Geological Thermal Energy Storage (GeoTES) for Seasonal Dispatching and its Hybridization with Solar Thermal, Carnot Batteries, and Data Center Cooling

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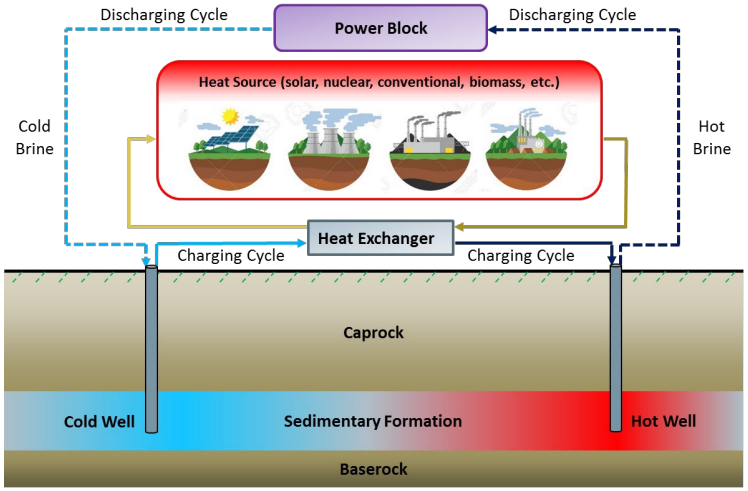
Thermal-Mechanical-Chemical Energy Storage Workshop

Geothermal Storage Concept: Geological Thermal Energy Storage (GeoTES)

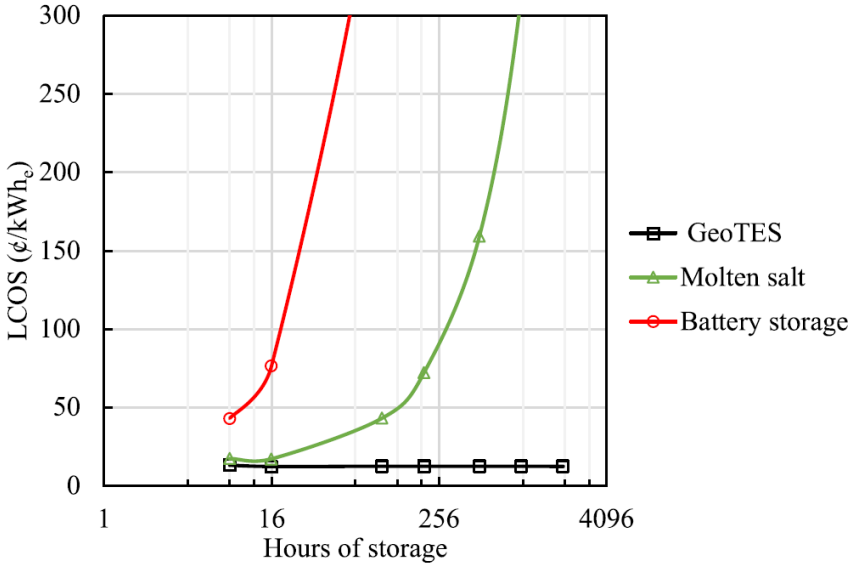
- Aka, Reservoir Thermal Energy Storage (RTES), Underground Thermal Energy Storage (UTES)



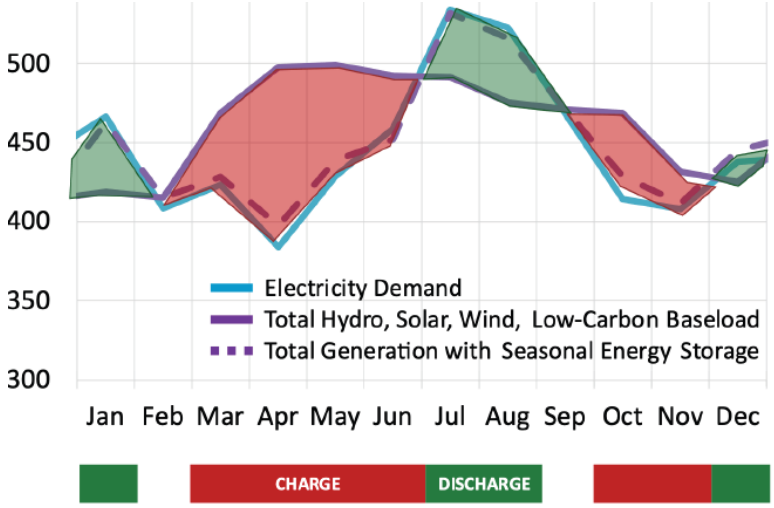
Energy In	(Thermal) Energy Storage	Energy Out
• Solar thermal • Excess grid renewable electricity • Waste heat from fossil fuel and energy end users • Excess nuclear heat	• Low-temperature water reservoirs • Depleted oil/gas reservoirs	• Electricity • Heating or cooling

