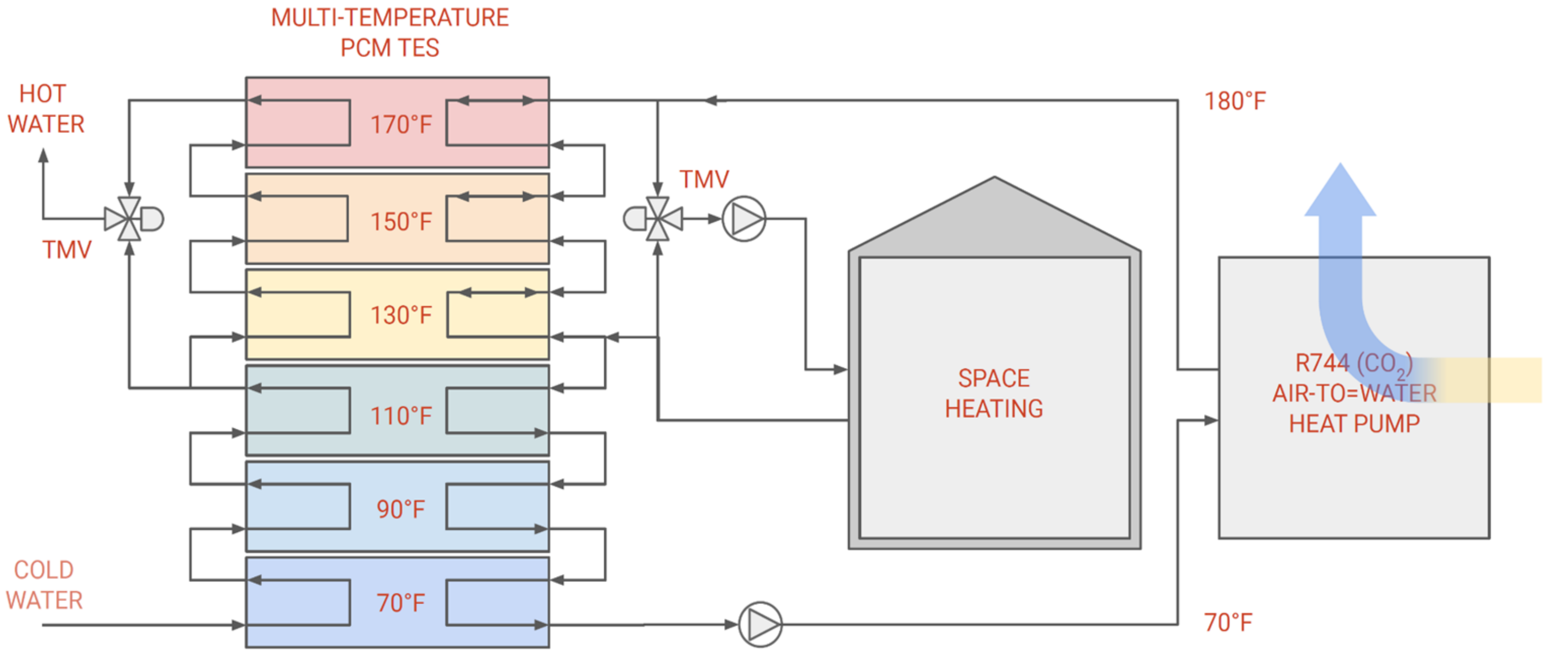
# Reduced Cost Heat Pump Space- And Water-Heating in Cold Climates




LBNL, ORNL, Emanant Systems, TRC, GTI Energy, Harvey Mudd College
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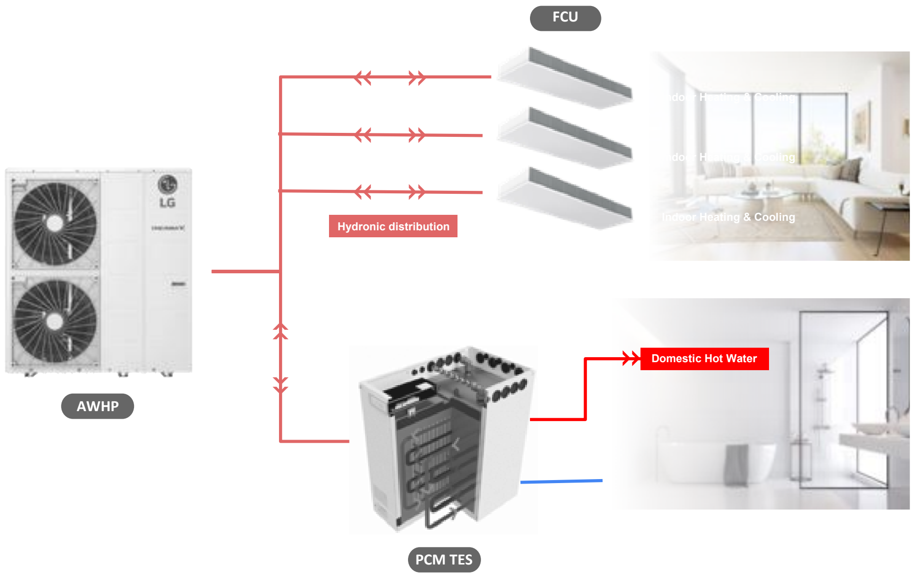
# Project Summary

## Objective and outcome

Objective is to lower the cost to provide heat and hot water in cold climate MF buildings

The outcome will be a low-GWP air-to-water combi heat pump combined with multi-temperature thermal energy storage that reduces installed costs by 20-30% and operating costs by 40%




## Team and Partners

LBNL: Iain Walker, Armando Casillas, Spencer Dutton
Harvey Mudd College: Dre Helmns
ORNL: Kashif Nawaz
GTI: Kaushik Biswas, Navin Kumar
TRC: Jingjuan Dove Feng, Gwelen Paliaga, Amin Delagah
Emanant Systems: Jonathan Woolley

