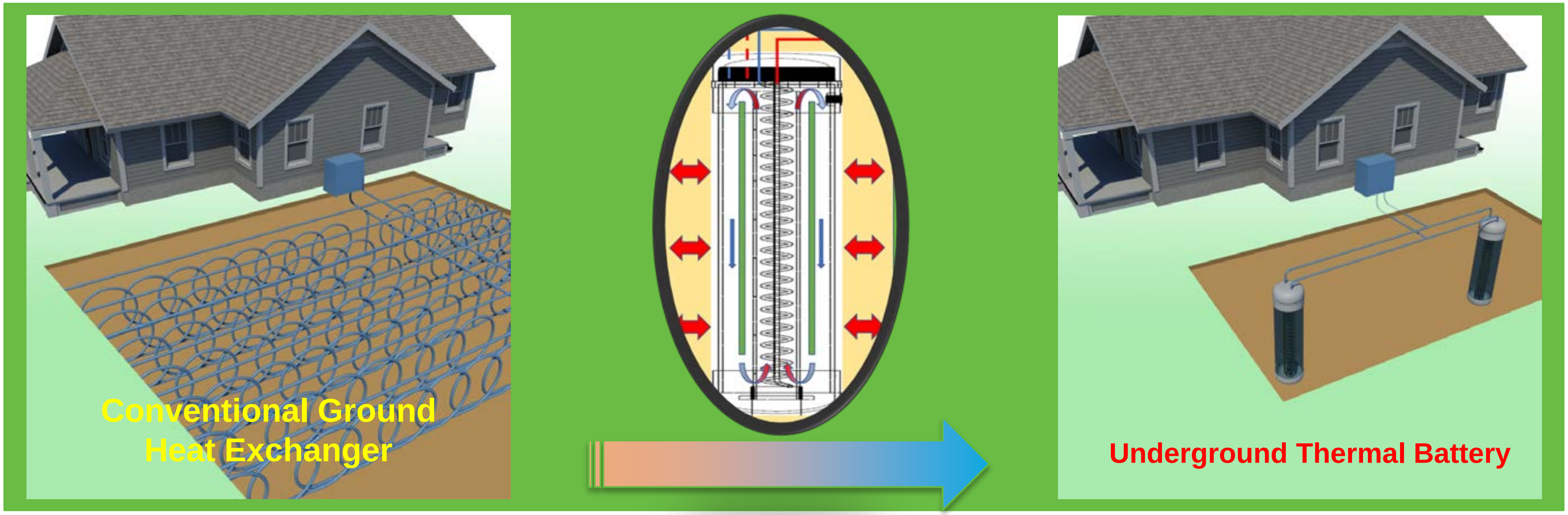
Innovative Low-Cost Ground Heat Exchanger for Geothermal Heat Pump Systems



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Project Summary

Timeline:

Start date: 10/1/2017

Planned end date: 9/30/2019

Key Milestones

1. Performance characterization through computer simulations: Jun. 2018
2. Design of a full-scale prototype: Sep. 2018
3. Field test of full-scale prototype: Sep. 2019

Key Partners:

Insolcorp, LLC.
University of Tennessee
NYDERDA (potential)
IGSHPA (potential)
Frontier Energy, Inc. (potential)

Budget:

Total Project $ to Date: $240K

- DOE: $240K
- Cost Share: NA

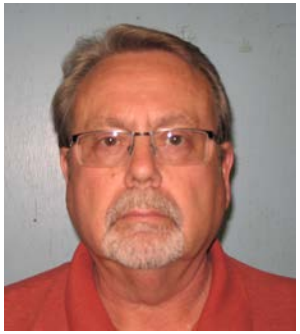
Total Project $: $410K

- DOE: $410K (planned)
- Cost Share: NA

Project Outcome:

An innovative and **cost-effective ground heat exchanger** that has potential to **make highly energy efficient ground source heat pump systems affordable** to millions of U.S. homes, which can **significantly reduce energy consumption and associated greenhouse emissions** in our nation.

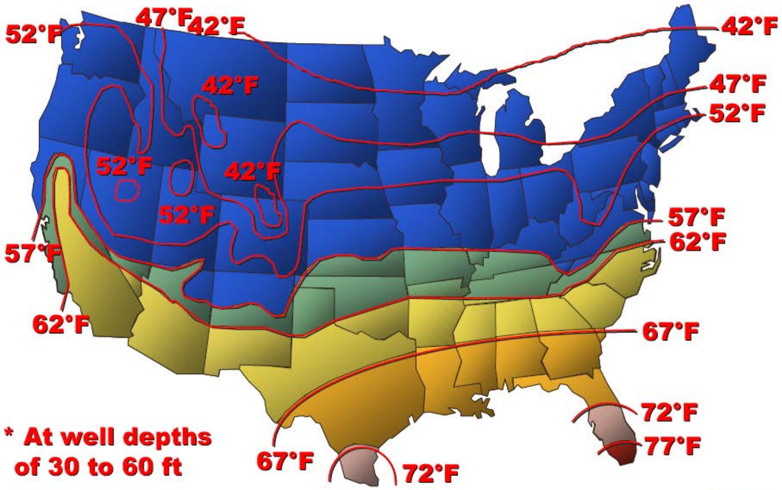
Team

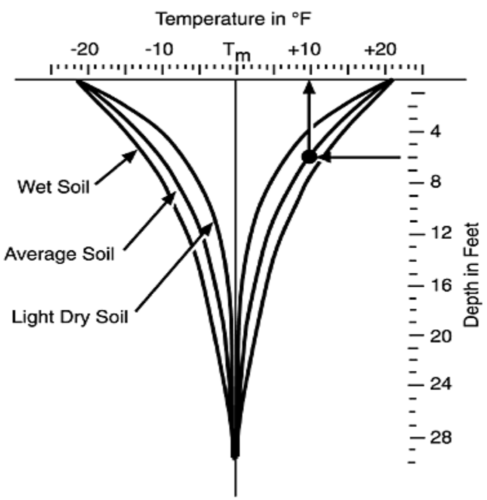
- **Dr. Xiaobing Liu**: 18 years experience in GSHP related R&D and applications. Current research chair of IGSHPA.
- **Dr. Biswas Kaushik**: Extensive experience with small- and large-scale experimental and numerical evaluations of phase change materials (PCMs). Task group chairman for ASTM standard C1784 for characterizing PCMs.
- **Dr. Mingkan Zhang**: 15 years of experience in CFD modeling and simulation.
- **Tony Gehl and Jerry Atchley**: Decades long experience in experimental instrument setup, data acquisition, and buildup of experimental artifacts.
- **Joseph Warner**: Masters student at University of Tennessee.

