NREL

Advancing Geothermal Research

Fiscal Year 2025 Accomplishments Report

NOVEMBER 2025

Executive Summary

The National Renewable Energy Laboratory's (NREL) expertise is advancing cutting-edge geothermal technologies and analysis that can open up tens of gigawatts of domestic resources for firm and reliable power, heating, cooling, and storage—by using the heat beneath our feet.

Fiscal Year 2025 (FY25) brought increased attention to the geothermal industry and NREL's geothermal research portfolio. With more than 70 active projects, NREL research spanned the areas of resource exploration and characterization; conventional and next-generation geothermal technologies; subsurface thermal energy storage; heating and cooling; co-production of geothermal with critical minerals and oil and gas; modeling and analysis leveraging expertise in data science and machine learning; and more.

In support of the U.S. Department of Energy (DOE) Geothermal Technologies Office's (GTO) mission to increase geothermal energy deployment through research, development, and demonstration of innovative technologies that enhance exploration and production, NREL led impactful research in geothermal technologies and resources, market acceleration, and grid integration while also demonstrating leadership in the industry and pursuing innovative partnerships across sectors.

Highlights of the geothermal program this year include pioneering research related to next-generation power technologies, storage applications, advancing NREL's Geothermal Showcase project, and optimizing three years of work incorporating geothermal into analysis tools. Growth was also particularly noted in the areas of data center cooling, cross-collaboration with the oil and gas industry, incorporation of artificial intelligence (AI) into research and data management, research in thermal energy networks, and advancing superhot geothermal energy.

Front cover: NREL geothermal researchers Estefanny Davalos Elizondo, Nicole Taverna, Diana Acero-Allard, and Geoffrey Mibei at a geothermal drilling site in Colorado that is part of the Geothermal Limitless Approach to Drilling Efficiencies (GLADE) project, led by Oxy, which aims to drill geothermal wells at depths, temperatures, and speeds that have not been attempted before. *Photo by Joe DelNero, NREL*

Inside cover: A geothermal drilling rig in Colorado. *Photo by Joe DelNero, NREL*

Back cover: A geothermal drilling rig. *Photo by Joe DelNero, NREL*

NREL Geothermal Research Program Overview and Development Highlights

SECTION 1

Research, Development, Demonstration, and Deployment

NREL's global leadership in geothermal research spans resource characterization and discovery, power generation, mineral production, heating and cooling, storage, and beyond to advance reliable, secure, flexible, always-on power.

Our next-generation geothermal research includes modeling of **enhanced geothermal system (EGS) reservoirs, closed-loop geothermal (CLG) systems, and superhot geothermal resources**. For all of these next-generation and conventional technologies and resources, NREL leads **techno-economic analysis and data collection, analysis, and dissemination**, enabling discovery of geothermal resources and de-risking access and development.

NREL **advances commercial-scale geothermal technologies** in the United States—helping unlock this abundant but underutilized resource. Researchers track, analyze, and disseminate data on geothermal technologies and cost targets, providing key analysis driving cost reductions and innovation.

- For example, NREL works with oil and gas technologies and industry partners to **reduce costs, drive geothermal innovation, and advance new uses for depleted and active oil and gas assets** through geothermal applications—all using American labor, skills, and technologies.
- NREL is also advancing superhot rock geothermal systems—which have the potential energy output of up to 10 times that of a typical geothermal well—through de-risking exploration of these new resource types and partnering on demonstration projects.
- NREL's research and development on geothermal storage and heating and cooling technologies contributes to reducing peak grid and data center loads, helping manage electricity prices and transmission upgrades.

Other key program impacts include:

- NREL's expertise in geothermal power generation and heating and cooling technologies is supporting the defense sector to secure U.S. military installations through geothermal technology implementation.
- NREL maintains national databases on the performance of geothermal technologies and added opportunities to secure domestic sources of critical minerals from geothermal resources—and performs flagship analysis in those areas.

NREL's geothermal research, development, demonstration, and deployment (RDD&D) efforts are centered around three pillars which support four strategic goals.