Is Geothermal Storage Competitive?

- Suitable for storage duration of a wide range, up to half a year.
  - There is minimal marginal cost for geothermal storage with increasing storage duration
  - We just need to find a reservoir, instead of building one!

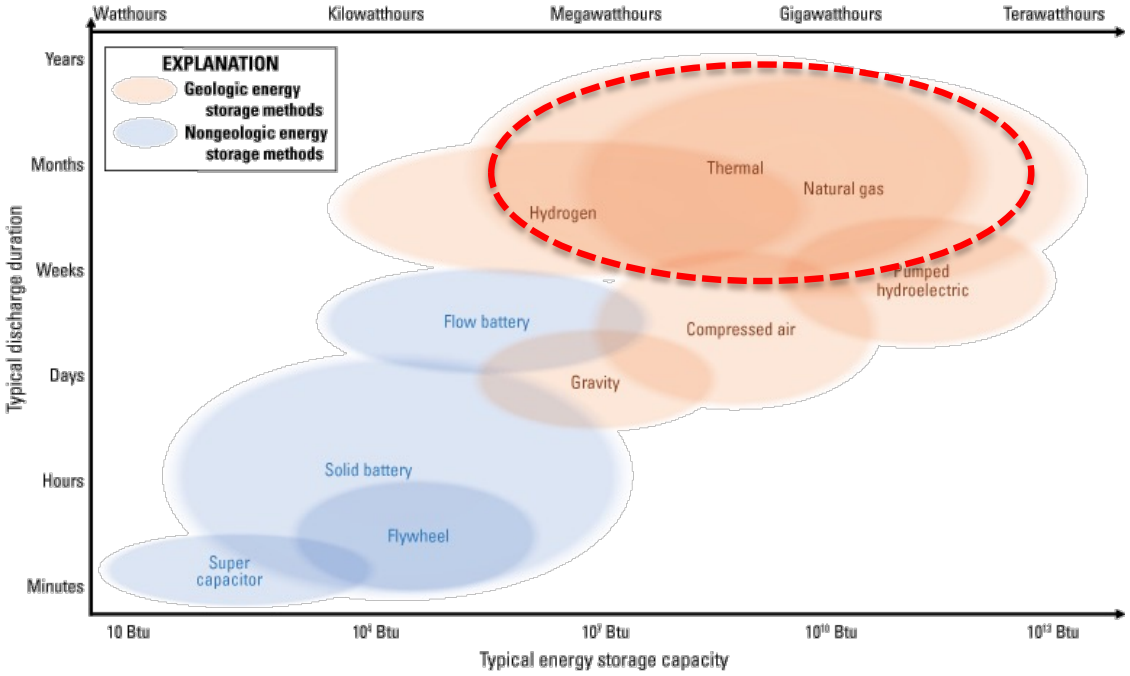


Sharan, McTigue, Zhu, et al. 2020. "Using concentrating solar power to create a geological thermal energy reservoir for seasonal storage and flexible power plant operation," *Journal of Energy Resources Technology*.



EPRI, 2022, Seasonal Energy Storage: A Technical and Economic Framework, https://www.epri.com/research/products/000000003002025178

Subsurface Energy Storage Systems



Buursink et al., 2023. Geologic energy storage. U.S. Geological Survey Fact Sheet 2022-3082, p. 4. https:// doi.org/10.3133/fs20223082

