

A Technical Approach to Prove the Power Generation Potential and Efficiency of Storing Thermal Energy in Porous Permeable Sandstone Reservoirs

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ABSTRACT

This paper presents a modeling framework to evaluate the power generation potential and thermal efficiency of storing solar-gathered heat in porous, permeable sandstone reservoirs at shallow depths (less than 3,000 ft). This process is called Geologic Thermal Energy Storage (GeoTES). Building on the U.S. Department of Energy Solar Energy Technologies Office (SETO) GeoTES Demonstration in Kern County, California, the study integrates proven thermal simulation tools with advanced 3D visualization using Blender. This combined workflow quantifies conductive and convective heat transport, retention dynamics, and recoverable energy over multiple thermal cycles. Results show that loosely consolidated, shallow formations with natural temperatures near 100°F can be economically converted into large-scale solar-charged geologic batteries. Modeled results demonstrate high thermal retention and recoverability, confirming that proven oilfields can be repurposed for dispatchable renewable power generation with near-zero exploration risk. Scaling this concept across the Western San Joaquin Valley could enable more than 100 gigawatts of clean, firm capacity—while introducing the novel idea of subsurface solar heat sequestration as both an energy-storage solution and a potential global cooling mechanism. This project is operated by Premier Resource Management with the following geothermal partners: DOE Geothermal Technologies Office, National Laboratory of the Rockies, Lawrence Berkeley National Laboratory, and Idaho National Laboratory. The GeoTES demonstration was awarded under the Biden Administration and is one of few awards approved by the Trump Administration - representing a bipartisan effort to Unleash GeoTES.

1. INTRODUCTION

Modern power systems increasingly depend on variable renewable generation while simultaneously facing growing exposure to extreme weather, seasonal demand swings, and reliability constraints. These conditions have elevated long-duration and ultra-long-duration energy storage from a supporting technology to a foundational requirement for modern electricity markets. Yet existing storage solutions struggle to provide multi-day to multi-week dispatchability at scale, particularly under extreme heat, prolonged cloud cover, or low-wind conditions. Addressing this gap requires a class of storage technologies that are physically robust, economically scalable, and capable of operating independent of surface-level weather events.

This paper presents a technical framework for demonstrating geologic thermal energy storage (GeoTES) using porous, permeable sandstone reservoirs that have been extensively characterized through decades of oilfield development. Central to this framework is the use of advanced 3D visualizations, developed in Blender, to accurately represent reservoir geometry, faulting, stratigraphic continuity, and physical properties in the subsurface. By integrating these visualizations with proven oilfield thermal recovery and reservoir simulation methodologies, the approach translates subsurface complexity into a form that is readily understood by power purchasers, system planners, and project financiers—stakeholders who must assess both performance certainty and capital risk.

The methodology builds directly on known thermal recovery technologies such as hot-water flooding and steam-assisted processes, which have demonstrated predictable heat transport, retention, and recoverability in similar geologic settings. Rather than proposing an untested subsurface concept, this work reframes mature oilfield practices as a scalable energy-storage solution capable of supporting dispatchable power generation. The visualization-driven modeling workflow provides a bridge between subsurface engineering realities and power-market requirements, enabling transparent evaluation of capacity, efficiency, and operational reliability.

Finally, the application of this approach to the largest oilfields on the west side of Kern County represents a potential step change in how oil, gas, and geothermal resources are perceived within a modern energy market. These fields offer exceptional reservoir continuity, areal extent, high levels of irradiance and existing infrastructure, positioning them as candidates for ultra-long-duration energy storage that can function through extreme weather and seasonal grid stress. By demonstrating technical feasibility and economic clarity, this work challenges conventional boundaries between hydrocarbons and renewables and presents a pathway for repurposing legacy oilfields into resilient, zero-combustion assets that underpin future power-system reliability.

2. INTEGRATION OF OILFIELD THERMAL SIMULATION WITH 3D VISUALIZATION AND HEAT-TRANSFER MODELING

Accurate evaluation of geologic thermal energy storage requires detailed understanding of subsurface geometry, reservoir continuity, faulting, and physical properties—information that is uniquely available in mature oilfields (See Figure 1). This work integrates

conventional oilfield thermal simulation outputs with three-dimensional visualization and heat-transfer modeling developed in Blender to create a comprehensive and intuitive representation of the subsurface system.

