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# Title: Meeting Energy and Water Demands: Collocated Geothermal Solutions

**Authors/Affiliations:**
Lead Author / Technical Point of Contact: Stephanie DiRaddo | PNNL | stephanie.diraddo@pnnl.gov
Contributing Authors (PNNL): Addison Goecker, Matthew Villante, Thomas B. Wild, Hassan Niazi
Industry Collaborator: Ross Rebich | Energy Northwest | rgrebich@energy-northwest.com
Business Point of Contact: Alison Colotelo | PNNL | alison.colotelo@pnnl.gov

**Focal Area(s):** This white paper examines strategies to optimize site- and project-scale geothermal operations (Enhanced Geothermal Systems (EGS), Advanced Geothermal Systems (AGS), and hydrothermal systems), aiming to identify water conservation and collocation opportunities tied to data centers and large-load industrial manufacturing facilities, enhancing long-term efficiencies and energy resiliency. Operational optimization strategies which consider site-specific collocation design across EGS, AGS, and hydrothermal power production are needed to enable water resiliency while meeting demand growth.

## Existing Challenge: Growing Infrastructure Needs and Resource Demands

Geothermal facilities are increasingly proposed to meet demands for reliable baseload electricity generation and require optimized water management strategies to improve the efficiency of geothermal power production. Geothermal technologies have the potential to address critical challenges related to growing energy demands, including those driven by rapid data center and large-load industrial manufacturing facility expansion. Between 2018 and 2023, U.S. data center energy consumption rose from 1.9% to 4.4% of total annual energy usage, with forecasts projecting consumption as high as 12.0% by 2028.[1] Geothermal energy, with reliable baseload generation, is uniquely positioned to meet this demand while addressing dual stresses on energy and water system resiliency. Current data center growth puts significant strain on both energy availability and water resources, as substantial cooling demands amplify water consumption.[2] Geothermal systems infrastructure (at both the surface and subsurface) offer innovative solutions to minimize or eliminate water consumption. Recent analyses have emphasized the value of geothermal energy for meeting increasing data center energy demand[3-5] but do not fully capture its potential to address both water and energy resiliency challenges associated with data center expansion. Moreover, data centers' substantial cooling demands highlight a critical gap in understanding how geothermal energy can be used to create co-benefits across sectors. The potential for geothermal energy to support large-load industrial manufacturing facilities and district heating and cooling networks (e.g., localized cooling), while reducing the additional energy generation required for conventional cooling, is not well understood.[6] Research is needed to optimize site-specific energy generation configurations for behind-the-meter and co-located systems. Additional analysis is also required to compare geothermal performance with other baseload energy sources. Together, these efforts are essential to mitigating energy-water resiliency challenges in a rapidly scaling industrial and digital economy. By integrating geothermal into site-specific designs, data centers could achieve both energy reliability and water conservation, addressing critical resilience challenges, while utilizing degraded or non-potable water sources to reduce strain on freshwater resources. Continued research informing future siting and design decisions is important for meeting growing energy demands while minimizing water consumption in an increasingly resource-intensive environment.

**Near-Term Opportunity:**

***Innovative approaches to water management and site-scale design*** offer significant opportunities to enhance energy-water resilience in geothermal systems, particularly Enhanced Geothermal Systems (EGS). Advancements in recycling technologies (e.g., closed-loop systems) could mitigate water depletion risks and improve sustainability. Cascading water reuse models may offer additional benefits by repurposing geothermal-produced water for secondary applications such as cooling, agriculture, or industrial processes, reducing strain on regional water resources.

***Site-specific design strategies*** are essential for improving fractured reservoir management and enabling stable production. Technologies that support blind systems modeling, AI-driven reservoir mapping, and water loss reduction innovations can optimize energy production efficiency in areas where the geothermal resource accessibility is limited or production from existing reservoirs is declining. Resource optimization resource can help streamline and prolong energy production, enabling long-term operational resilience in regions where water loss risks related to blind systems can result in productivity losses.

***Collocation of geothermal energy production with data centers*** introduces a powerful opportunity to create co-benefits at the intersection of energy and water systems aligned with administration priorities.[7, 8] Using geothermal energy's reliable baseload generation to power data centers ensures operational stability, while repurposing geothermal-produced water for cooling helps optimize shared resources and reduce inefficiencies. Additional collocation opportunities exist for large-load industrial manufacturing facility and include wastewater, industrial heat, and load resiliency co-benefits.

***Modeling experiments using integrated multisector models*** such as the Global Change Analysis Model (GCAM) can inform the scale of data center demand growth and the feasibility of geothermal technologies as an energy source in the context of market competition with other technologies.[9-12] Simultaneous accounting of cooling water demands and water reuse potential for sectoral use could also inform large-scale feasibility, implications, and optimization potential of geothermal.

**Success Measure:**

Optimizing infrastructure and operations at both surface and subsurface are crucial for increasing geothermal electricity generation efficiencies, particularly through improved reservoir management, surface plant performance, and cooling operations, while addressing water conservation and site-specific impacts. Example project success metrics pertaining to opportunities presented in this white paper are shown in **Table 1**.