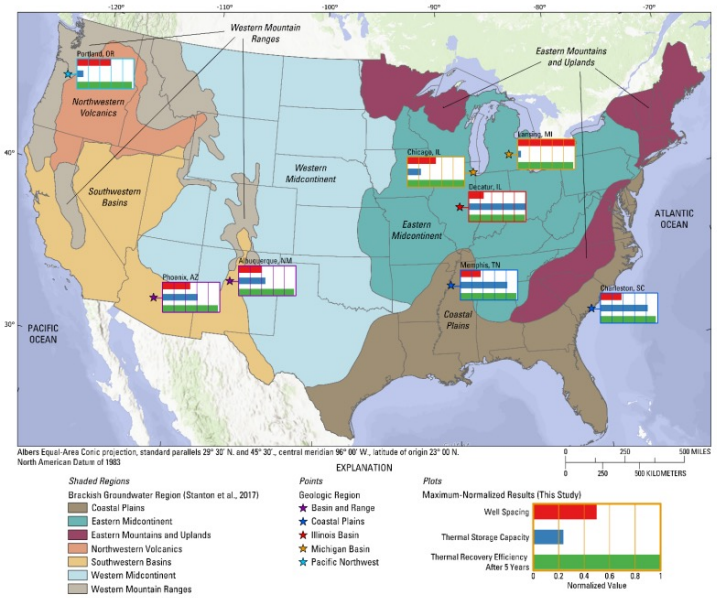
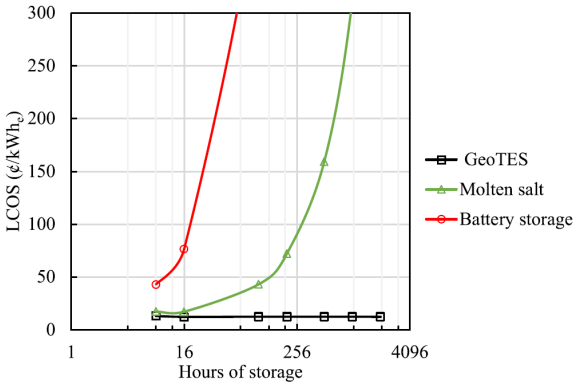


Figure 4: Maximum-normalized results for well spacing, thermal storage capacity, and thermal recovery efficiency after 5 years for each analyzed city. Results are grouped by geologic region and are overlain on the brackish groundwater regions of the United States of Stanton et al. (2017).

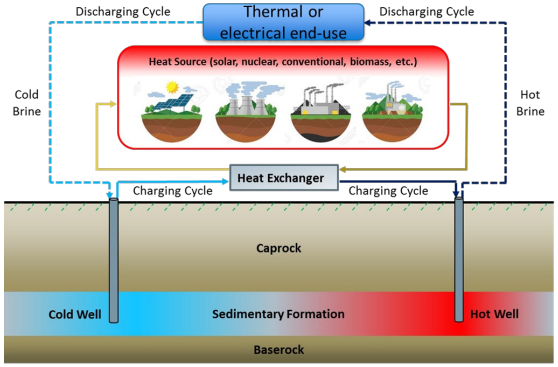
Pepin et al., 2021, "National-Scale Reservoir Thermal Energy Storage Pre-Assessment for the United States", Stanford Geothermal Workshop, https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2021/Pepin.pdf

GeoTES Opportunities

Low marginal cost of energy capacity

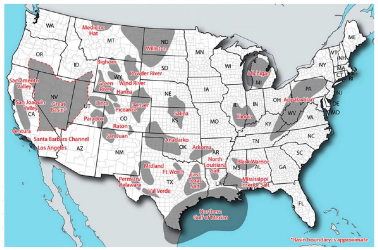


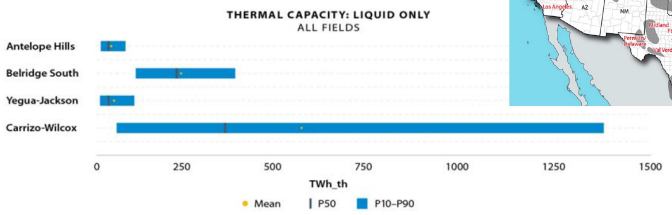
Flexibility of design and application



Large capacities available and possible

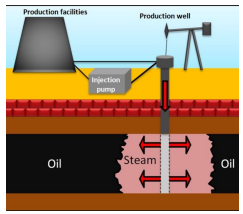
A reservoir with a cubic side-length of 270 m can provide 200 MW_e (or 1 GW_{th}) for >1,300 hrs





Left: Akindipe et al., 2024. NREL/TP-5700-91225. https://www.nrel.gov/docs/fy25osti/91225.pdf.
Right: Porro et al., 2012, "An Estimate of the Geothermal Energy Resource in the Major Sedimentary Basins in the United States," Proceedings of GRC, Reno, NV."