Challenge

- Ground source heat pumps (GSHPs) have huge potential to reduce energy consumption and carbon emissions.
- High initial cost of ground heat exchangers (GHX) prevents wider adoption of GSHPs.
- Conventional GHXs are either expensive, require large land area to install, or need easy access to pond, lake or groundwater.
- **Cost of GHXs must be reduced to enable large scale and rapid application of GSHPs.**



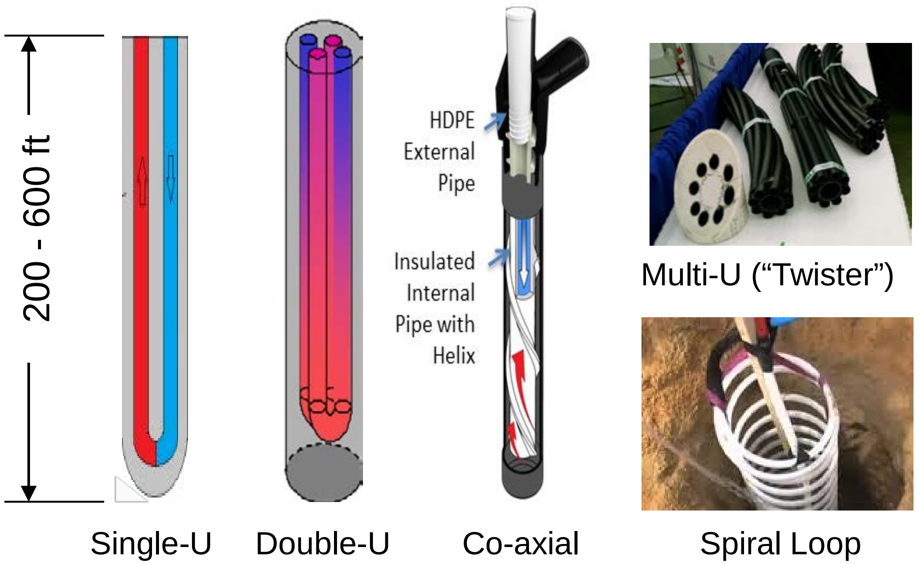
Undisturbed Ground Temperature in the US
(Source: www.geoexchange.org)



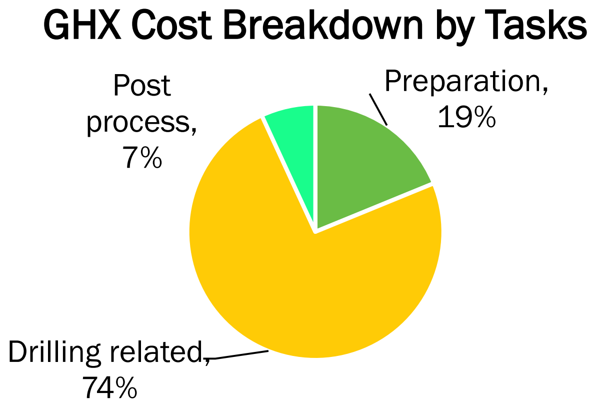
Deviation from Undisturbed Ground Temperature

Challenge: How to Reduce Cost of GHX?

- **Previous R&Ds focus on improving borehole heat transfer.**
  - Thermally enhanced grout
  - High performance plastic pipe
  - New heat exchanger design
- **Cost reduction potential is limited.**
  - Relatively small impact on overall ground heat transfer
- **Drilling contributes the most to the overall GHX cost (~$3K/cooling ton).**

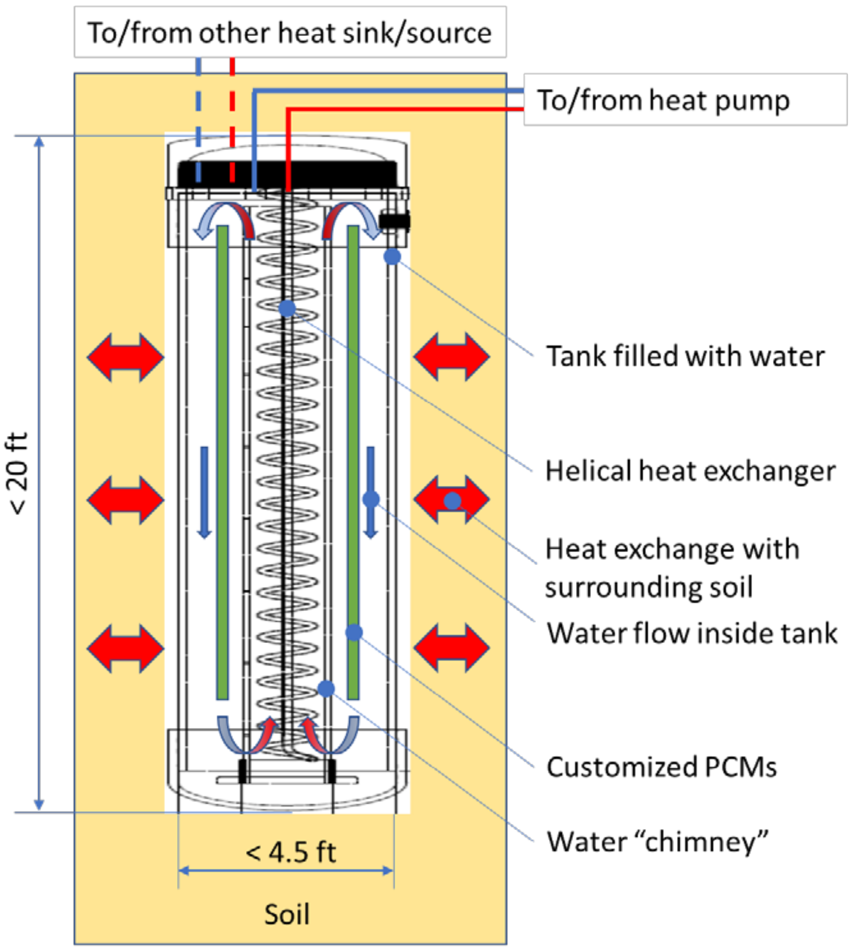


Since ground temperature below 30 ft. from the grade is constant, and only inside-borehole can be engineered, why drill deep with small boreholes?