## Stats

Performance Period: 10/1/2022 to 10/1/2025

DOE budget: $3,000k Cost Share: $1078k

Milestone 1: Complete mechanical design of modular R744 combi HP with low-cost PCM TES

Milestone 2: Complete laboratory testing of modular R744 combi HP with low-cost PCM TES

Milestone 3: Complete summary presentation on results from field evaluation

# Problem: Decarbonizing cold-climate multifamily buildings

Biggest energy use/$CO_2$ emissions from heat and hot water

Replace current gas DHW/boiler systems with Heat Pumps

Performance Issues:

- Poor low temperature capacity and efficiency
- High peak electric demand

Cost issues

- Installation: electric infrastructure + multiple devices
- Operating costs: often electricity more per kWh

# Alignment with DOE Goals

1. Lower costs to increase deployment at scale and make decarbonization available to lower income households
2. Enable demand flexibility by storing energy for use at peak times
3. Primary application in about 3 million non-electric cold climate MF buildings (could be extended to other 5 million non cold climate MF and also SF homes)
4. Performance goals:

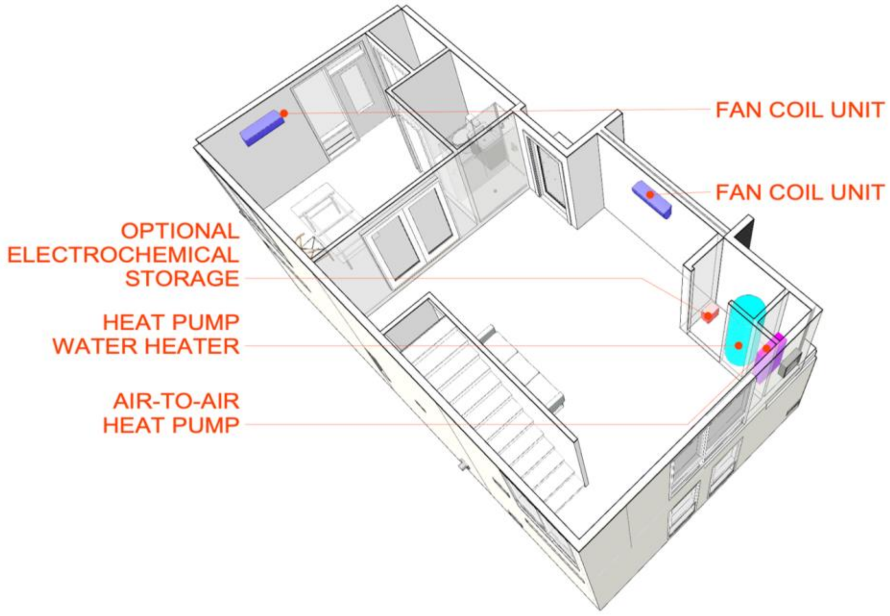
- Reduce energy use for heat and hot water by 40% in cold climates
- Reduce upfront costs by 20-30%
- Reduce grid impacts by reducing peak demand by >70%

# Approach – Combi HP with low-cost PCM TES

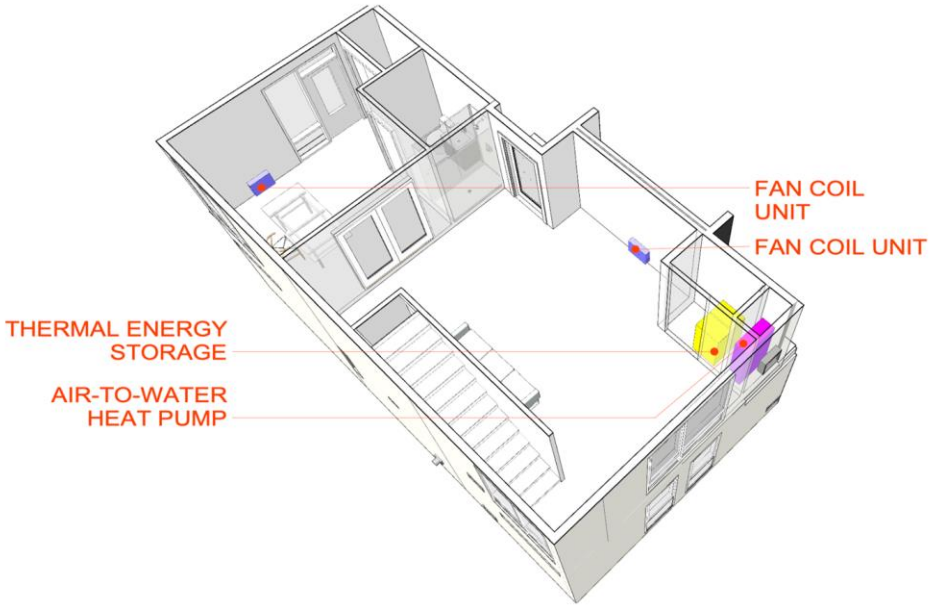
Combine into modular packaged unit:

1. Low GWP (R32 or $CO_2$ (R744)) cold climate heat pumps
2. Heat and DHW into one unit – space saving
3. Thermal Energy Storage (TES) - less electric upgrades, grid integration

Baseline System
(HP + HPWH)