Combination of commercial technologies



Left: Image 48255, Dennis Schroeder, NREL
Middle: Guangdong Zhu
Right: http://large.stanford.edu/courses/2015/ph240/zerkalov2/

GeoTES Projects

Title	Performance Period	Team (14 members)	Sponsor
Techno-Economic Analysis and Market Potential of Reservoir Thermal Energy Storage Charged with Solar Thermal and Heat Pumps	01/2023–09/2026	**NREL***, INL, LBNL, PRM, EarthBridge	DOE-GTO
Data Centers and Subsurface Thermal Energy Storage – Matching Data Center Cooling Needs with Recharging of Subsurface Thermal Energy Storage	01/2023–06/2024	LBNL (lead), INL, **NREL**	DOE-GTO
Lowering Data Center Peak Demand and Grid Infrastructure Costs Through Long Duration Cold Geological Thermal Energy Storage (GeoTES)	01/2025–12/2025	**NREL***, LBNL, U. Chicago, Princeton	DOE-GTO
ConocoPhillips GeoTES Collaboration with NREL, INL and LBNL: techno-economic feasibility study	08/2025–12/2026	**NREL***, INL and LBNL	ConocoPhilips
Daily and Long Duration Storage for CST using Geological Thermal Energy Storage: Pilot Plant and Techno-Economic Analysis	03/2025–12/2028 (Pending)	**PRM*,** NREL, Ramsgate Engineering, Gossamer Space Frames	DOE-SETO
Combined Wellbore Construction High-Temperature Tools and Reservoir Thermal Energy Storage	03/2025–12/2028 (Pending)	**PDS***, CRC, NREL, Blade Energy Partners, EMCOR group	DOE-GTO

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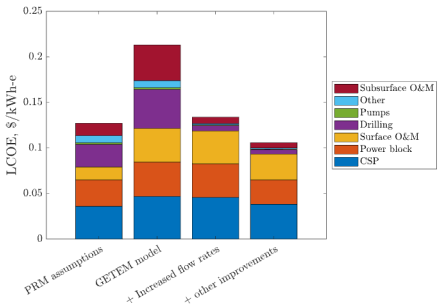
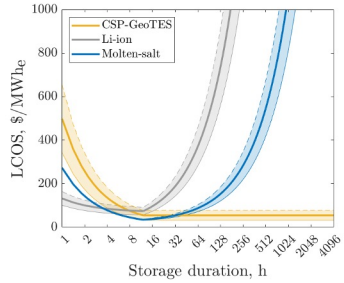
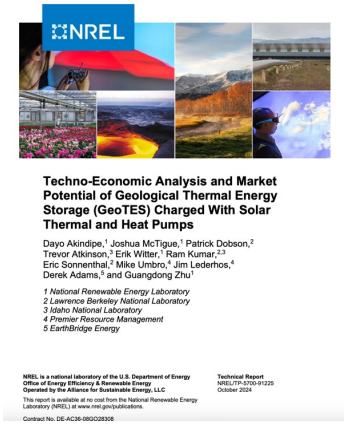
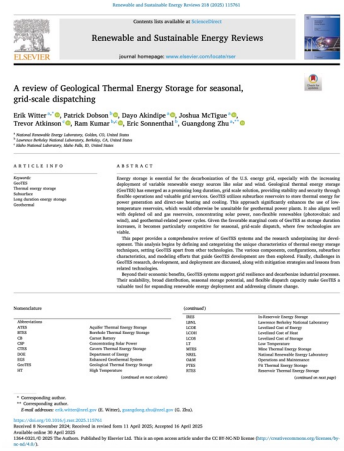
Outcomes

- Evaluation of technical and economic potential of two GeoTES technologies through case studies.
- Development of initial publicly available modeling tool for system assessment, initial optimization, and performance prediction.
- Documentation of the technical and deployment barriers of GeoTES technologies.
- Identification of potential geographical locations, completion of case studies of RTES, and evaluation of initial market potential in the United States.









