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NATIONAL LABORATORY OF THE ROCKIES

Geological Thermal Energy Storage for Long Duration Energy Storage Applications

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OBJECTIVE

- Develop and apply a capacity estimation framework to demonstrate the availability and scale of suitable formations within the U.S.
- Estimate well count and capital costs to demonstrate the feasibility of GeoTES deployment.

INTRODUCTION

- GeoTES stores heat in subsurface formations and later delivers it as heating/cooling or electricity, enabling long-duration energy storage.
- It accesses widely available formations such as brackish/saline aquifers and depleted oil and gas reservoirs in sedimentary basins.
- GeoTES operates over broad temperature ranges, integrates with diverse heat sources, and serves industrial/process heat, district energy, and power applications.

METHODS

Used a Monte-Carlo method to address input uncertainty.

	Less Favorable	More Favorable	Unit
Area	1	1	km²
Thickness	50	100	m
Porosity	0.30	0.38	%
Density of water	1,000	1,010	kg/m³
Specific heat of water	4,182	4,182	J/kg·C
Density of solid	2,350	2,350	kg/m³
Specific heat of solid	930	930	J/kg·C
Temperature Difference	100	200	°C
Thermal Recovery Factor	0.70	0.90	%
Well Mass Flow Rate	25	100	kg/s
Discharge Duration	3,600,000	3,600,000	s
Cost per well	1,250,000	750,000	$/well

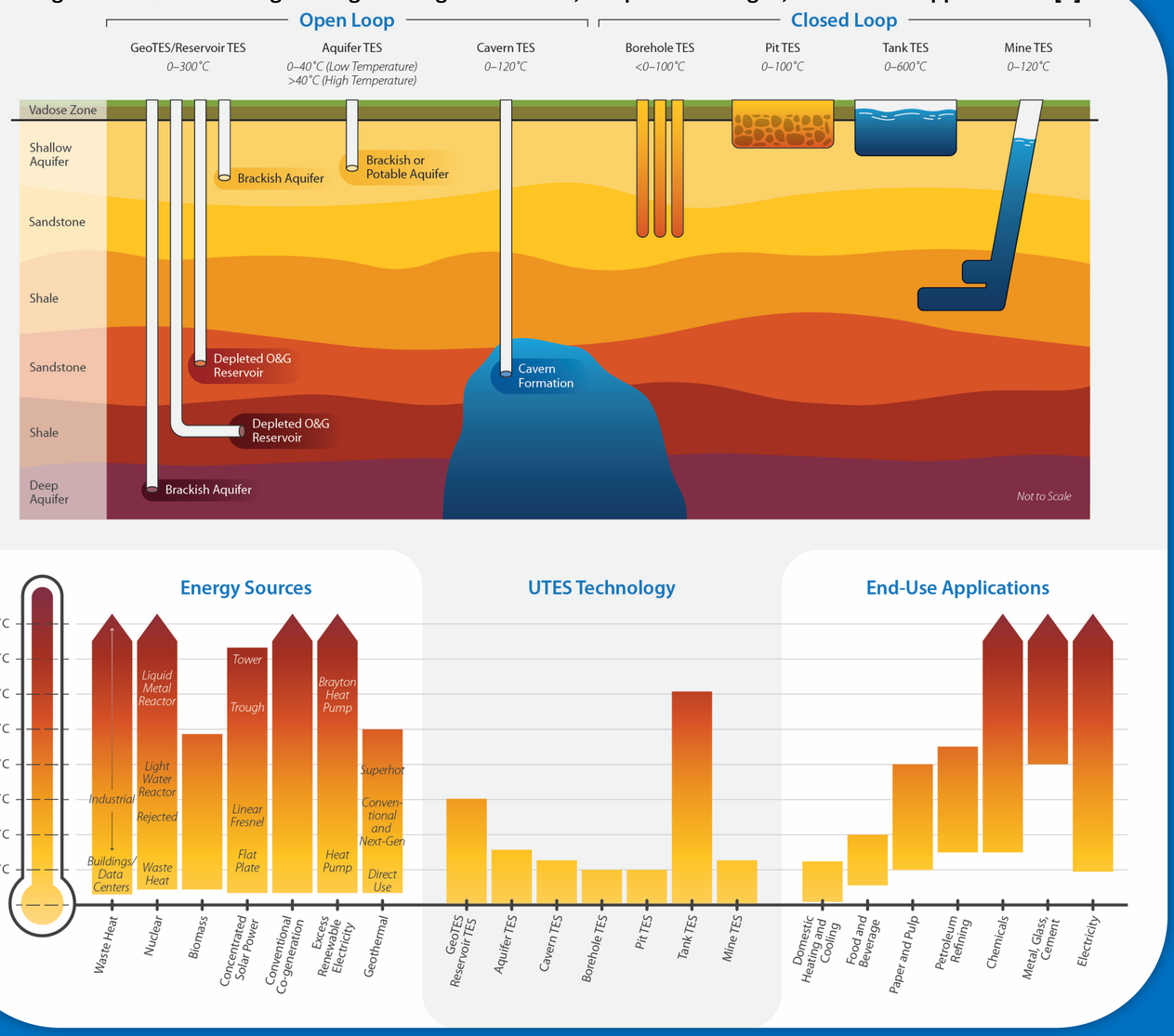
Table 1. Input assumptions for well count and cost analysis.