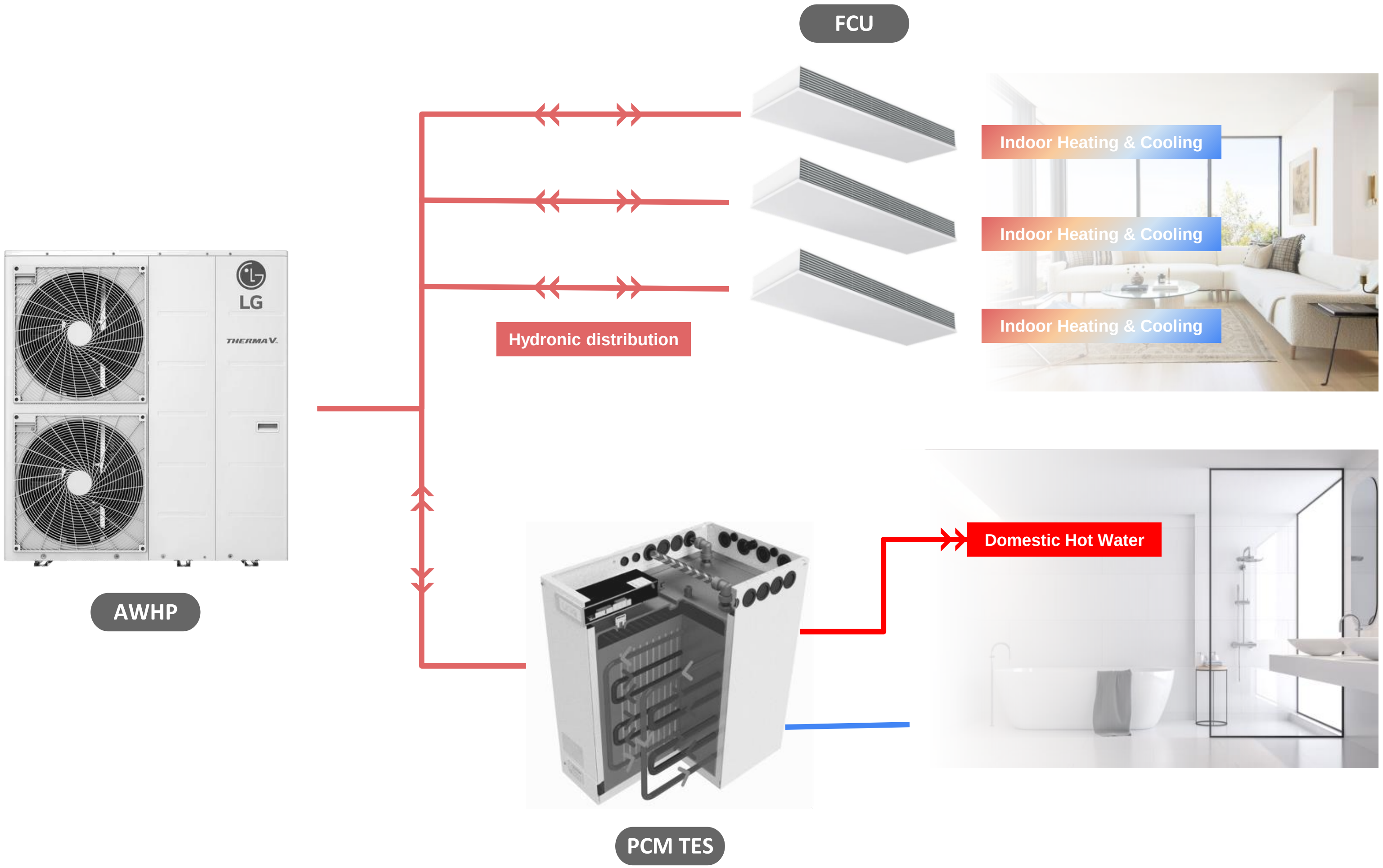



Proposed System
Combi HP with low-cost PCM TES



# Approach – Heat pump

1. Low power heat pump: no new electric circuits/panels/utility service drops – saves $1,000s.
2. Heat pump using $CO_2$ that has very low GWP (= 1) and good low temperature performance (UEF = 3.75, SCOP = 2.9)
3. Full capacity performance and high COP with heating design temperature of -15 to -5° F
4. Hydronic systems need 190 deg F supply water for retrofit/compatibility