Approach

Next-generation GHX: Underground Thermal Battery (UTB)

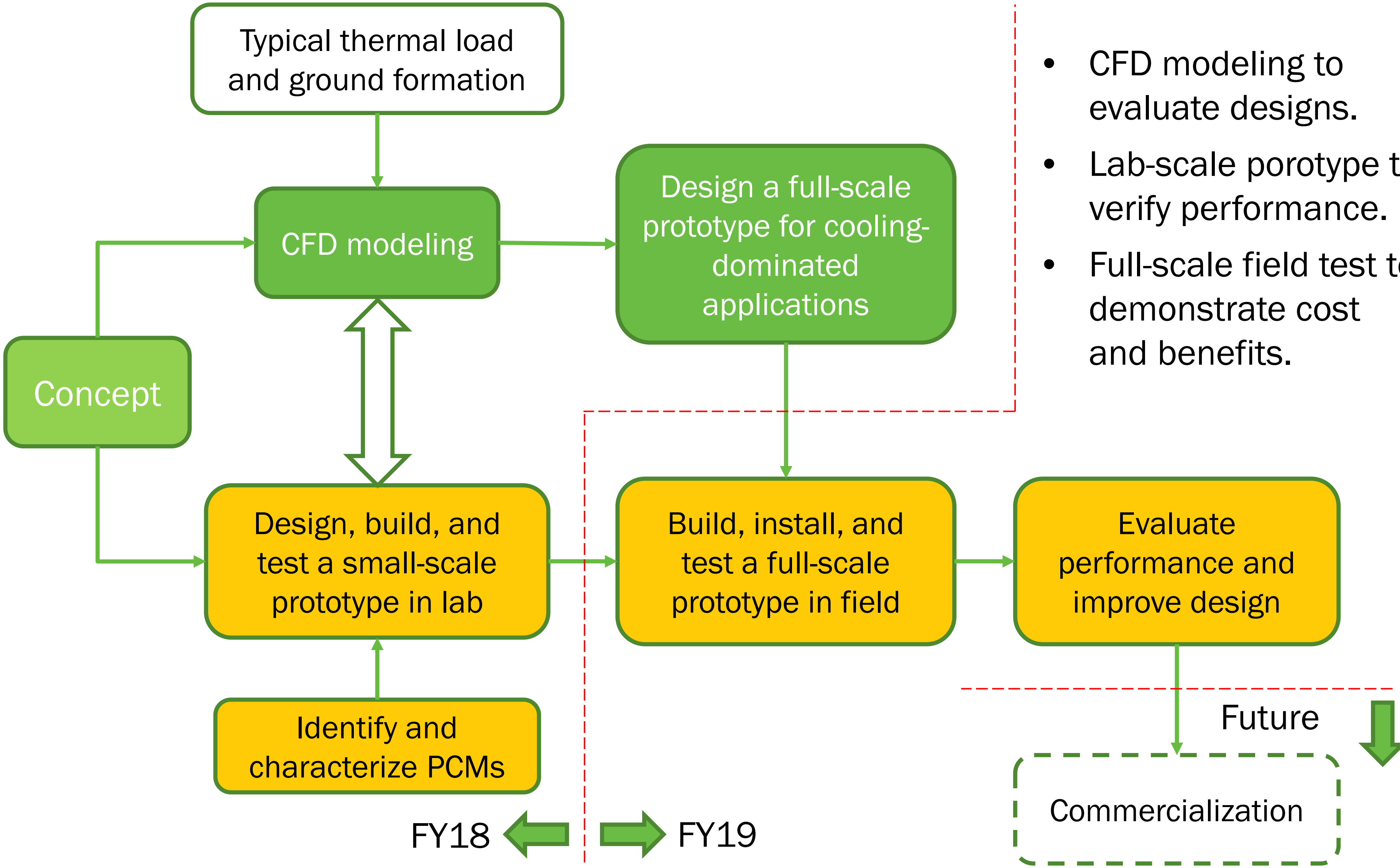


ORNL Invention Disclosure: 201804082, DOE S-138,749

- Installed in shallow subsurface → **less drilling**.
- Filled with water and PCMs → **much higher heat capacity** than ground formation.
- Hybridized with other heat sink/source → **rechargeable**.

	Soil/rock (typical)	Water	Inorganic PCM
Specific heat [kJ/(m^3-C)]	2,070	4,200	~3,000
Heat of fusion [kJ/m^3]	NA	334,000	312,880
Thermal conductivity [W/(m-C)]	1.7	Liquid: 0.6; Solid: 2.2	Liquid: 0.5; Solid: 1.1

Approach (Cont'd)