NREL NATIONAL RENEWABLE ENERGY LABORATORY

INL Idaho National Laboratory

BERKELEY LAB

Premier Resource Management, LLC

EarthBridge ENERGY

Title	Performance Period	Team	Sponsor
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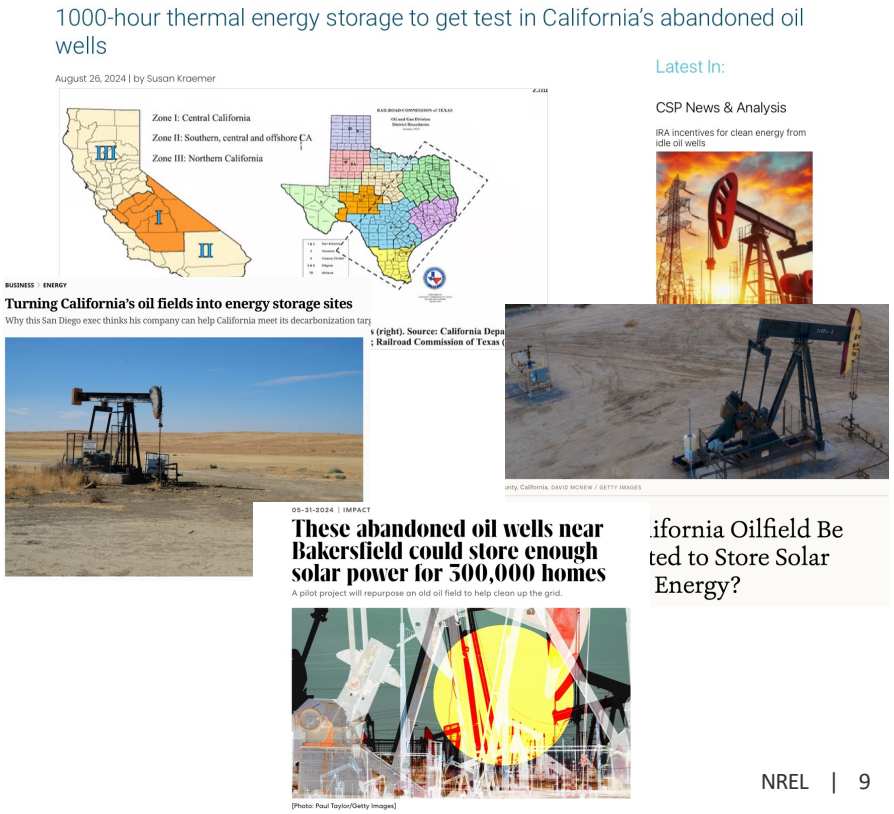
Impacts

- Two new demonstration projects
- One private-entity-funded feasibility study
- Wider recognition of GeoTES value



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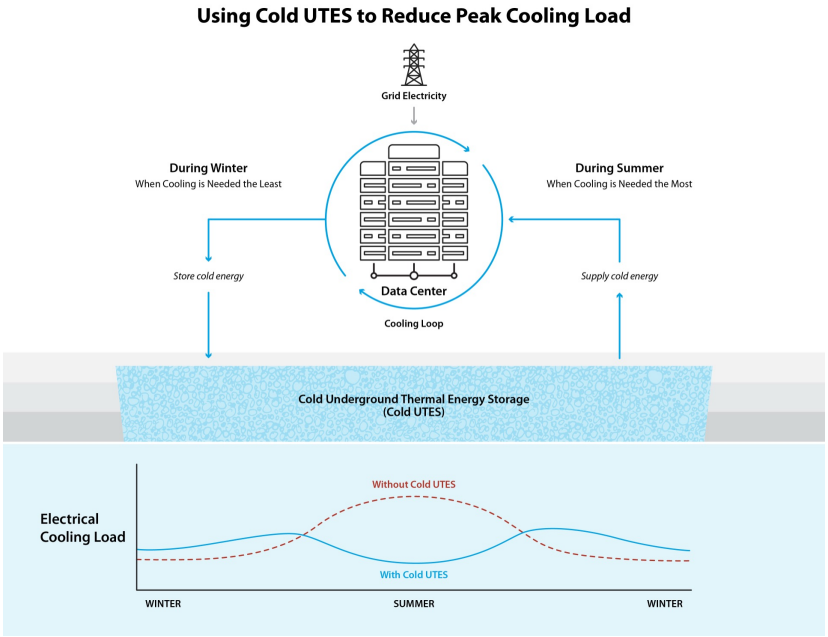
Title	Performance Period	Team	Notes
Reducing Data Center Peak Cooling Demand and Energy Costs With Underground Thermal Energy Storage (UTES)	01/2025 – 12/2025	NREL*, LBNL, U. Chicago, Princeton	Funded by GTO