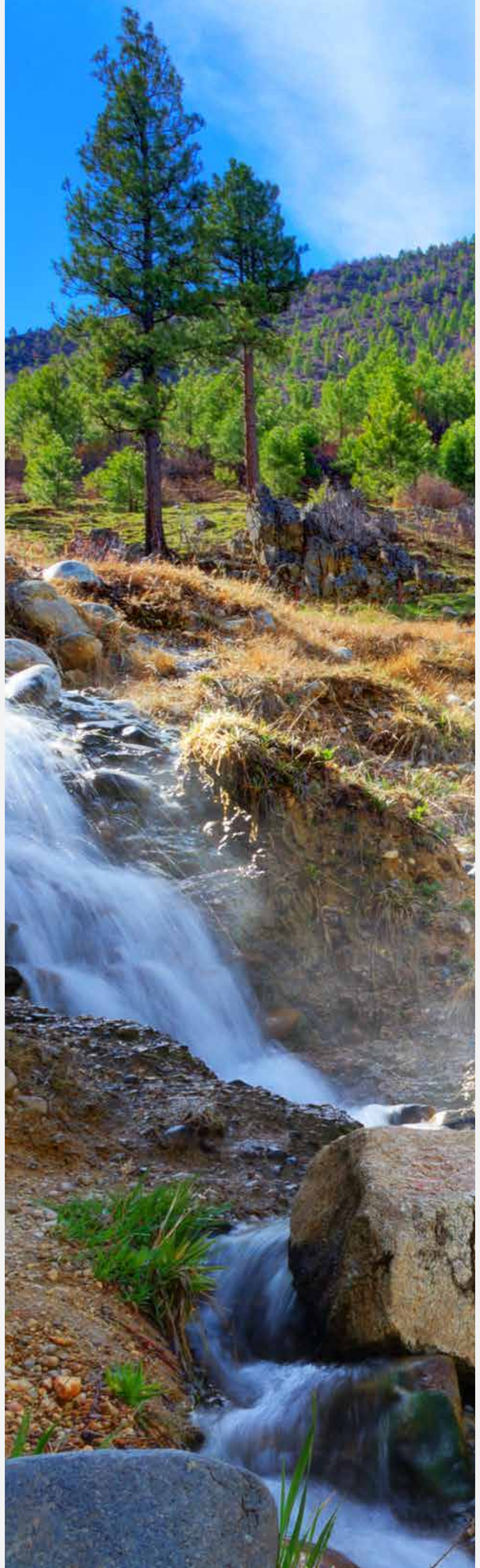
Pillar 1	Pillar 2	Pillar 3
Technologies and resources	**Market acceleration**	**Grid integration**

Goal 1: Advance geothermal technology by research and development to support hydrothermal and next-generation geothermal technologies; geothermal heating and cooling; storage; and crossover with oil and gas and mining.

Goal 2: Demonstrate the value of geothermal through strategic analysis and modeling of the impact of geothermal power, storage, and heating/cooling technologies on current and future grids.

Goal 3: Reduce geothermal development risk through research, development, and demonstration of new exploration, drilling, and subsurface characterization methods and leveraging AI, machine learning, and play fairway analysis.

Goal 4: Accelerate deployment by researching the geothermal market and exploring the economic and nontechnical impacts of geothermal energy use.



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SECTION 2

Laboratory Investment In Geothermal Research Capabilities

NREL invested in geothermal technologies in FY25, including completing test boreholes for a thermal energy network (TEN) for the campus in partnership with Celsius Energy. Geologic hydrogen was another area of interest for NREL leadership, leading to the Laboratory Directed Research and Development program funding early-stage geologic hydrogen research. Work has also continued on the GHP system on NREL's Mesa Top facility, including creating educational displays of real-time data at the NREL Education Center.

SECTION 3

Strategic Partnerships

NREL's work is highly collaborative, with much of our GTO-funded RDD&D activities occurring in partnership with industry, other national laboratories, as well as universities, companies, state and federal agencies, and other entities. In FY25, NREL also had cooperative research agreements outside of DOE that supported a range of RDD&D efforts, including partnerships with international governments, the U.S. Department of Defense, GA Drilling, TDA Research, the Bureau of Land Management, and more.