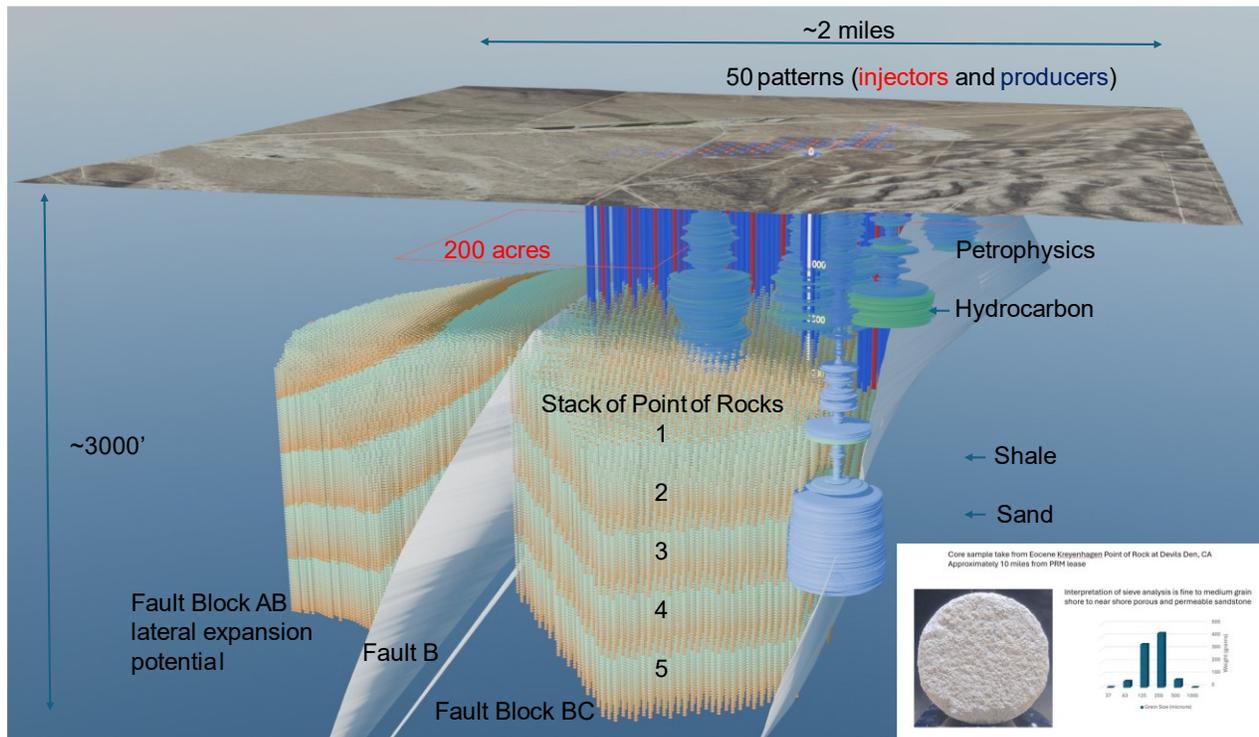


Figure 1: Outcrop and regional geologic mapping demonstrating reservoir continuity and scale in the Devils Den / Point of Rocks system

Oilfield data defining reservoir boundaries, vertical and lateral continuity, fault offsets, well spacing, and fluid properties are used to construct spatially accurate 3D reservoir models. These models allow conductive and convective heat-transfer processes to be visualized dynamically, illustrating the movement of thermal fronts, circulation pathways, and temperature gradients over time (See Figure 1). Blender-based workflow not only allows presentation of the reservoir processes, but also can show how it interlinks with the surface facilities – concentrated solar thermal systems, heat exchangers, turbines, and the utility grid.

This integrated approach provides a critical bridge between subsurface engineering analysis and power-market evaluation. By clearly illustrating the physical behavior of the system, the modeling framework allows power purchasers and financiers to assess performance, scalability, and risk using representations that align with infrastructure-level decision making. The visualization framework directly mirrors the system architecture described in the GeoTES patents, in which surface heat collection, subsurface storage, and heat recovery are treated as a set of linked integrated thermodynamic systems rather than independent components.