- **System concept**
  - Using cold UTES for seasonal energy dispatching to mitigate the cooling demand to the grid
  - Charging cycle typically in winter:
    - Use the abundant capacity of surface cooling infrastructure (chiller and dry coolers)
  - Discharging cycle typically in summer (or other seasons if needed)
    - Provide cooling load to data center cooling need, partially or wholly, for a given time of day.
- **UTES technologies**
  - Reservoir thermal energy storage
  - Borehole thermal energy storage



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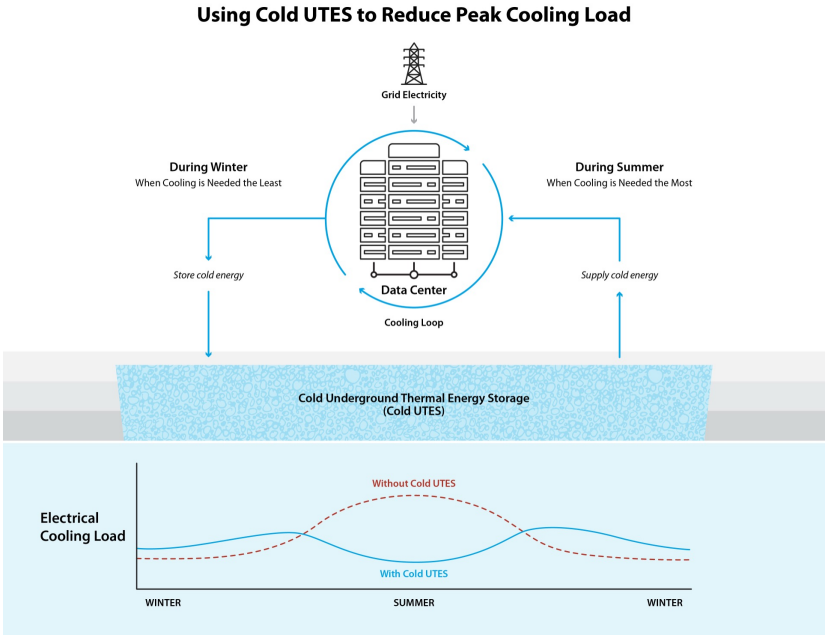
Project Objectives

- To tackle the very challenges of increasing grid stress with new data center deployment
  - Increasing grid peak load
  - Required grid expansion
- To introduce an emerging technology to support the accelerated data center deployment
  - Cold UTES for dispatching cooling load over a wide time scale up to seasonal scale, with no water consumption
- Quantify system-level benefits, including avoided energy cost, water consumption, and grid infrastructure costs.
- Support grid resilience with time-shifted energy storage and load management.
  - Under various realistic deployment scenarios such as electric market, location, and behind-of-meter generation

Cold UTES Technology



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Approach

- Task 1: System Analysis
  - Establish projected performance of data center cooling systems with and without using cold UTES
- Task 2: Data Center Load Projection
  - Establish projected cooling load needs of data centers in the future
- Task 3: Grid Impact Analysis
  - Evaluate the grip impact value of cold UTES for data center cooling
- Task 4: Technical Advisory Groups
  - Seek feedbacks and advices from technology and commercial stakeholders
- Task 5: Reporting, Communication & Outreach
  - Promote the project and disseminate the learnings

- Technical Advisory Groups (TAGs)
  - **TAG 1**: Utility stakeholders
  - **TAG 2**: Subsurface technologies experts
  - **TAG 3**: Data center developers

