1. **Title:** Energy-Water Resilience through Underground Pumped Storage Hydropower (UPSH): Integrating Water Infrastructure for Enhanced Energy and Water Security

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3. **Focal Area(s):** This concept addresses the water for energy and energy-water intersection topics by proposing a novel form of underground pumped storage hydropower (UPSH) by cycling excess surface water, treated wastewater, or brackish groundwater through subsurface formations using downhole energy devices. It leverages existing geologic formations and abandoned wells in depleted groundwater aquifers or oil and gas fields to store water energy and stabilize the grid, minimizing surface water use and land disruption compared to conventional PSH.

4. **Existing Challenge:** A key challenge in today's energy landscape is delivering reliable, dispatchable power where it's needed most. As renewables expand, rural and remote areas struggle to balance intermittent supply with local demand, especially without access to large-scale storage. Unlocking a new form of PSH in these regions offers a scalable, long-duration solution that enhances grid stability and water resilience by reducing reliance on surface water for energy generation.

   Traditional above-ground PSH systems rely on elevation differences and large surface water reservoirs to store and release energy. This requirement limits deployment to specific geographic regions with suitable topography, leaving vast areas of the country, particularly flat or arid regions, without access to this type of long-duration, grid-scale energy storage. For example, the Bath County PSH facility, VA (Zagars, 1982), and Raccoon Mountain, TN (Adkins, 1987), are both located in mountainous terrain, far from many of the nation's growing energy demand centers. Similarly, the Helms PSH facility in California (Yeung, 2008) is situated in the Sierra Nevada, hundreds of miles from the Central Valley and Southern California load centers. These projects demonstrate the effectiveness of PSH for energy storage and grid stability. However, they also highlight its geographic limitations and the need for more flexible, distributed alternatives.

   Meanwhile, the U.S. faces a growing environmental and economic liability from over 117,000 orphaned oil and gas wells (Merrill et al., 2023), many in regions unsuitable for traditional PSH. These wells pose environmental risks including leakage potential caused by aging infrastructure and resultant groundwater contamination. However, many of these wells, along with thousands of abandoned groundwater wells, are in regions that lack the topographic features required for PSH. They offer access to deep subsurface

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formations that could be repurposed for subsurface energy storage, transforming a costly liability into a strategic, distributed energy asset.

5. **Near-Term Opportunity:** To address the geographic limitations of traditional PSH and meet growing demand for dispatchable energy in underserved regions, UPSH offers a flexible, long-duration solution. By leveraging subsurface infrastructure, such as wells in depleted aquifers and oil and gas fields, UPSH enables downhole energy storage through fluid cycling, using non-potable sources like brackish groundwater or treated wastewater. Water is pumped to the surface during low-cost periods and returned underground to generate electricity during peak demand, minimizing impacts on freshwater supplies while supporting both energy and water resilience. (Beuhler, 2017, Beuhler, 2020)

   Early-stage demonstrations by companies like Sage Geosystems and Quidnet Energy have validated the technical feasibility of subsurface energy storage using geomechanical and pressure-based systems across diverse geologic settings (Figure 1). These efforts highlight the broader potential of adapting similar principles for UPSH, while underscoring the need for continued research to expand applicability, reduce risk, and tailor solutions to regional energy-water challenges.

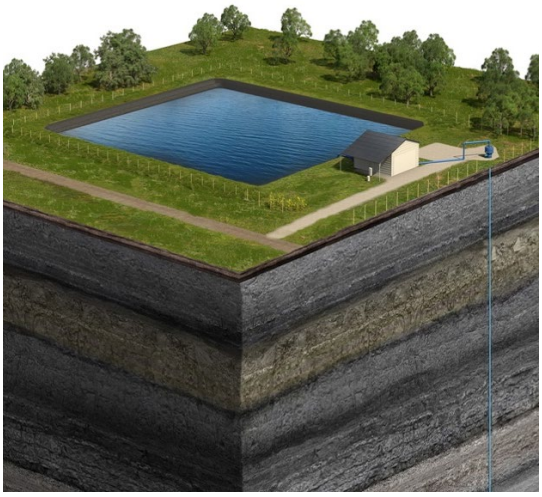


Figure 1: Conceptual diagrams of Quidnet Energy's Geomechanical Energy Storage (Quidnetenergy.com).

UPSH strengthens water resilience by repurposing non-potable sources and abandoned wells—restoring value to stranded assets in drought-prone regions like California's Central Valley. For municipal water utilities and treatment systems, UPSH delivers flexible, on-demand energy to support critical operations, reduce reliance on surface water, and maintain essential services during grid disruptions. By leveraging brackish groundwater or treated wastewater, UPSH minimizes competition with drinking water supplies and enables utilities to build redundancy directly into their infrastructure. This dual-purpose approach enhances operational resilience, cost efficiency, and sustainable

water management, providing tangible benefits to communities facing energy and water challenges.

Realizing this potential requires a national scale understanding of where and how UPSH can be deployed. This includes identifying favorable geologic formations, assessing proximity to grid infrastructure, and evaluating storage potential. A spatially enabled framework, similar to DOE's NATCARB Carbon Storage Atlas (Gray, 2015), could help pinpoint high-impact UPSH opportunities. Complementary tools are also needed to assess technical feasibility, environmental risk, and economic viability across varied geologic and operating conditions.

Repurposing shut-in, abandoned, or orphaned wells presents a promising pathway, though technical challenges remain. Many existing wells were designed for high-pressure, high-energy fluids and have narrow diameters that limit UPSH flow rates. Structural issues such as corrosion, leakage, or incomplete cementation are also common. However, newer, large-diameter, multi-stage unconventional wells offer better integrity and may be acquired at low or no cost by offsetting operators' plugging and abandonment liabilities. These wells can serve as valuable testbeds for feasibility studies, and if results are favorable, justify purpose-drilled wells for commercial deployment.

Finally, the federal government's Federal Orphaned Wells Program (2024) presents a timely opportunity to integrate UPSH site evaluations. Select wells could be retained for formation testing, relogging, or pilot demonstrations – advancing technical innovation while aligning with national energy and environmental goals. A coordinated effort that integrates data, modeling, and stakeholder input will be essential to unlock this new class of energy-water resilience solution.

6. **Success Measure:** Near-term success will be measured both quantitatively and qualitatively. Key metrics include the number of viable UPSH sites identified, estimated total storage capacity, reductions in surface water use and land footprint compared to traditional PSH, and cost-per-kWh benchmarks relative to lithium-ion-based storage. Qualitatively, near-term success can be measured by demonstrating UPSH feasibility in flatland regions, achieving strong stakeholder engagement, and integrating findings into DOE's energy-water resilience planning tools. Long-term impacts include repurposing orphaned oil and gas infrastructure, improving grid reliability, and supporting rural and remote communities in reducing energy costs. By addressing broader community and societal needs, this work has the potential to deliver benefits well beyond the energy-water nexus. Underground pumped storage hydropower (UPSH) provides a practical, near-term solution to energy and infrastructure challenges by converting legacy wells and non-potable water sources into long-duration energy storage assets. This approach supports grid reliability, reduces environmental impact, and aligns with national goals for resilient, American-made energy systems.

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