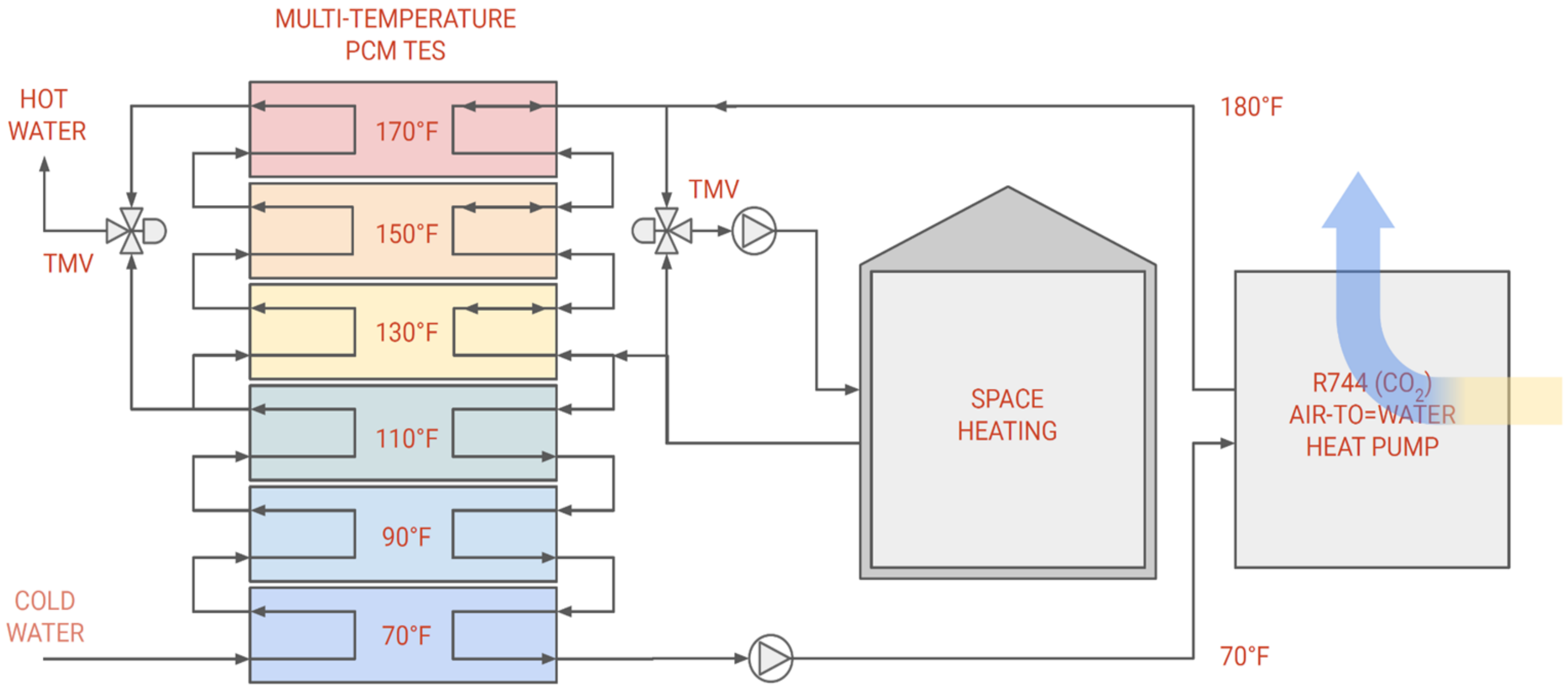
# Approach – Thermal Energy Storage

Staged PCM:

- **increases system efficiency at low temperatures**
- **enhance compatibility with operating temperatures for low GWP heat pumps**
  - Low water return temp – high temperature output
- **shifts energy use off-peak**
- **allows low-capacity HP – system output not HP output**

**Energy dense: 25-50% of H2O equivalent**
**Low cost: <$20/kWh) salt hydrate**

**Inexpensive polymer heat exchanger**



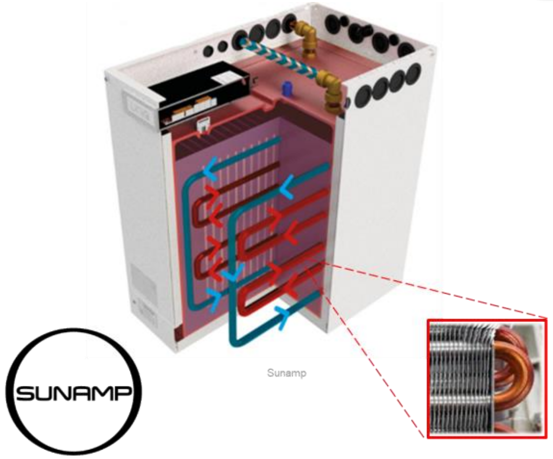
# Approach - Engineered Packaged System

Heat pumps

LG ThermaV
R32 (GWP = 677)
Operates to -13°F
Supply water to 149°F


SanCO2
$CO_2$ (GWP = 1)
Operates to -25°F
Supply water to 150°F

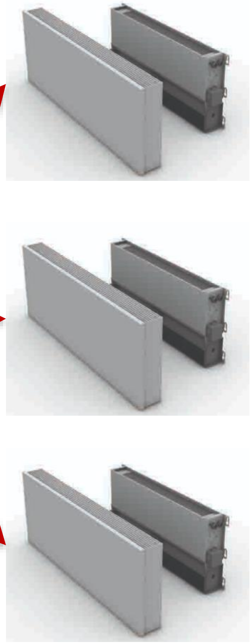

Cascaded PCM




Multiple PCM in series
Low return temp
Improve HP performance

Hydronic distribution

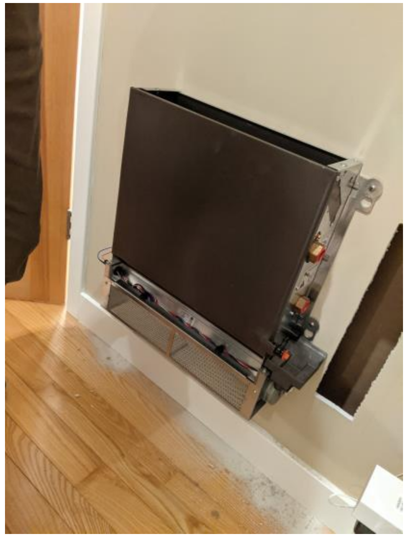
Fan coil units



DHW

# Approach – Project Outline

1. **Market research on cost reduction for HPs multifamily cold climate HPs**
   - **Build on previous California Energy Commission project by TRC**
2. **Model and design a packaged $CO_2$ combi HP with refrigerant-to-PCM TES**
3. **Staged prototype development and validation:**
   1. Field evaluation of R32 HP with PCM TES in cold climate (Massachusetts) – Emanant Systems, LG & Sunamp
   2. Design, fabricate and lab test staged TES and $CO_2$ HP prototype - GTI
   3. Field evaluation of $CO_2$ combi air-to-water HP with PCM TES in cold climate multifamily building




# Approach – Key Challenges

## FEASIBILITY?

1. **Multi-temperature phase change materials and polymer PCM-refrigerant heat exchanger require considerable prototype development .**
2. **Lack of engineered solutions combining the heat pump, heat exchangers, and thermal storage into a packaged easy to install unit.**
3. **Lack of existing control strategies**