The use of advanced water management practices can improve load flexibility through variable geothermal generation or deferred data center/industrial workloads, alleviating strain on regional grids. Monthly to quarterly grid-integration analyses can quantify the share of workloads or energy output shifted, providing valuable insights into system optimization. Geothermal systems are also well-suited to manage cooling energy variability caused by fluctuations in data center cooling demands between day/night and seasonal peaks. Technologies such as geothermal heat exchange and produced-water reuse can help balance variations, improving energy efficiency and reducing water consumption during peak periods. Quantitative monitoring of cooling energy demand changes allows facilities to adapt operations effectively, ensuring cooling needs are met while minimizing excess energy or water use. Finally, geothermal energy delivers consistent baseload power and supports load curtailment tolerance by maintaining system reliability even when geothermal-electric output or facility demand is reduced by <0.5% during peak usage. Annual system-level assessments across grid zones can determine how geothermal-electric output moderation supports grid resilience while preserving operational reliability. Additional success measures may include site-specific impacts in water table stability and resource management within the immediate project area. Careful reservoir management can prevent water depletion and salinization and protect local water tables, ensuring the longevity of geothermal operations and energy generation resilience.

**Table 1**. Examples of success metrics related to this white paper. Metric timeframes and parameters described are informed by Duke University's Nicholas Institute report. [13]

| **Objective** | **Description** | **Timeframe** |
|---|---|---|
| Load Flexibility Potential | Share of facility workloads or geothermal generation output that can be deferred to off-peak hours or shifted among regional facilities to reduce grid strain | Monthly to quarterly grid-integration analysis |
| Cooling Energy Variability | Percent change in plant and data-center cooling energy demand between day/night and seasonal peaks; variation managed through geothermal heat exchange or produced-water reuse | Quarterly to seasonal monitoring |
| Load Curtailment Tolerance | Percentage of geothermal-electric output or data center demand that can be curtailed (<0.5%) without affecting operational reliability or performance | Annual system-level assessment across grid zones |

**References**


(1) Shehabi, A.; Newkirk, A.; Smith, S. J.; Hubbard, A.; Lei, N.; Siddik, M. A. B.; Holecek, B.; Koomey, J.; Masanet, E.; Sartor, D. 2024 United States Data Center Energy Usage Report. **2024–12–20**. DOI: 10.71468/P1WC7Q.
(2) Yañez-Barnuevo, M. Data Centers and Water Consumption. Environmental and energy Study Institute: 2025.
(3) Project InnerSpace, F. V. *Fore Core to Code: Powering the AI Revolution with Geothermal Energy*; 2025. https://projectinnerspace.org/resources/Powering-the-AI-Revolution.pdf.
(4) Rhodium Group. *The Potential for Geothermal Energy to Meet Growing Data Center Electricity Demand*; 2025. https://rhg.com/research/geothermal-data-center-electricity-demand/.
(5) International Energy Agency. *Energy and AI*; 2025. https://www.iea.org/reports/energy-and-ai.
(6) Yuan, X.; Liu, J.; Sun, S.; Lin, X.; Fan, X.; Zhao, W.; Kosonen, R. Data center waste heat for district heating networks: A review. *Renewable and Sustainable Energy Reviews* **2025/09/01**, *219*. DOI: 10.1016/j.rser.2025.115863.
(7) United States, E. O. o. t. P. Executive Order 14318: Accelerating Federal Permitting of Data Center Infrastructure. 2025.
(8) United States, E. O. o. t. P. Winning the Race America's AI Action Plan. 2025.
(9) Binsted, M.; Iyer, G.; Patel, P.; Graham, N. T.; Ou, Y.; Khan, Z.; Kholod, N.; Narayan, K.; Hejazi, M.; Kim, S.; et al. GCAM-USA v5.3_water_dispatch: integrated modeling of subnational US energy, water, and land systems within a global framework. *Geoscientific Model Development* **2022/03/25**, *15* (6). DOI: 10.5194/gmd-15-2533-2022.
(10) Hannam, P., et al.,. Deployment of geothermal energy using a new characterization in GCAM 1.0. **2009**, *PNNL-19231*.
(11) Vernon, C. R.; Rice, J. S.; Zuljevic, N.; Mongird, K.; Nelson, K.; Iyer, G.; Voisin, N.; Binsted, M. cerf: A Python package to evaluate the feasibility and costs of power plant siting for alternative futures. *Journal of Open Source Software* **2021/09/26**, *6* (65). DOI: 10.21105/joss.03601.
(12) Thompson, I.; Vernon, C. R.; Khan, Z. Tethys: A Spatiotemporal Downscaling Model for Global Water Demand. *Journal of Open Source Software* **2024/05/29**, *9* (97). DOI: 10.21105/joss.05855.
(13) Norris, T., Timothy Profeta, Dalia Patino-Echeverri and Adam Cowie-Haskell. *Rethinking Load Growth: Assessing the Potential for Integration of Large Flexible Loads in US Power Systems*; 2025. http://nicholasinstitute.duke.edu/publications/rethinking-load-growth.