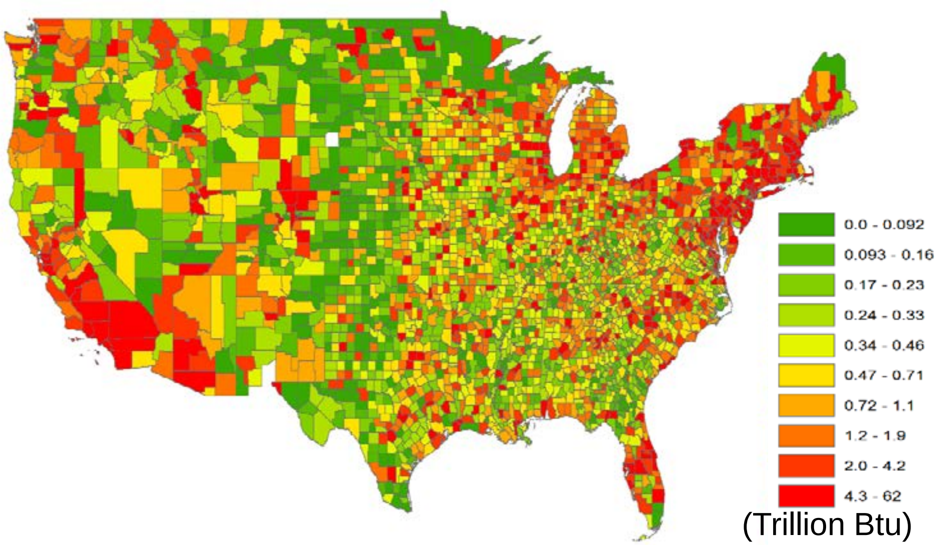


- CFD modeling to evaluate designs.
- Lab-scale porotype to verify performance.
- Full-scale field test to demonstrate cost and benefits.

Impact

- Enable wider adoption of GSHPs by reducing initial cost and land requirement/disturbance → Reduced primary energy consumption and carbon emissions.
- Create more jobs and foster sustainable economic growth.
- Support transactive controls with thermal energy storage → Improved stability and resilience of electric grids.

Primary Energy Saving Potential of GSHPs in Each County



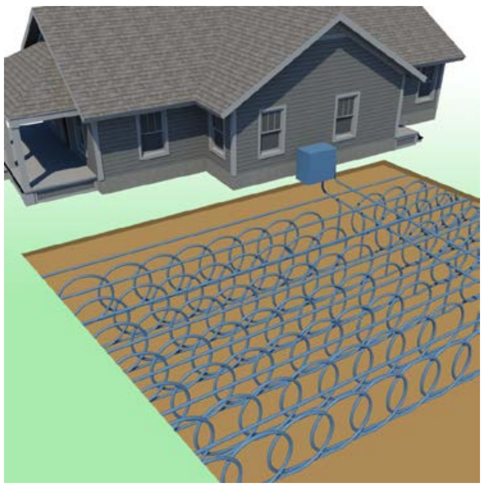
National Technical Potential of GSHPs

	Annual Source Energy Savings	Annual Carbon Emission Reductions	Annual Energy Cost Savings
	Quad Btu	Million Mt	Billion $
Residential	4.3	271.1	38.2
Commercial	1.3	85.2	11.6
Total	5.6	356.3	49.8

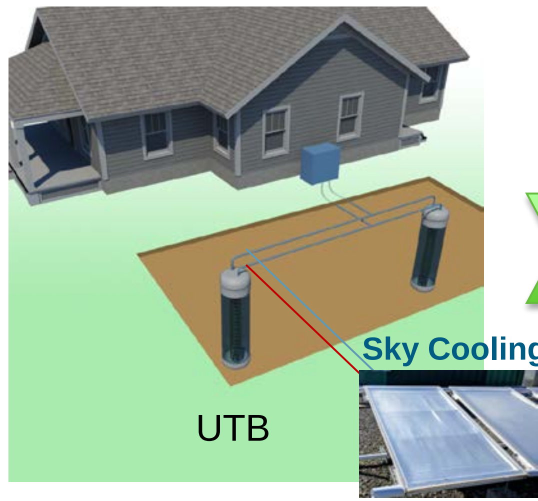
Source: Liu et al. 2017

Impact (Cont'd)

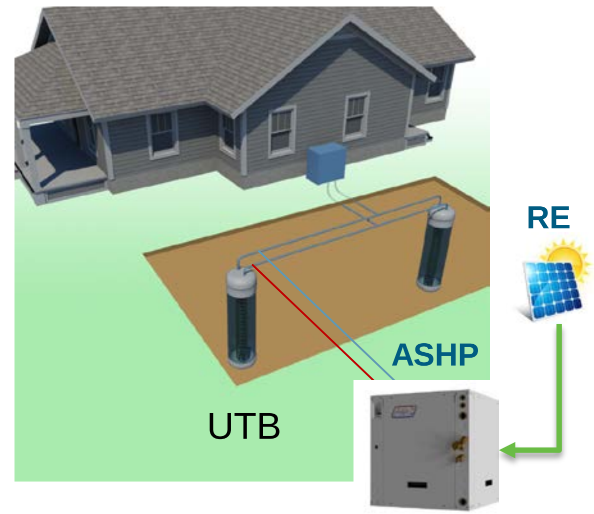
- Transform GSHP from an expensive energy efficient HVAC technology to a cost effective electric-load-shaping technology.



Replace expensive (vertical) or large area (horizontal) conventional GHXs.



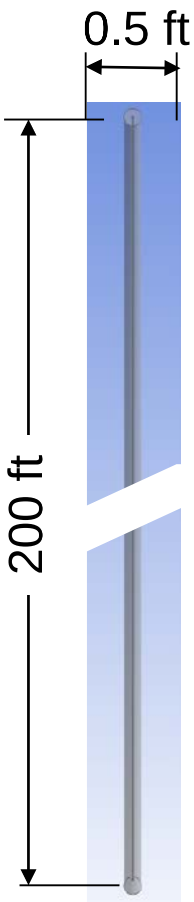
Hybrid with other low-grade heat sink/source (air, solar thermal, waste water, etc.).



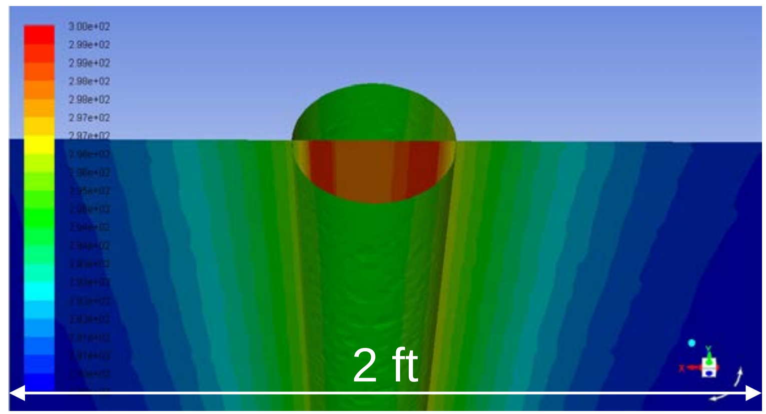
Decouple thermal demand from electricity supply → reduced peak electricity demand and improved stability of grids.