3. THERMAL RETENTION AND RECOVERABILITY IN POROUS SANDSTONE RESERVOIRS

Thermal retention in porous sandstone reservoirs is controlled by a combination of reservoir confinement, rock and fluid heat capacity, and the low thermal diffusivity of surrounding formations. Once heat is injected, conductive losses asymptotically vanish, while advective heat transport remains confined to the circulating fluid system. This behavior has been extensively observed in long-term thermal recovery projects, where injected heat persists for decades and continues to influence reservoir performance (See Figure 2).

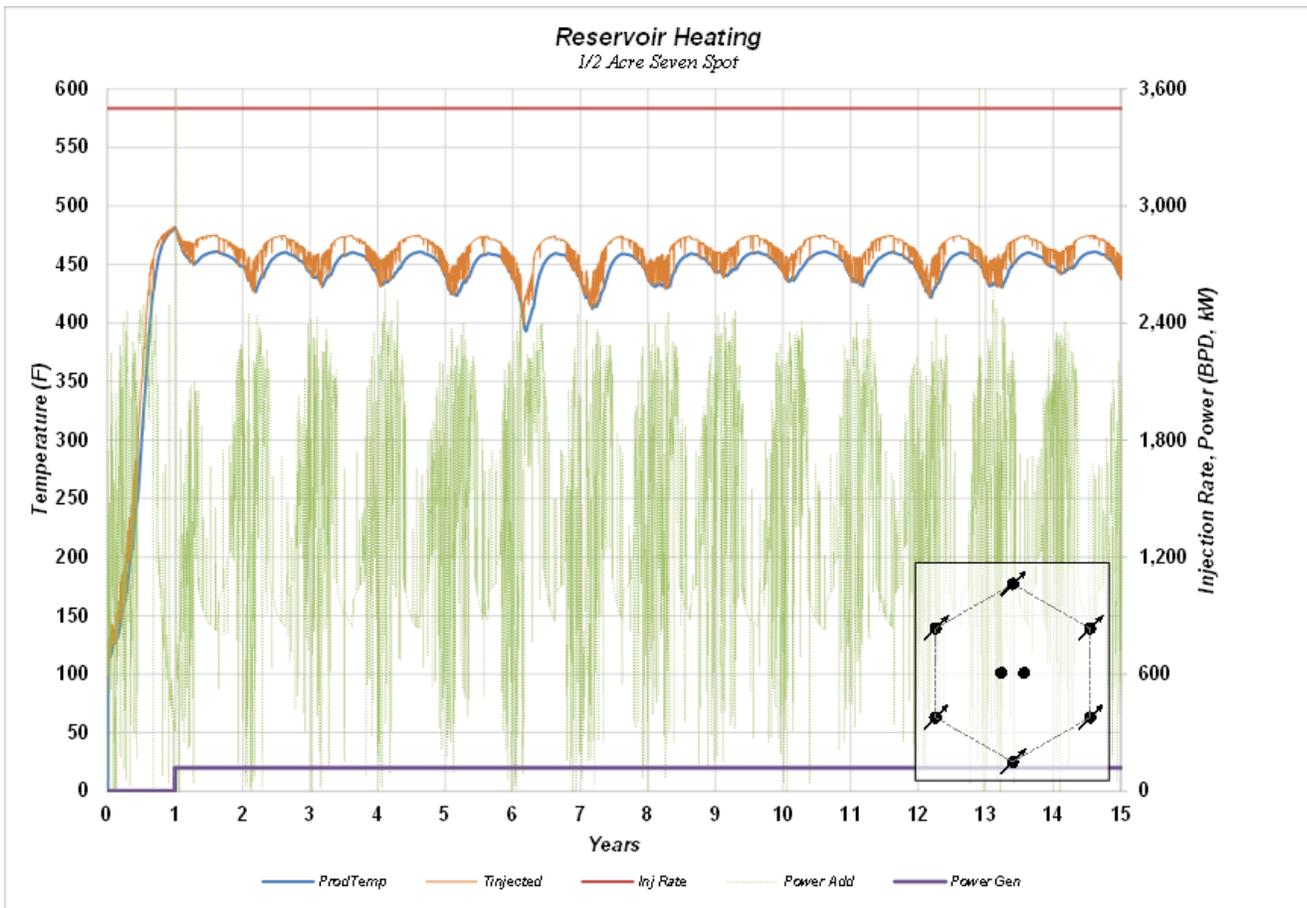


Figure 2: Thermal energy required to heat reservoir rock volume and implications for long-term heat retention

Recoverability of stored thermal energy is achieved through controlled production of heated fluids to the surface, where heat exchangers convert the recovered enthalpy into usable power. The GeoTES patent architecture explicitly leverages this closed-loop circulation to decouple energy recovery from subsurface fluid depletion, enabling repeated and extended discharge events without material loss of storage capacity.