**Technical risks and mitigation strategies are:**

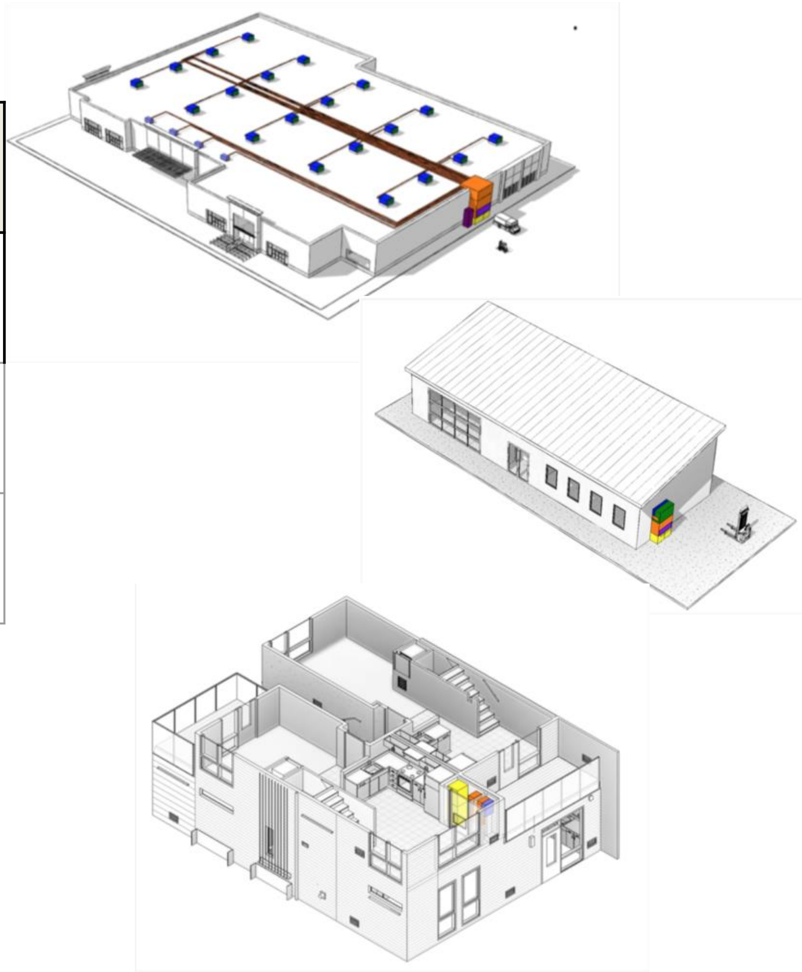
1. Failure to realize theoretical performance improvements – identify alternatives and options for improvement
2. Failure to develop PCM compatible with CO2 heat pump – choose an alternate low GWP heat pump
3. Failure to find a field testing site – identify more than one possible site and begin site search early in the project
4. Failure of prototype in field testing – *repair and retest and include fail-safe systems (e.g. existing or additional back-up heating infrastructure)*

# Feasibility

## Overview of previous modelling [*Modelica*]

Modeled 3 buildings x 3 systems

| | Baseline<br>Gas + Electric | Baseline All Electric | Proposed System |
|---|---|---|---|
| **Retail store (HVAC)** | AC + Furnace | AAHP<br>(+ ECS) | AWHP + ECS<br>+ PCM TES |
| **Classroom (HVAC)** | AC + Furnace | AAHP (+ ECS) | AWHP + ECS<br>+ PCM TES |
| **Apartment (HVAC+DHW)** | AC + Furnace<br>+ Tankless DHW | AAHP + HPWH<br>(+ ECS) | AWHP<br>+ PCM TES |



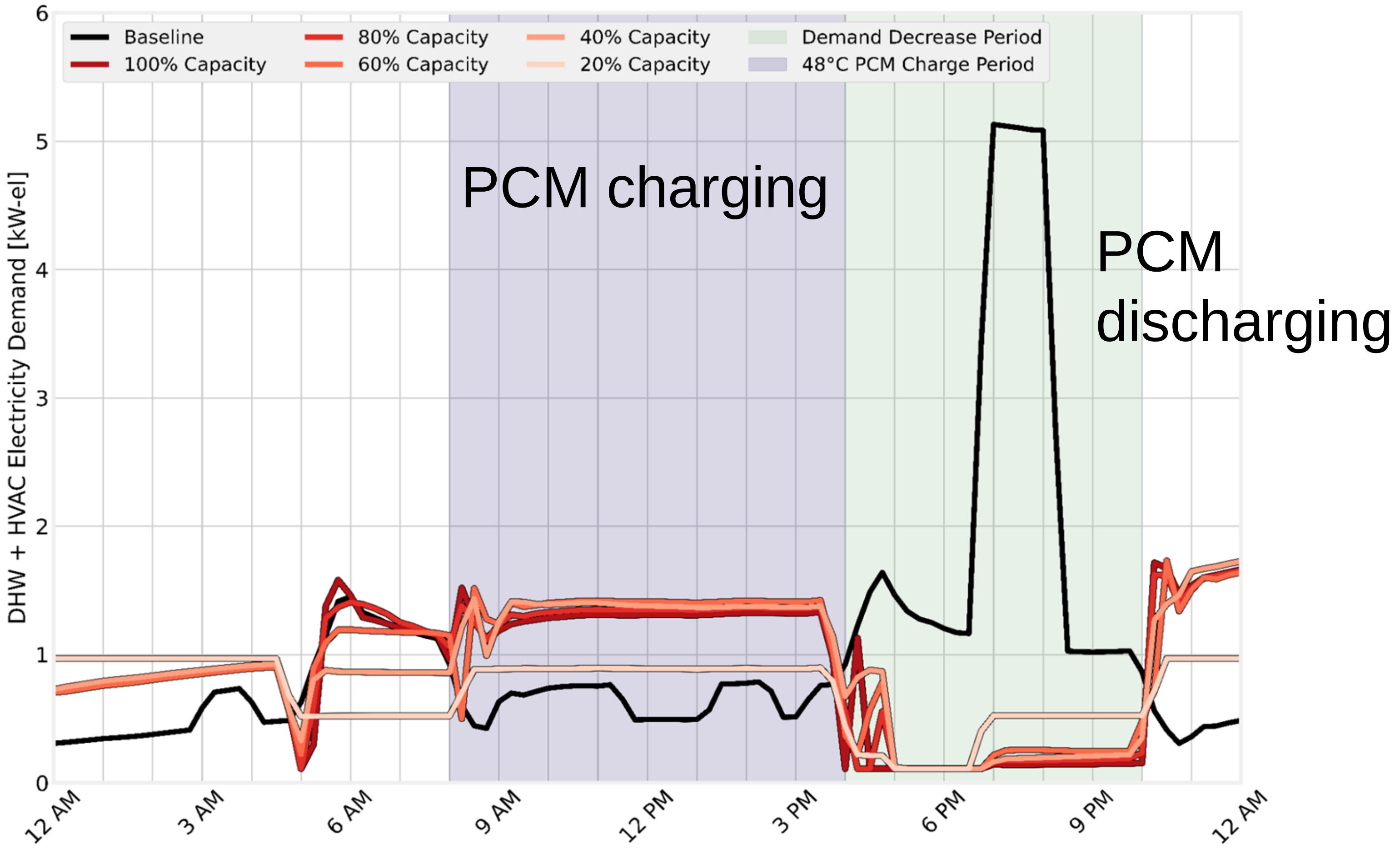
40% less energy
80% less peak demand
70% lower power requirement