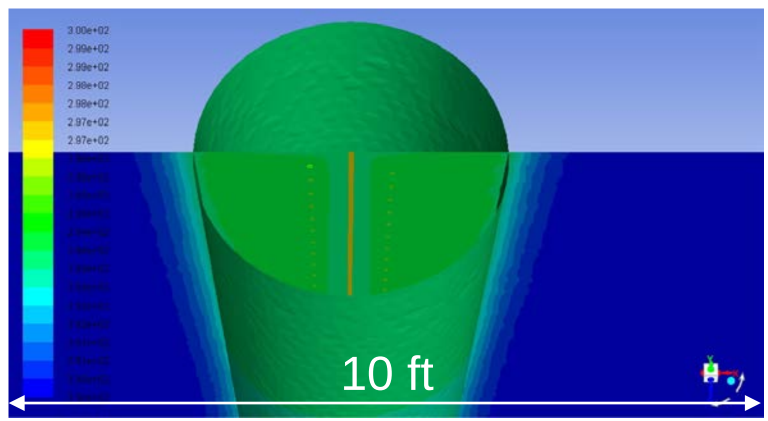
Progress (Early-Stage): CFD Modeling

CFD models were created for both the conventional vertical bore GHX (VBGHX) and UTB. Simulation results indicate water circulation inside tank is critical for fully utilizing the thermal capacity of UTB.

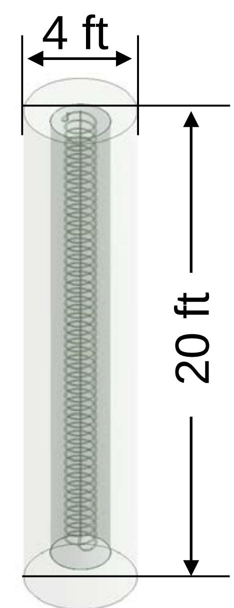


Conventional VBGHX



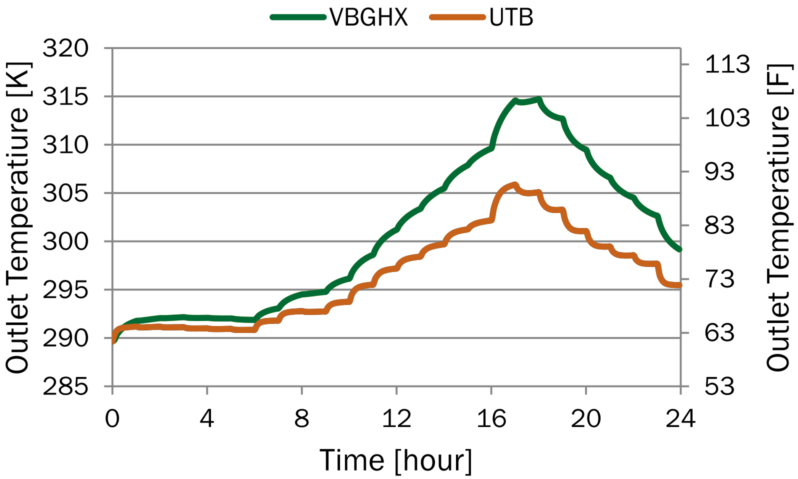


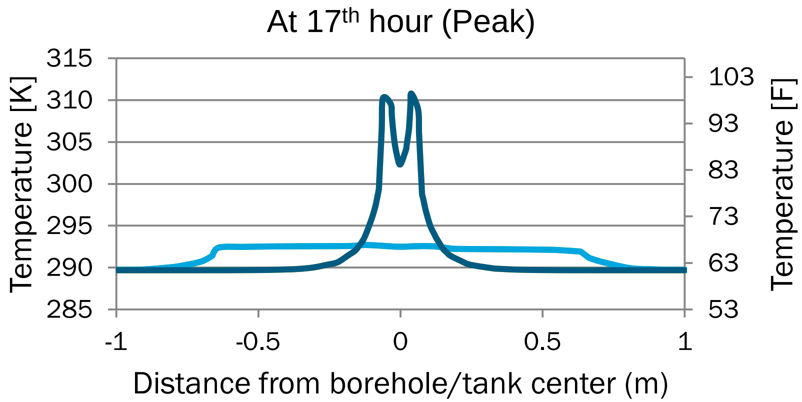
UTB

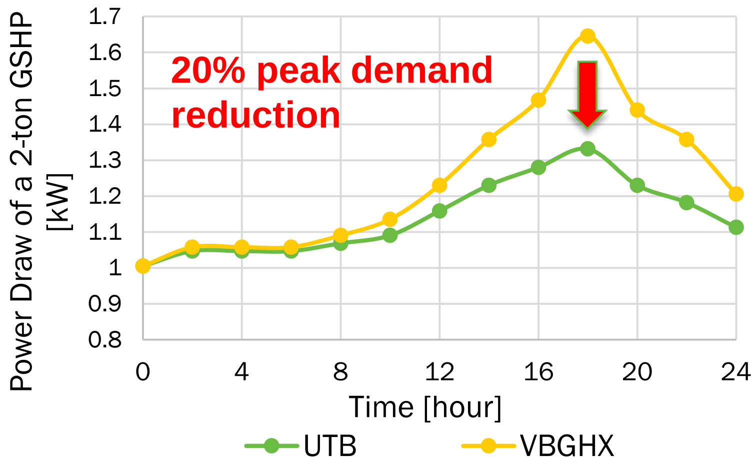


Temperature distribution within borehole/tank and the surrounding soil after rejecting heat for 24 hours.