$$E_t = hA\left[\begin{matrix}(1-\varepsilon)\rho_s c_s \\ +\varepsilon\rho_w c_w\end{matrix}\right]\Delta T\eta_t$$

$$\frac{N_{well}}{E_t} = \frac{2}{\dot{m}_{well}\tau_{dis}c_w\Delta T}$$

$$\frac{C_{\text{total}}}{E_t} = \frac{2\bar{C}}{\dot{m}_{well}\tau_{dis}c_w\Delta T}$$

Figure 1. UTES technologies' target storage formations, temperature ranges, and end use applications. [1]



RESULTS

Thermal and Electrical Storage Capacity

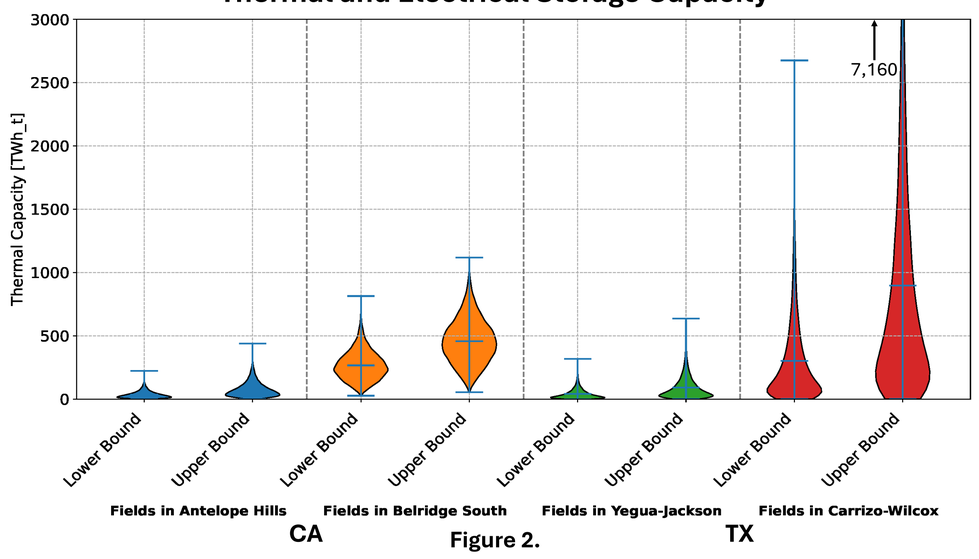


Figure 2.

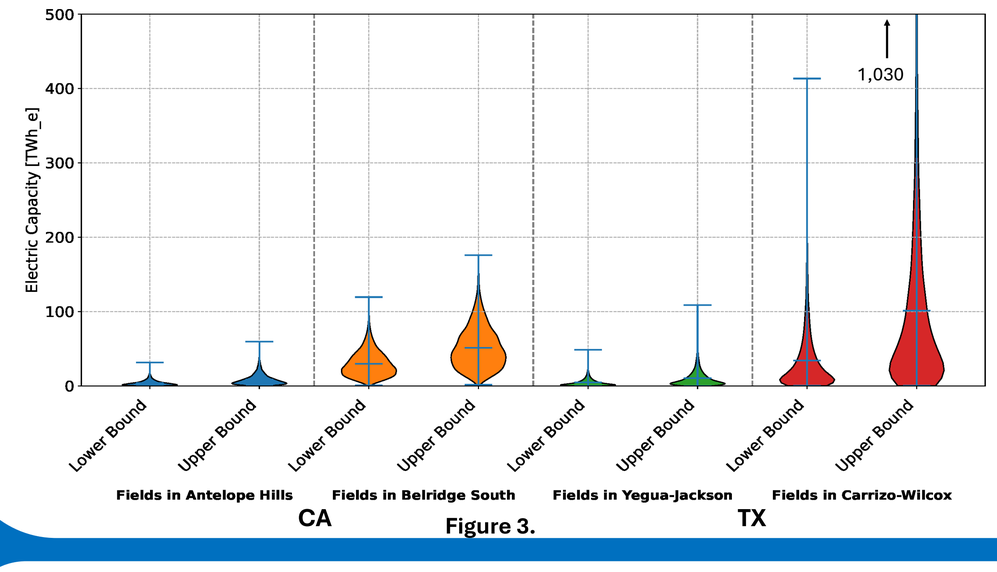


Figure 3.