SECTION 4

Industry Leadership

NREL continued its leadership role in geothermal research by hosting several industry workshops, serving on panels and delivering presentations at conferences and external workshops, briefing a variety of stakeholders on NREL geothermal RDD&D program, tools and analyses, hosting VIP visitors, and more.

Advancing Geothermal Research **2025 Accomplishments Report**

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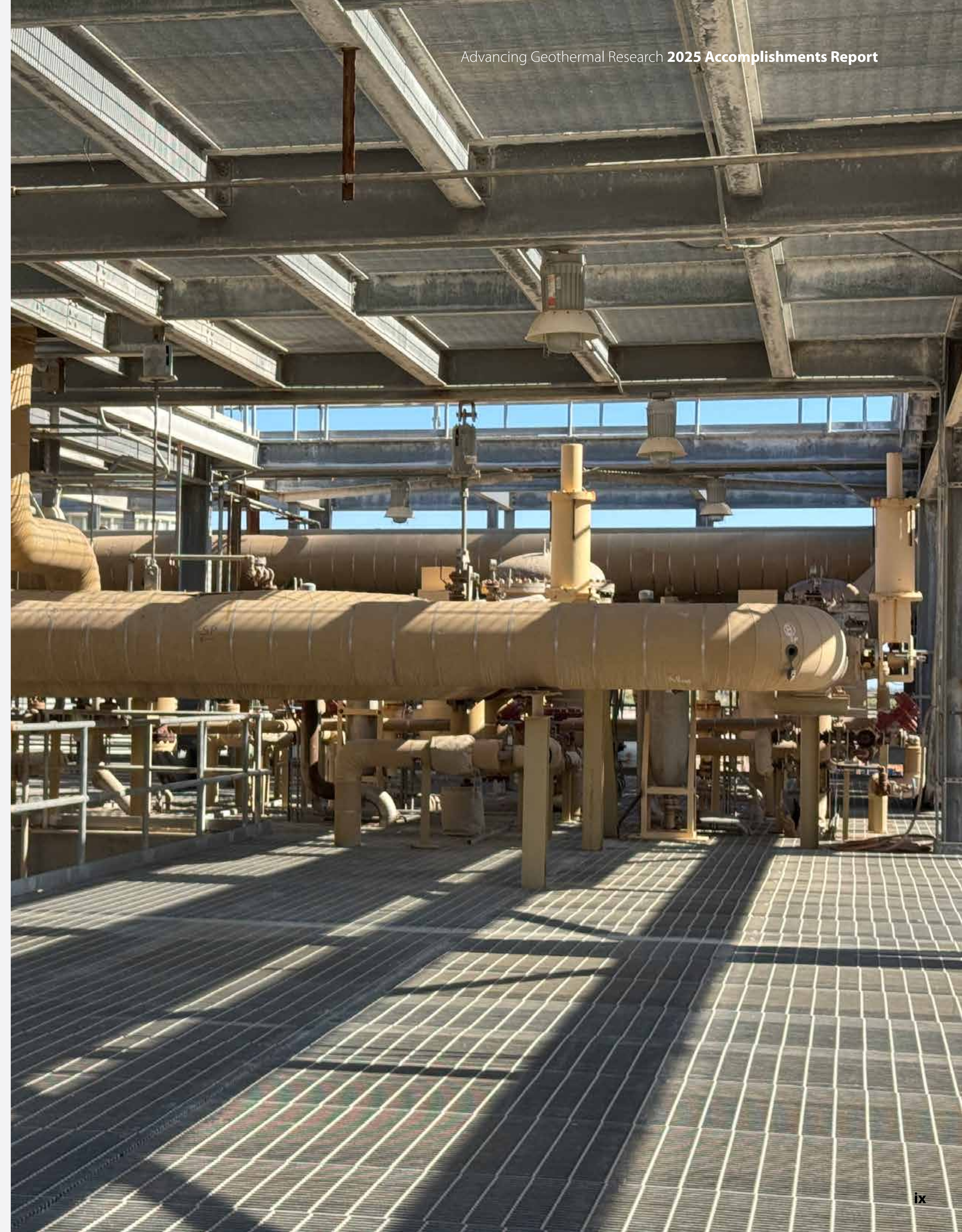
Acronyms