These characteristics enable ultra-long-duration energy storage, measured in weeks rather than hours. Under conditions of prolonged cloud cover, low wind generation, or extreme weather events, the reservoir can be called upon to deliver continuous power without exhausting the stored heat. This level of durability and reliability distinguishes geologic thermal energy storage from surface-based storage technologies and supports its role as a foundational component of future power systems. The following section extends this technical framework to the largest thermally enhanced oilfields in Kern County, California, where scale, geologic continuity, and existing infrastructure enable system-level deployment.

4. SYNTHETIC GEOTHERMAL IN KERN COUNTY, CALIFORNIA

This experiment will demonstrate that concentrated solar thermal power using geologic formations as heat storage (CST-GeoTES, or Synthetic Geothermal [SG]) can stabilize California’s power grid and provide a clear path to meet long-duration energy storage goals by 2040. Permitting for this demonstration has been under review by multiple California state agencies since 2018. The project is partially funded by a \$6 million grant from the U.S. Department of Energy’s Solar Energy Technologies Office.

CST-GeoTES combines proven technologies—parabolic solar reflectors and thermally enhanced oilfields—and shows strong potential for grid reliability. The concept uses sun-tracking parabolic mirrors, heat exchangers, and injection and production wells to deliver zero-emissions power on demand. The process is documented in multiple patents, as shown below.

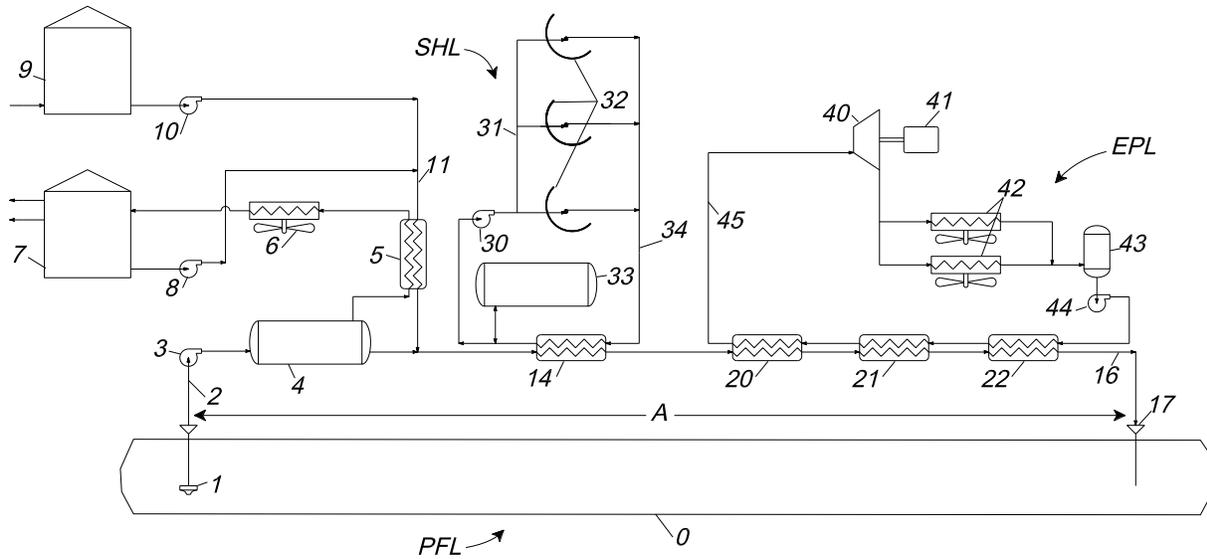


Figure 3: Process Flow from USPTO 12,487,011

4.1 Fluids Circulation in the Reservoir

As shown, fluids are continuously circulated through a reservoir, the definition of which is created from oilfield exploration and exploitation, and without same, the opportunity to apply the methods would be impracticable. Features of this concept require the reservoir, shown as “0”, above, to possess:

Vertical and lateral boundaries, reservoir closure, vertical continuity, lateral continuity, high porosity, high permeability, sufficient areal extent, sufficient vertical extent, full liquid saturation, operability at natural pressures, availability of compatible brackish waters to replace removed contaminants, available surface for a large solar heat collecting installation.