# Feasibility

## Overview of previous modelling *[950 ft$^2$ Apartment Unit in Minneapolis, MN]*

**Major benefits** of the combi system:

- reduces **HP capacity** by 60% while still providing space and DHW comfort
- reduces **peak demand** by 40-80% compared to baseline all-electric
- enables **grid response,** reducing electricity consumption by 40-60% during shed periods



# Feasibility: Low GWP heat pump status

**LG ThermaV**

- R32 refrigerant
- Operation to –25°C (–13°F)
- Leaving water temperature 65°C (149°F)
- Heating, cooling, and domestic hot water
- Not commercially available in US
- Ongoing conversations with LG

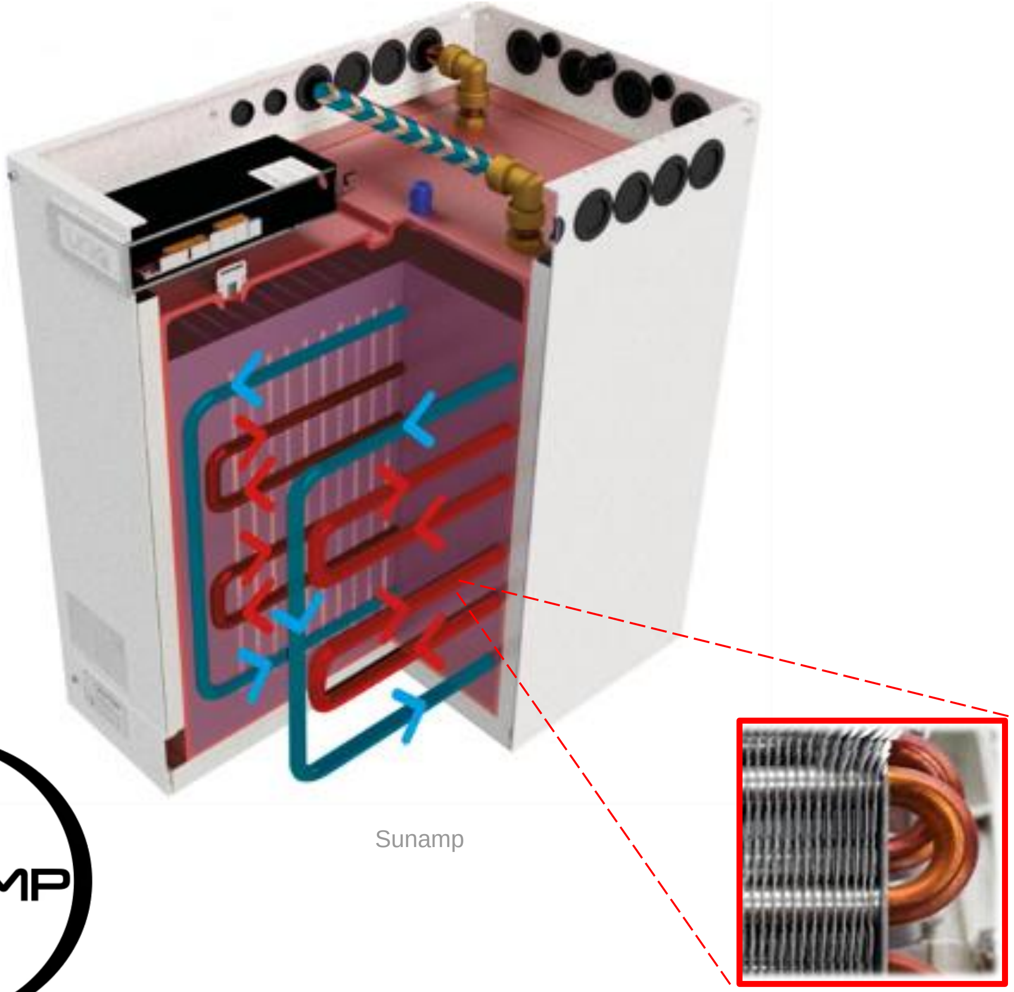


**SanCO2**

- $CO_2$ refrigerant
- Operation to –32°C (–25°F)
- Leaving water temperature 65°C (150°F)
- Commercially available HPWH
- Occasionally used in combi systems
  - E.g. Harvest Thermal

# Feasibility: Thermal storage

- Proprietary material composition
- Food grade sodium acetate trihydrate
- Several sizes available
- Many nominal phase change temperatures available
  - R32 field site uses 58°C (136°F)
  - Project goal: Cascaded system
- Fin-tube heat exchangers embedded in PCM reservoir
- Also available with integrated electric resistance heat
- Currently introducing products in the United States
- Some installations in Europe using heat pumps