Alcatex
Arcadis
Conifer
Delta Energy Lab
Equinix
FirstEnergy
Green Tech
Harvard
Iron Mountain Data Centers
J.M. Gross Engineering, LLC
Meta > Open AI
Nvidia
Sabey Data Centers
TeraWulf
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Ava Energy
NASEO
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Bedrock Energy
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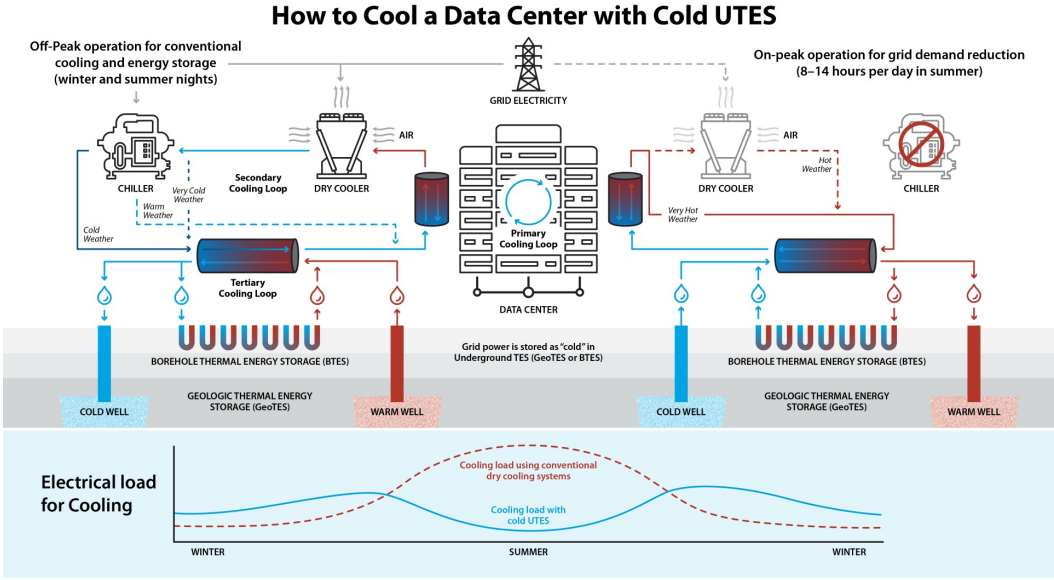
Anticipated outcomes

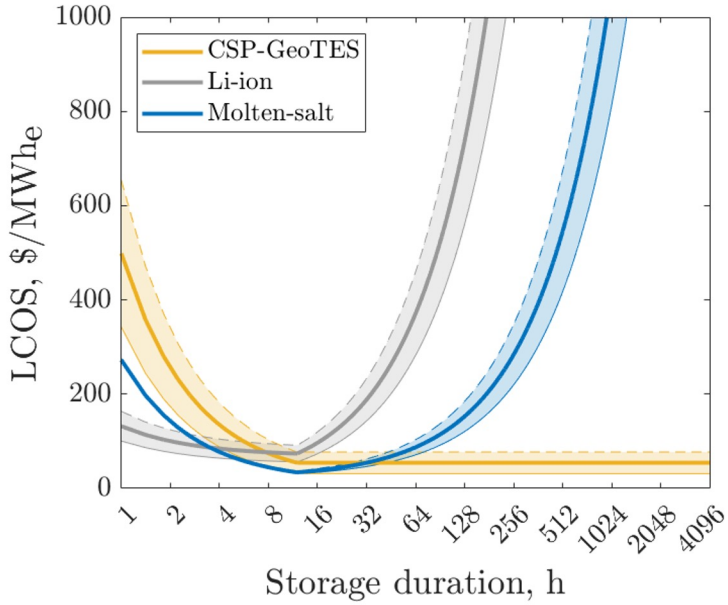
- A report summarizing
  - The benefit of cold UTES for lowering data center peak load at a grid level and grid infrastructure cost
  - Commercial viability of proposed cold UTES technologies
- Public awareness of cold UTES to key stakeholders, including data center designers, utilities, and technology developers
- Recommended strategy to advance cold UTES technologies.



Conclusions

"Geothermal is a triple resource: an **energy** source for heating, cooling, and power; a **storage** resource; and a **mineral** resource," said Amanda Kolker, geothermal laboratory program manager at the National Renewable Energy Laboratory (NREL).

- No marginal cost on GeoTES with the increasing storage duration
  - Suitable for seasonal storage
- Essentially, GeoTES is an integration of mature technologies from various energy sectors:
  - Power cycle, CSP, geothermal, oil/gas.
- Foreseen impacts to the energy needs of grid, heating and cooling demands.



Questions?

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