Progress (Early-Stage): CFD Modeling





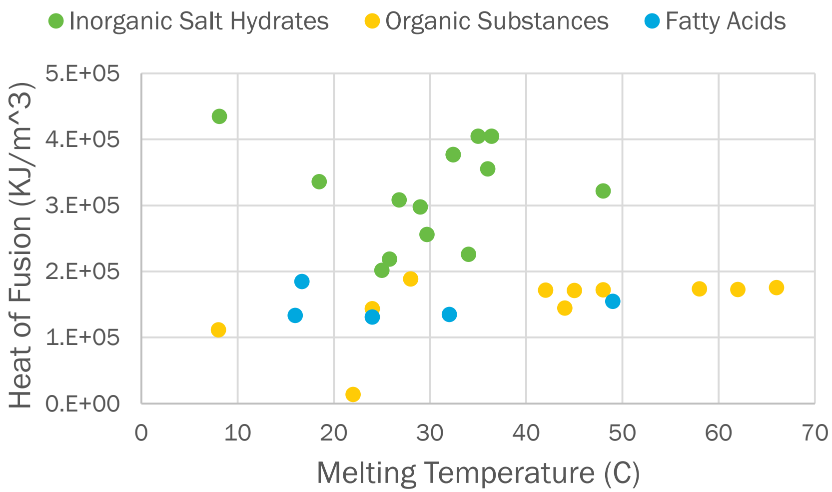


- During cooling (heat rejection) operation, UTB's outlet temperature is lower than that of VBGHX, especially at peak hour, which results in higher cooling efficiency of a GSHP.
- Tank water temperature is uniform and lower than the ground temperature near VBGHX even without PCMs.

Progress (Early-Stage): PCM Study

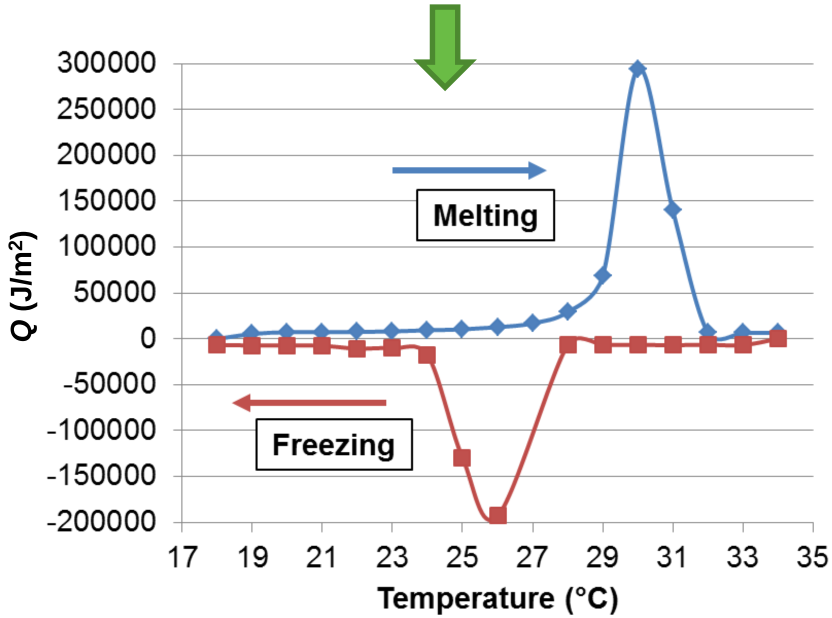
Selected PCMs based on melting temperature, thermal capacity, packaging, and cost.

Latent Heat of Various PCMs



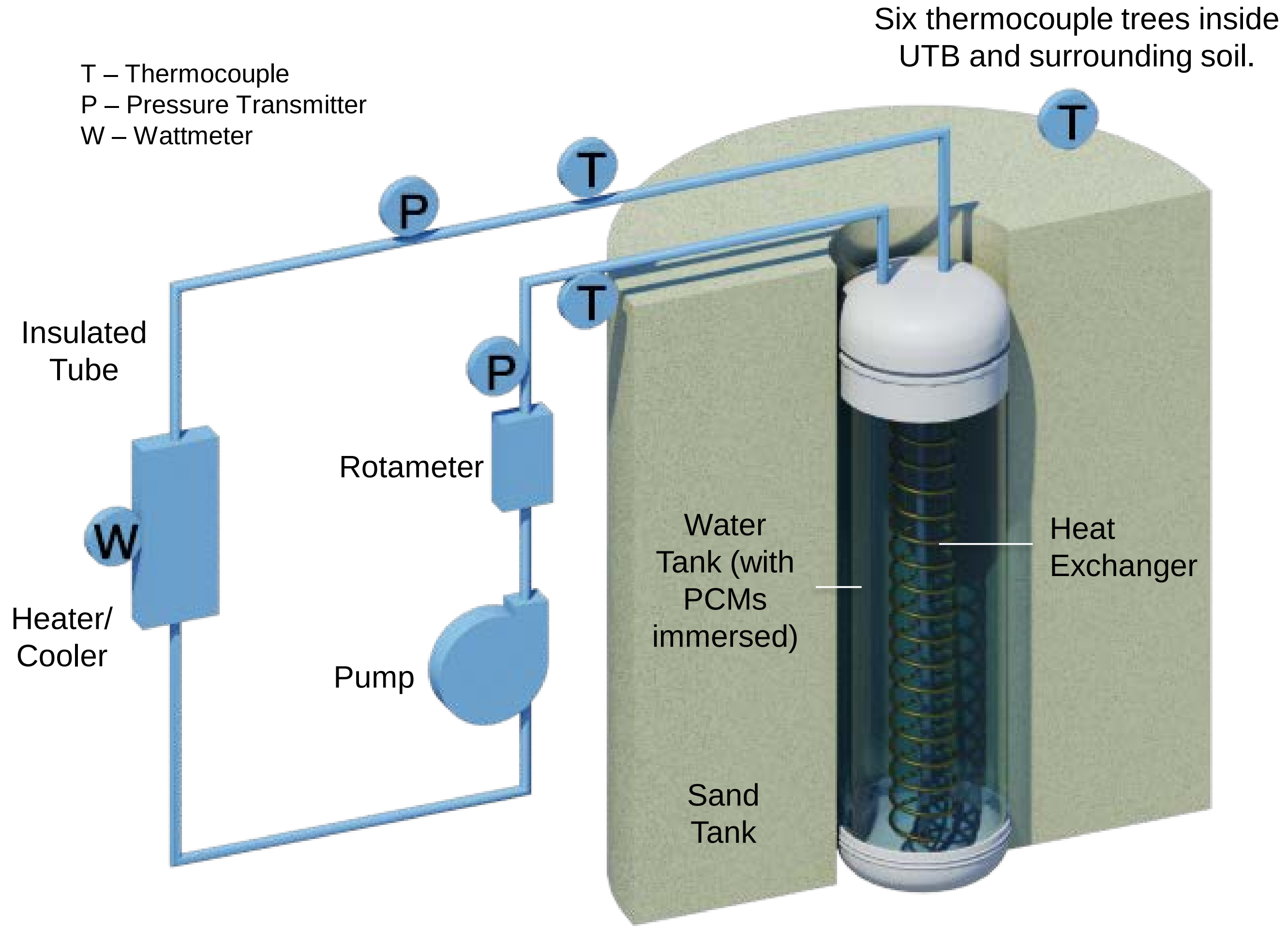
- Inorganic PCMs have higher volumetric heat capacities (close to water/ice), better thermal conductivity (about 0.5 W/mK) and lower cost (about 0.3 $/lb.) than other PCMs.