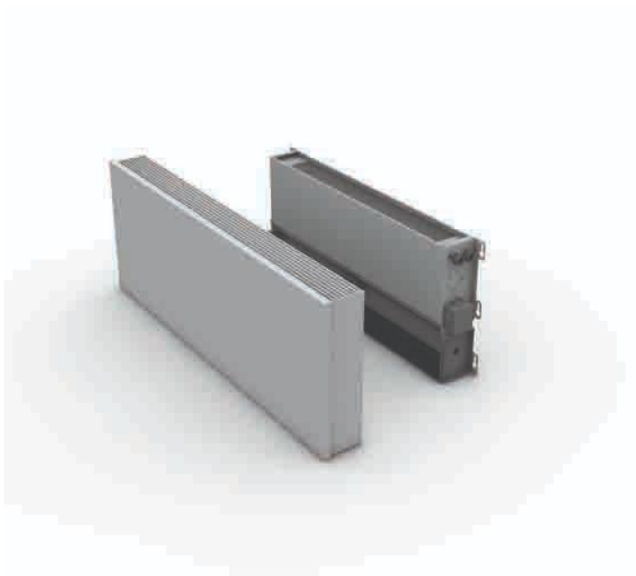


Sunamp

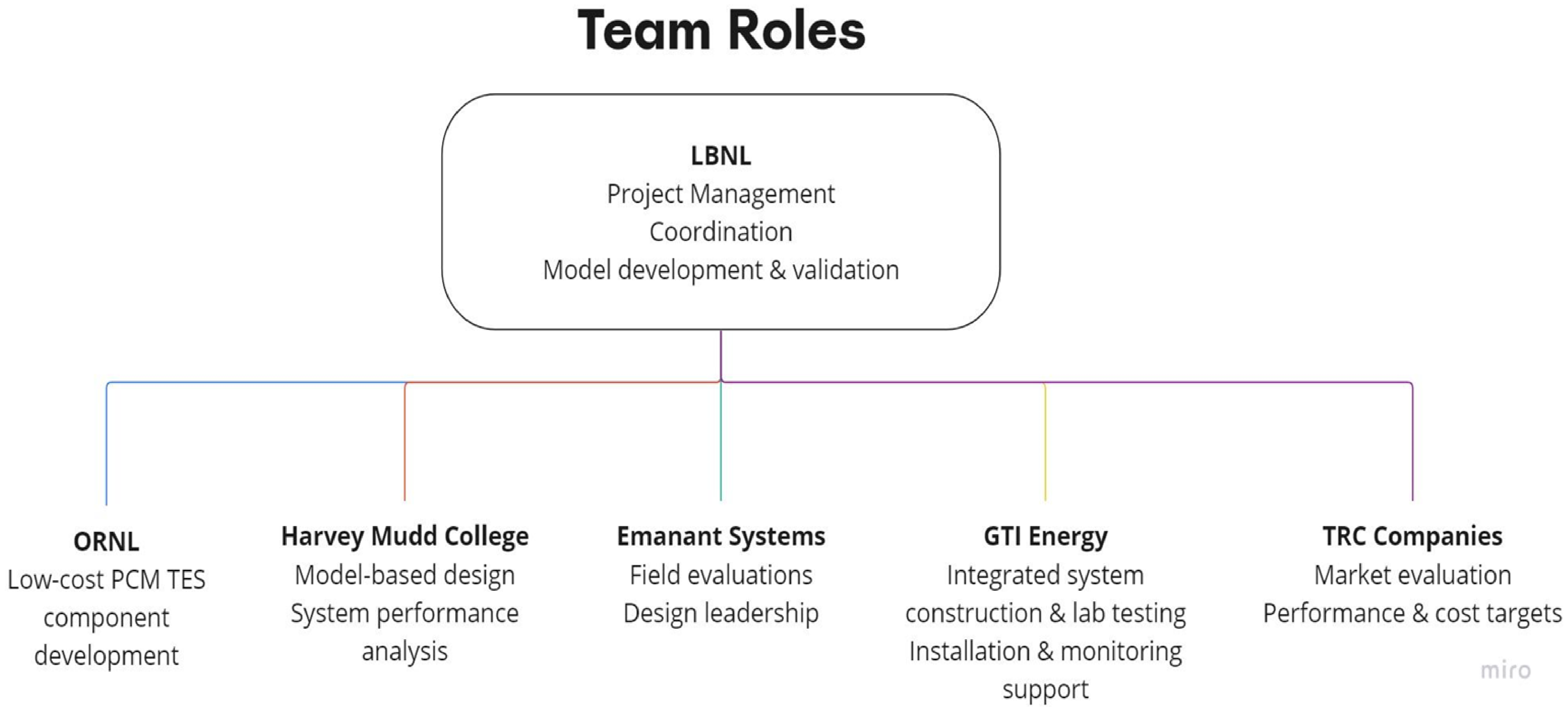
# Feasibility - Modularization

## Streamlined modular hydronic system design

- Hydronic fan coil units and radiant floor
- Simple to retrofit wall and ceiling mount fan coil units
- Quiet variable speed DC motor fans
- Daisy chain low voltage power for all fan coil units & zone valves
- PEX distribution to fan coil units
- Modular, factory built, hydronic subcomponent assemblies
- Pump stations, manifolds, and hydraulic separators
- Insulated assembly housings
- Stand-alone sub-assembly controls
- Constant pressure variable speed pumps
- Thermostatic mixing valves
- Wireless controls for all pumps, zone valves, and fan coil units
- Lightweight home automation provides controls integration