As such, these requirements explain the imperative to use oilfield reservoir-description data; the upfront cost to explore for compatible reservoirs would be uneconomically high. As can be seen in Figure 3 the fluids circulated through reservoir “0” are continuously circulated in a nearly sealed manner, with only contaminants removed to improve circulating fluid system cleanliness over time. Note that the fluid masses circulated are kept in balance, thereby ensuring reservoir boundaries are not violated and that heat-losing fluid losses are eliminated, and thereby create a highly efficient heat storage and retrieval process. Note also, that power production is directly proportional to the fluid circulation rate through reservoir “0”, making the above reservoir properties, especially permeability and thickness, keys to economic success, also demonstrating how the process can effectively balance power production with power demands. This process is planned to be applied to a small trial area in an oilfield, Antelope Hills Field, to demonstrate its efficacy and economic viability. The Antelope Hills Field’s Point of Rocks Formation has a depth of at least 1,500 feet below surface and several hundred acres of surface area, with the above characteristic properties being satisfied. It is estimated, in application of the CST-GeoTES methods shown above, the Antelope Hills Field can be used to produce ~400MW of electric power in perpetuity for five hours each night, or when seasonal demands (such as when persistent cloud cover and static wind conditions prevents photovoltaic and wind power plants from operating) the field can be called on to continuously produce these same 400MW of power for over 40 days without exhausting the stored heat deposited in and thence recovered from the reservoir.

4.2 Scope of Technology Application

As can be seen in Figure 4, there are a large number of oil and gas fields defined in the San Joaquin Valley. Shown, ringed in blue, is the North Antelope Hills Field where the trial project is planned for implementation.

