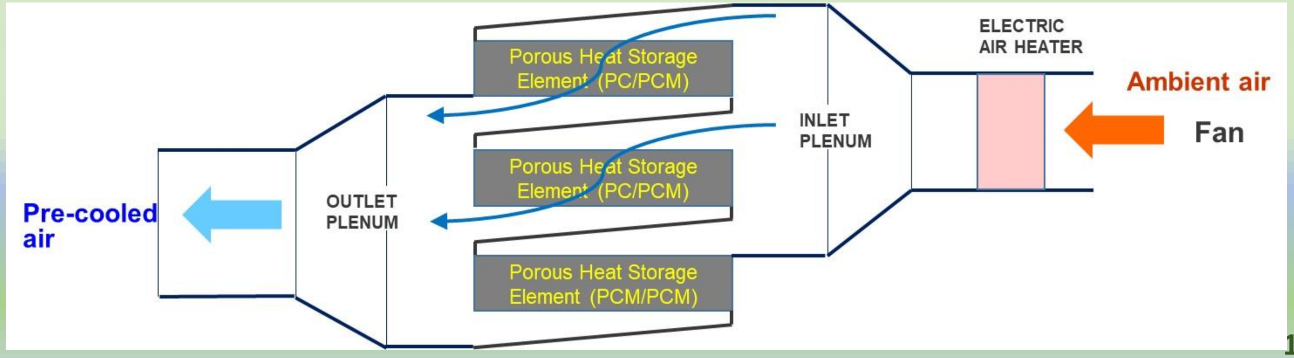
Technical Approach

- Prototype test facility and prototype-scale tests
  - A 10 kWh-scale prototype will be designed, fabricated, and tested under realistic temperature cycling conditions to enable experimental verification of CTES system thermal performance (static and dynamic) during charging and discharging.
  - Based on the lab-scale test results, the best module design will be selected between **Designs a-c** and tested on a prototype scale. **Design d** will be used as a benchmark for comparison.
  - The prototype-scale tests will establish the CTES system performance envelope and determine its characteristics under relevant and realistic operating conditions.
  - Primary parameters investigated in this task will include charging and discharging rates and energy storage (kW, kWh), cycle stability and repeatability, and power requirements.

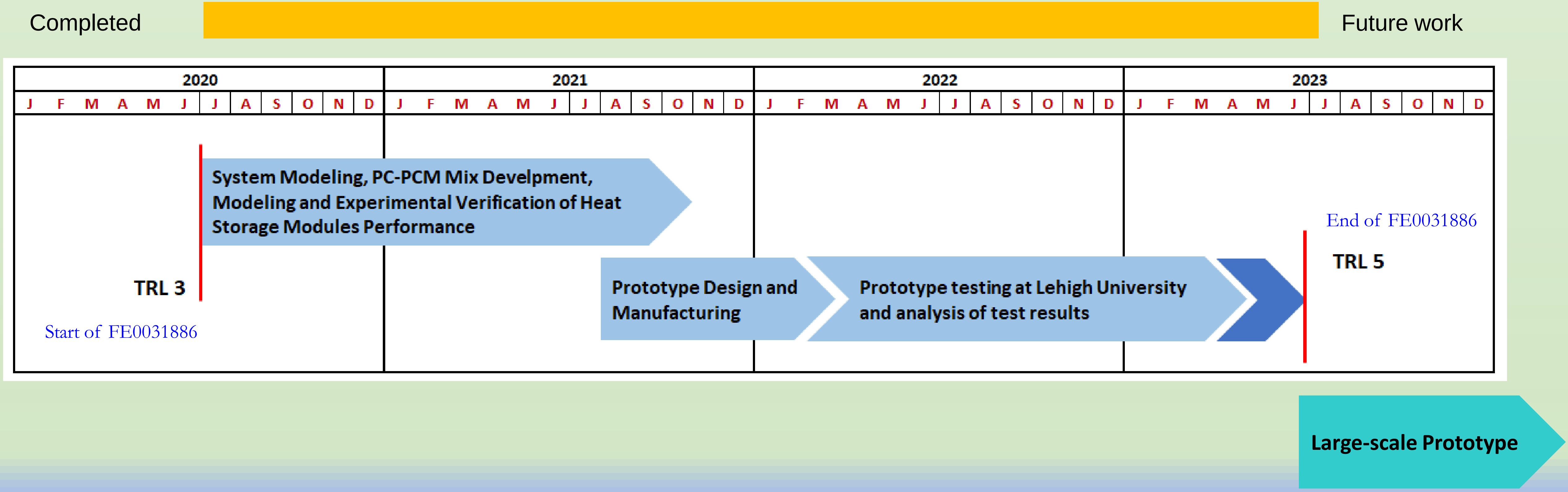
Charging Tests



Discharging Tests



Project Timeline



Commercialization

- Worley, a professional engineering company with extensive experience in the power generation area will provide the following assistance to the project team:
  - Develop Pre-FEED level accuracy (+/- 35%) Total Investment Cost (TIC) estimation for a full-size CTES system retrofit into a large coal plant with ACC.
  - Worley's high-level review will be based upon $/kW installed, output, heat rate etc. and comparing them against industry standard.
  - Perform a techno-economic analysis (TEA) to determine benefits of performance improvement and costs, and their trade-offs.
  - The net gain will be determined as either a net power output increase for the same fuel input or net efficiency improvement (reduction in heat input) for a fixed power output.
  - **Worley's industrial experience and insight is expected to yield a realistic path for the commercialization plan and ways of reaching a TRL of 9.**
  - The project team has also enrolled participation of Baltimore Air Coil (BAC), and Gas Technology Institute (GTI) as industrial advisors and potential partners.

Summary

- Project started at an estimated **TRL 3**, based on previous work related to:
  - PCMs engineered to work congruently at the temperature range of the current application.
  - Characterization and optimization of PC for applications similar to the current application
  - Application of CTES system for performance improvement of dry cooling systems.
- A plan to take the CTES technology to a **TRL 5** has been developed and it contains:
  - Additional development of system materials and components, filling the gap established at the onset of the project.
  - Computer modeling of proposed PCM+PC designs.
  - Design and fabrication of a small-scale laboratory apparatus for testing of heat storage modules in a laboratory environment.
  - Design and fabrication of a 10 kWh-scale prototype for evaluation of designs under cycling conditions and relevant environment.
  - Additional technical and commercial analysis to position CTES technology ready for next engineering-scale of development (TRL 8 and 9).

Acknowledgment and Diclamer

- **Acknowledgment**:

  This material is based upon work supported by the Department of Energy Award Number DE-FE0031886

For More Information Contact:

Dr. Nenad Sarunac

UNCC EPIC

9201 University City Blvd
Charlotte, NC 28223-0001
T|(704) 687-1089|M (610) 653-9119

Dr. Carlos Romero

Energy Research Center, Lehigh University

117 ATLSS Drive
Bethlehem, PA 18015-4729
T|(610) 758-4090