# Feasibility – Team Experience & Domain Knowledge



# Approach – beyond prototype development

- Analyses to monetization of upstream benefits in Forward Capacity-, Demand Flexibility-, and GHG markets
- Create publicly available simulation tools to support design, sizing, and control
- Present at conferences and in journal articles
- Potential for IP and invention disclosures
- ASHRAE seminars, the ACEEE Hot Water Forum, and ACEEE Summer Study. We will participate in various industry technical committees including ASHRAE TC 6.6 (Service Water Heating Systems), TC 6.9 (Thermal Storage), and TC 4.1 (Load Calculation Data and Procedures). We will also participate in the Advanced Water Heating Initiative.
- Project partners will participate in disseminating project results: LG, Small Planet Supply, InsolCorp, Senseware, Sunamp, ComEd, Consumers Energy, NEEA

# Progress and Future Work

Project is still in start-up phase

Subcontracts are in place with partners after some delay

Some project deliverables shifted by a few months

Next steps:

- Identify multifamily field test site
- Commission R32 combi HP with PCM TES at a Massachusetts field demonstration site - COMPLETE
- Compile design drawings, tech references, and bill of materials for low-cost PCM TES fabrication
- Complete mechanical design of modular R744 combi HP with low-cost PCM TES
- Begin market assessment study

# Thank You

LBNL, ORNL, GTI Energy, TRC, Emanant Systems, & Harvey Mudd College
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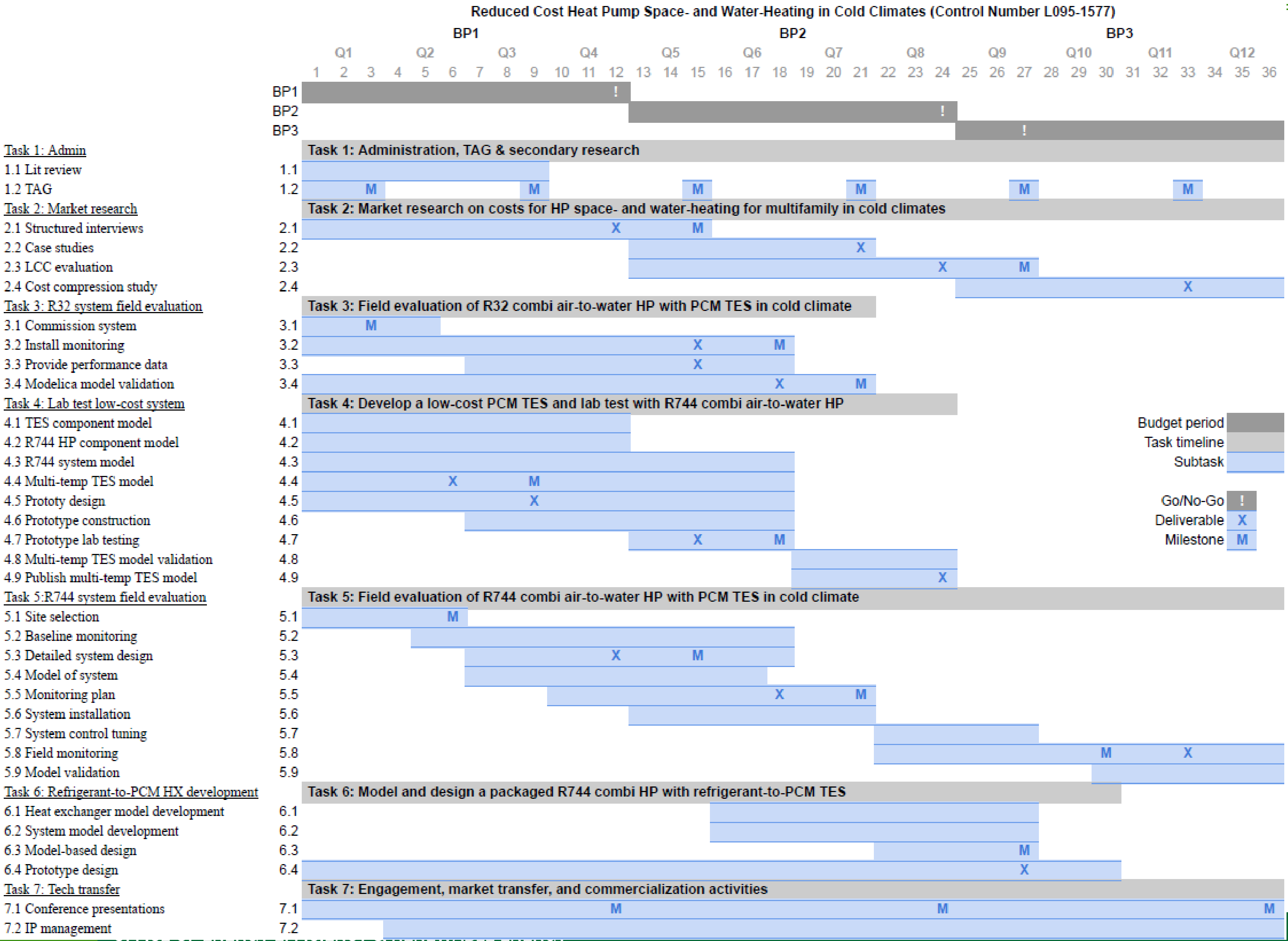
# REFERENCE SLIDES

# Project Execution



# Team

**Lawrence Berkeley National Lab:**

- lead project management, support modeling and simulation, lab testing, and field evaluation, publish results

**Emanant Systems:**

- lead system design and field evaluation, support market research, lab testing, and simulation validation

**Harvey Mudd College:**

- lead modeling and simulation, support system design, lead performance optimization

**Oak Ridge National Lab:**

- PCM TES heat exchanger design and fabrication for R744 HP integration, support performance optimization

**TRC:**

- lead market research, current costs and best practices for multifamily decarbonization

**Gas Technology Institute:**

- lead PCM TES and R744 HP integration, lab testing, support market research and field evaluation