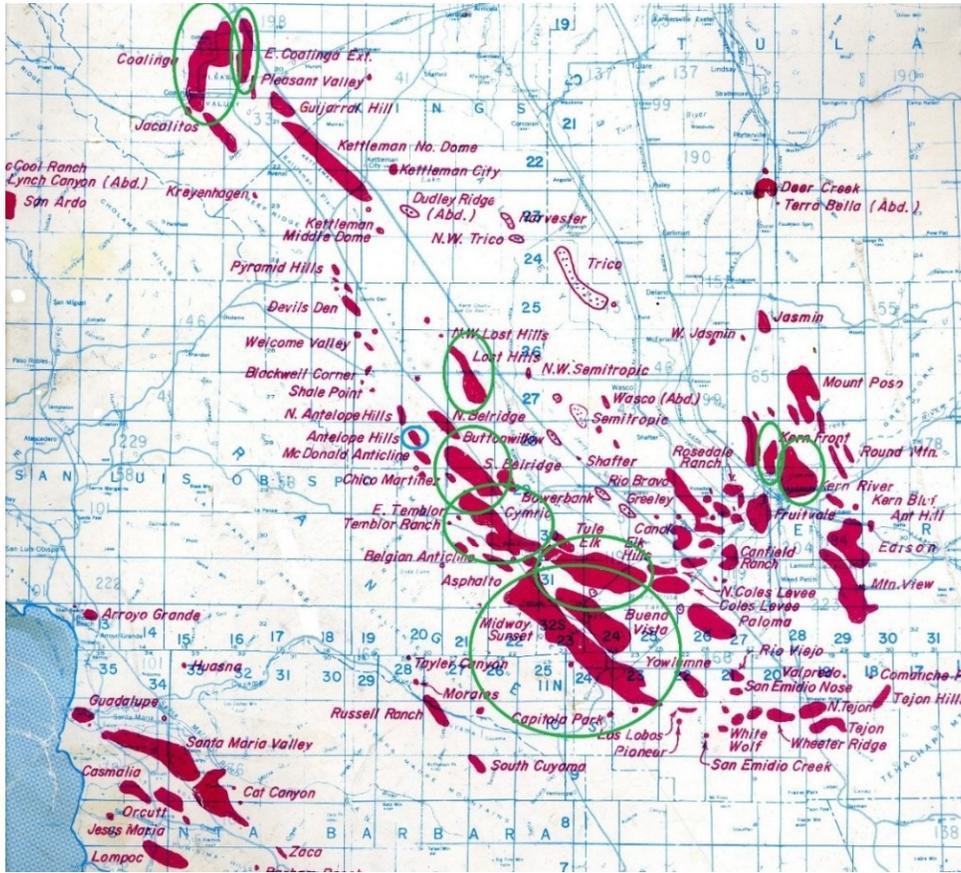


Figure 4: Map showing nine fields (green) evaluated for the energy storage table comparing to the pilot field (blue).

To assess the opportunity for application of Synthetic Geothermal to major oilfields in the San Joaquin Valley an assessment of nine largely thermally-enhanced oilfields were considered for this purpose, all possessing the above-described *Required Reservoir Properties*. These fields; Midway-Sunset, Belridge, Elk Hills, Kern River, Kern Front, Cymric, Lost Hills, Coalinga West and Coalinga East, circled in green, present a large opportunity in application of SG.

The map shows, however, that there are many more such fields which could employ this power production method. One question which could be asked is how large could this renewable, dispatchable power production opportunity be?

Shown in Table 1 enumerating these fields’ potential for power production is a listing of each field’s minimal 5-hour power production capacity, as well as how much energy can minimally be stored, along with an estimate of the amount of the surface of each field which could be minimally employed for SG purposes:

Table 1: Estimated capacity of nine oilfields for use in synthetic geothermal service.

Field	Area (sq. mi.)	Avg. Daily Irradiance GWh	Storage Capacity TWh	Usable Area	Power Production GW
Midway-Sunset	80	2,280	6,971	35%	401
Belridge	50	1,425	2,905	80%	382
Elk Hills	49	1,397	2,846	25%	117
Kern River	25	713	2,905	30%	143
Kern Front	24	684	1,394	45%	103
Lost Hills	16	456	1,394	50%	115
Cymric	10	285	1,162	40%	76
Coalinga West	16	456	2,788	40%	184
Coalinga East	6	171	1,046	50%	86
Sum		7,866	23,411		1,608

As shown, while the State of California power demands are about 50GW, these nine fields should be usable to provide around 1,600GW of power, or over 30 times the State’s current total power demands. Such capital investment, however, would only be made to profitably meet California’s power demands. Still, the opportunity to supply all of California’s power from these few oilfields appears to be practicable. Further, as Figure 4 shows, there are many more such oilfields in the Southern San Joaquin Valley which could be employed for the purpose. And, in each case, a large amount of solar radiation (over 23 PWh for the nine fields shown), which currently heats the planet, would be gathered and stored for power production or other process heating purposes. Note also that there are multiple other oilfields shown on the map which are not in the San Joaquin Valley, but which have excellent geologic properties which could also be employed for local power production, thereby reducing power transmission investments.

4.3 Impact on Oilfield Operations

The continuous, closed-loop circulation of heated waters through confined oilfield reservoirs will create a process which, over an extended period approaching 100 years, enhance recovery of the oil in place. This process, known as hot waterflooding, achieves this enhancement through the change in fluid mobility, as described by researchers, Buckley and Leverett. This effect in enhancing fluid mobility is shown in the following Figure 5. Therefore, there is an opportunity for the application of solar heating to oil reservoirs to increase oil recovery rates, and with that, to fund the large upfront capital investment required for solar plant installations.