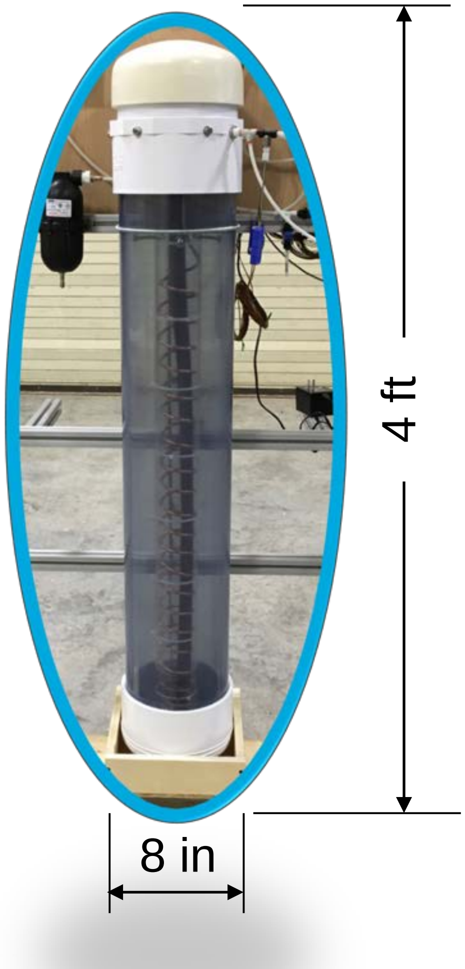
Test Results of Candidate PCM Products



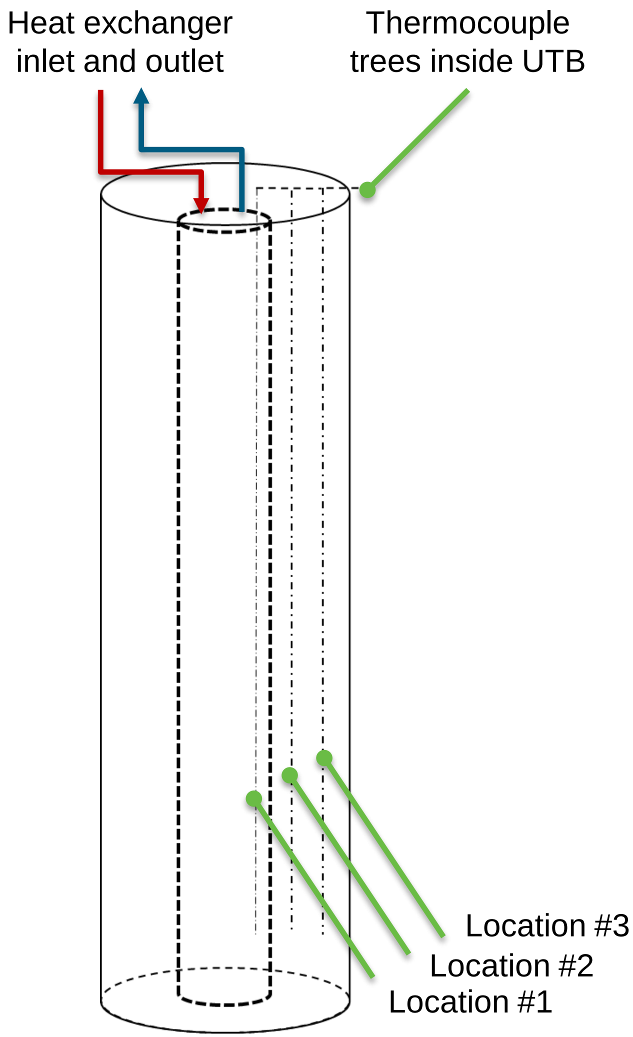
Progress (Early-Stage): Lab-Scale Prototype