Potential Storage Formations

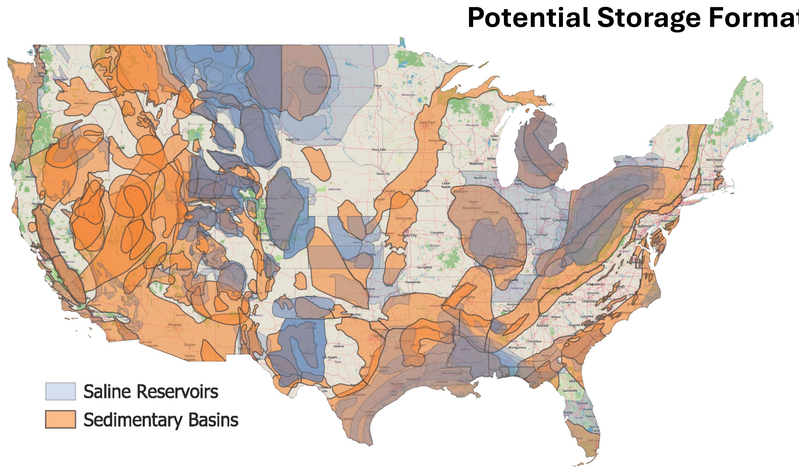


Figure 4 (above). Saline reservoirs and sedimentary basins in the U.S. [2] [3]

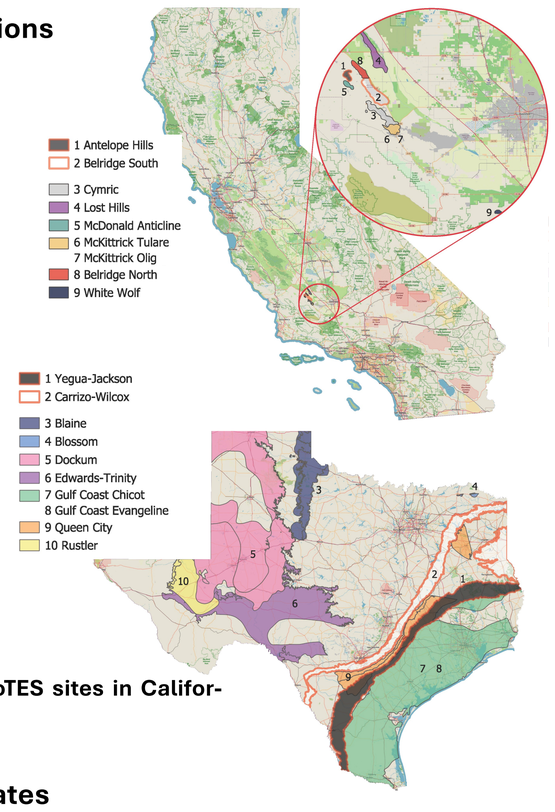


Figure 5 (right). Potential GeoTES sites in California and Texas. [1]

Well Count & Cost Estimates

		Less Favorable	More Favorable
Liquid Only (Lower Bound)	Number of wells	234	192
	Energy Storage Capacity [TWh]	1.2	8.0
	Total Cost (M$)	291.7	143.9
Liquid + Solid (Upper Bound)	Number of wells	5178	354
	Energy Storage Capacity [TWh]	2.7	14.8
	Total Cost (M$)	647.3	265.4
Both Scenarios	Wells/TWh	191.3	23.9
	$/kWh	0.239	0.018

Table 2. Size, cost, and well count metrics.

DISCUSSION

- GeoTES offers **terawatt-hour-scale, long-duration storage** potential across much of the U.S., leveraging **abundant formations**.
- **Low marginal cost of energy capacity** and reliance on **mature oil, gas, and geothermal infrastructure and practices** make GeoTES a **competitive LDES** option for reducing curtailment, enhancing reliability, and providing seasonal shifting.
- Results highlight the need to **pair capacity with site-specific characterization** (geology, infrastructure, constraints) **to de-risk projects** and optimize design and operations.

FUTURE WORK

- Integrate capacity estimates with siting and permitting factors (faults, land use, grid/access, end-user proximity, economics).
- Improve modelling of recovery factors and conversion efficiency (e.g., account for groundwater flow, storage geometry, fracture/porosity/permeability effects, and cycle-specific power conversion).
- Apply data-driven tools (e.g., machine learning for site screening, adapt NLR's reV for GeoTES) and extend analysis to cold thermal storage for district cooling and data centers.

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