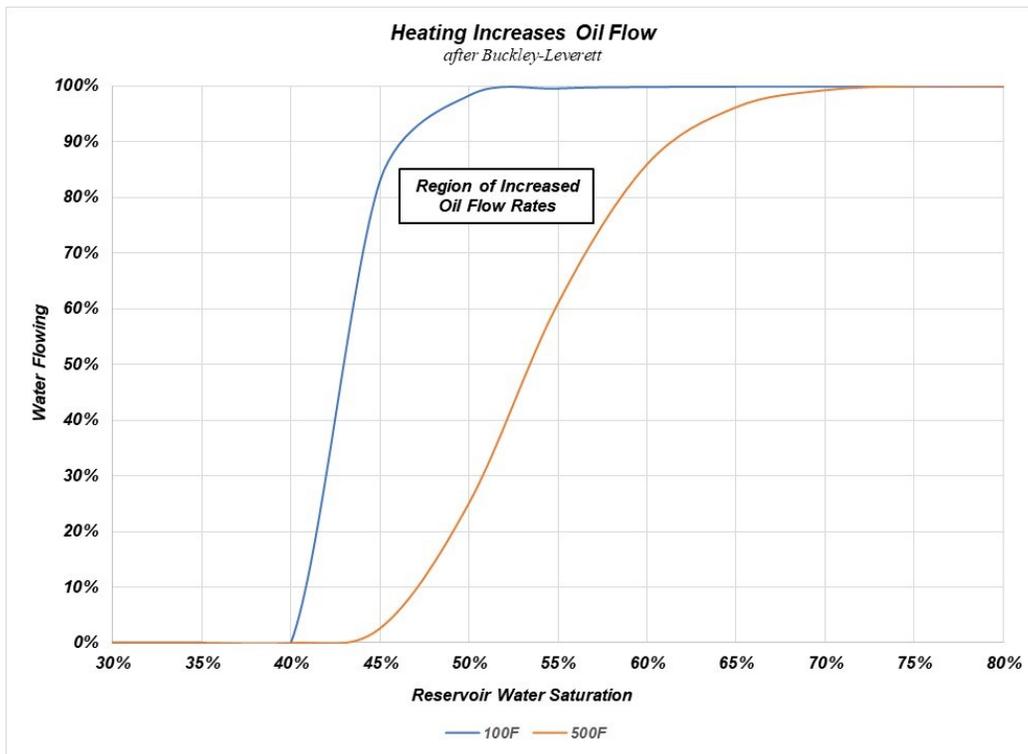


Figure 5: Flowing fraction changes as a function of reservoir temperature.

As can be seen, CST-GeoTES, Synthetic Geothermal technology, presents the opportunity to renewably and perpetually produce many times the electric power required in the State of California, with no combustion emissions, conventional geothermal project poisonous emissions or nuclear powerplant radioactive safety problems or wastes.

CONCLUSION

This work demonstrates that geologic thermal energy storage in porous, permeable sandstone reservoirs represents a fundamentally different class of energy storage—one defined not by manufactured components, but by volumetric geology. Using mature oilfield data, proven thermal recovery physics, and modern visualization tools, the GeoTES framework shows that subsurface reservoirs can be engineered to function as ultra-long-duration, dispatchable energy storage assets that operate independent of surface weather and seasonal variability.

A useful analogy is to compare GeoTES storage capacity to the Tesla Powerwall, a familiar benchmark in the energy-storage landscape. A single home-based Tesla Powerwall © stores approximately 13.5 kWh of energy. By contrast, the thermal energy stored within even a modest pilot-scale GeoTES reservoir corresponds to millions of Powerwalls operating in parallel, with discharge durations measured in weeks rather than hours. At the North Antelope Hills demonstration site, the effective subsurface storage capacity dwarfs any surface-based battery installation that could be practically deployed over decades (limited by material resources and manufacturing systems capacities) , while relying on low-cost drilling, existing infrastructure, and well-characterized geology.

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When this concept is extended across the west side of Kern County—where reservoir continuity spans tens of miles and hundreds of square miles—the scale becomes system-defining. Full-area development of these oilfields represents the equivalent of tens to hundreds of millions of Tesla Powerwalls, embedded directly into the subsurface, immune to wildfire, heat waves, and material supply-chain constraints. Unlike electrochemical storage, this capacity does not degrade through cycling, does not require rare minerals, and does not depend on just-in-time manufacturing.

In this context, GeoTES reframes legacy oilfields not as declining hydrocarbon assets, but as enduring energy infrastructure capable of supporting modern power demands. The west side of Kern County offers a rare convergence of geology, infrastructure, and solar resource that enables this transition at unprecedented scale. As power markets increasingly demand firm, long-duration, and resilient energy storage, geologic thermal energy storage provides a pathway to meet those requirements using resources that already exist beneath our feet.

REFERENCES

Geologic Thermal Energy Storage Systems and Methods for Concentrated Solar Power Integration, U.S. Patent No. 12,487,011, USPTO.