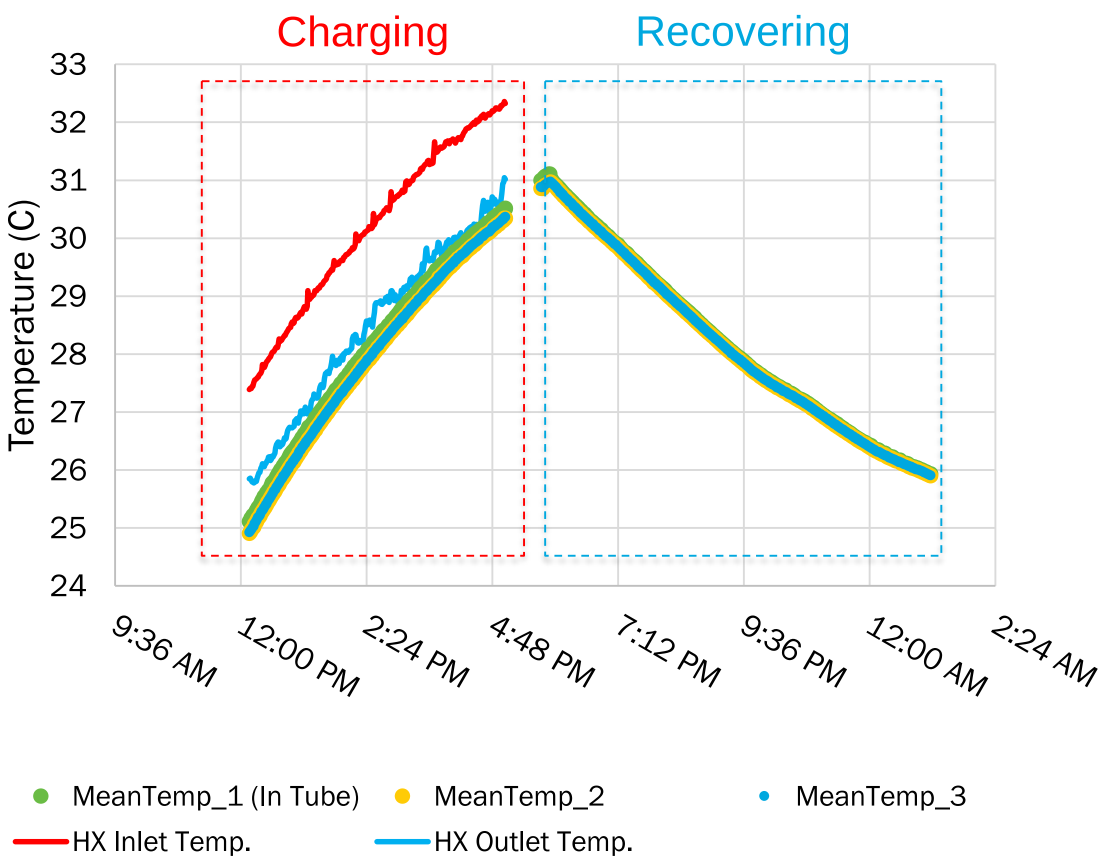
Design and build a small-scale prototype for lab test to characterize performance, validate CFD model, and analyze cost.





Progress (Early-Stage): Lab-Scale Prototype

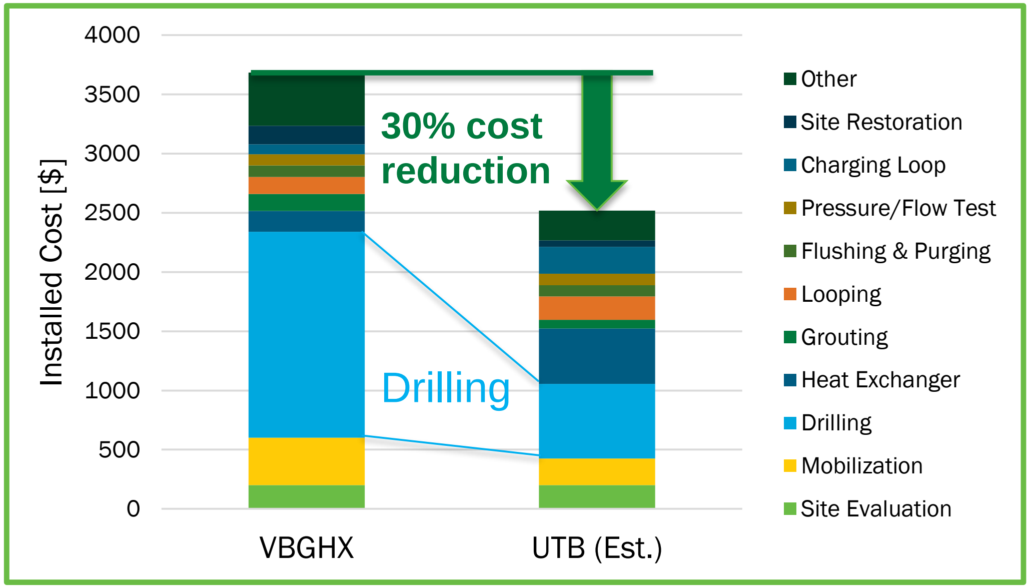




Base case (without PCM) results: (1) uniform water temperature resulting from natural convection; (2) effective heat transfer between heat exchanger and water; and (3) longer time for recovering than charging.

Stakeholder Engagement (Early-Stage)

- Work with NYSERDA to investigate feasibility of applying UTB in cold climate (a proposal has been selected by NYSERDA).
- Introduce UTB to GSHP industry for field test and improvement.
- Collaborate with utilities to apply UTB for transactive control.
- Engage with industry partners for manufacturing UTB as a self-contained product.



Significant Cost Reduction Potential with UTB

Auger Drilling for Large Diameter but Shallow Boreholes

Remaining Project Work

- Improve CFD modeling
  - Model selected PCMs
  - Account for seasonal change of soil temperature in the shallow subsurface
- Conduct lab tests to characterize performance of small-scale prototype
  - Evaluate impact of PCMs
  - Analyze recovery rate of thermal capacity
- Design full-scale prototype
  - Optimize configuration (e.g., materials, dimension, ratio between water and PCMs) to improve cost effectiveness
  - Develop procedures for assembling, installing, and maintaining UTB
- Field test of full-scale UTB (planned for FY19)
  - Identify test site, assemble and install UTB
  - Monitor and analyze performance
- Disseminate results (planned for FY19)

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: DOE $240K in FY18
Variances: None
Cost to Date: Spent $110K by March 2018
Additional Funding: None

Budget History					
FY 2017 (past)		FY 2018 (current)		FY 2019 – 09/30/2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
0	0	$240K	0	$170K	0

Project Plan and Schedule

Project Schedule												
Project Start: 10/1/2017		Completed Work										
Projected End: 9/30/2019		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned)										
		Milestone/Deliverable (Actual)										
	FY2018				FY2019				FY2020			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Concept design of UTB												
Q2 Milestone: CFD model of UTB												
Current/Future Work												
Q3 Milestone: Performance evaluation of UTB through CFD simulation and lab-test												
Q4 Milestone: Design of a full-scale prototype												
Q4 Milestone: Field test of a full-scale prototype												