AI	artificial intelligence
ARIES	Advanced Research on Integrated Energy Systems
ARPA-E	Advanced Research Projects Agency-Energy
ATB	Annual Technology Baseline
ATTEN	Advanced Thermal Test and Emulation Network
BAU	business as usual
BLM	Bureau of Land Management
BTES	borehole thermal energy storage
CLG	closed-loop geothermal
CLGWG	Closed Loop Geothermal Working Group
DEEPEN	DE-risking Exploration for geothermal Plays in magmatic Environments project
dGeo	Distributed Geothermal Market Demand model
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EGS	enhanced geothermal system
EPRI	Electric Power Research Institute
ESIF	Energy Systems Integration Facility
FY	fiscal year
GDR	Geothermal Data Repository
GEODE	Geothermal Energy from Oil and Gas Demonstrated Engineering project
GeoDES	geothermal district energy system
GeoTES	geological thermal energy storage
GETEM	Geothermal Electricity Technology Evaluation Model
GHE	ground heat exchanger
GHP	geothermal heat pump
GOOML	Geothermal Operational Optimization with Machine Learning software
GRC	Geothermal Rising Conference
GTO	Geothermal Technologies Office
HVAC	heating, ventilating, and air conditioning
LCOE	levelized cost of energy
LCOH	levelized cost of heat
MMBtu	million British thermal units
MWe	megawatt-electric
MWh	megawatt-hour
NREL	National Renewable Energy Laboratory
OSU	Oklahoma State University
PFA	play fairway analysis
PI	principal investigator
PPA	power purchase agreement
RDD&D	research, development, demonstration, and deployment
ReEDS	Regional Energy Deployment System model
ReV	Renewable Energy Potential model
SAM	System Advisor Model
SHEGS	superhot enhanced geothermal systems
SRRL	Solar Radiation Research Laboratory
TEN	thermal energy network
UTES	underground thermal energy storage
VOI	value of information
WOO	Wells of Opportunity



Salton Sea geothermal power plant. *Photo by Nicole Taverna, NREL*

Advancing Geothermal Research **2025 Accomplishments Report**

SECTION 1

Research, Development, Demonstration, and Deployment

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Reducing Data Center Peak Cooling Demand and Energy Costs With Underground Thermal Energy Storage (UTES)

By some estimates, data center energy needs are projected to consume as much as 9% of U.S. annual electricity generation by 2030, driven primarily by expanded demand from cloud services, big data analytics, and artificial intelligence (AI) (Aljbour et al. 2024). As much as 40% of data center total energy consumption are loads associated with the site infrastructure cooling systems, and these are often highly water consumptive (e.g., Shehabi et al. 2016). For energy system planners, this presents enormous challenges to meet and manage the anticipated loads—especially the peak loads of projected data center deployments.

A new FY25 project led by NREL explores emerging industrial-scale, energy-efficient geothermal cooling solutions to reduce data center peak cooling loads, such as Cold Underground Thermal Energy Storage ("Cold UTES"). Cold UTES can be hybridized with other cooling technologies and optimized based on time-of-use so that grid-integration impacts are minimized as compared to alternative cooling options. GTO is funding this work to understand the integrated grid and systemwide value, costs, and impacts of deploying these emergent cooling solutions at scale.

Specific work this year ranged from organizational efforts to technical efforts. Organizational efforts included project planning, developing collaborations and subcontracts, a kick-off meeting and a workshop, and outreach to a Technical Advisory Group. Technical efforts included developing models of data centers, cooling systems, UTES systems, and adapting grid-level models to be able to represent UTES systems and their value. Ultimately, the project aims to assess the economic viability and grid impacts of Cold UTES, while developing a system model to capture the annual performance of data center energy systems with and without Cold UTES. The project will also validate the grid impact analysis model with a secondary model.

PRINCIPAL INVESTIGATOR
Guangdong Zhu

IMPACT
Reduce strain on the grid while also reducing the costs associated with cooling data centers by utilizing geothermal energy.

PARTNERS
Lawrence Berkeley National Laboratory, the University of Chicago, Princeton University

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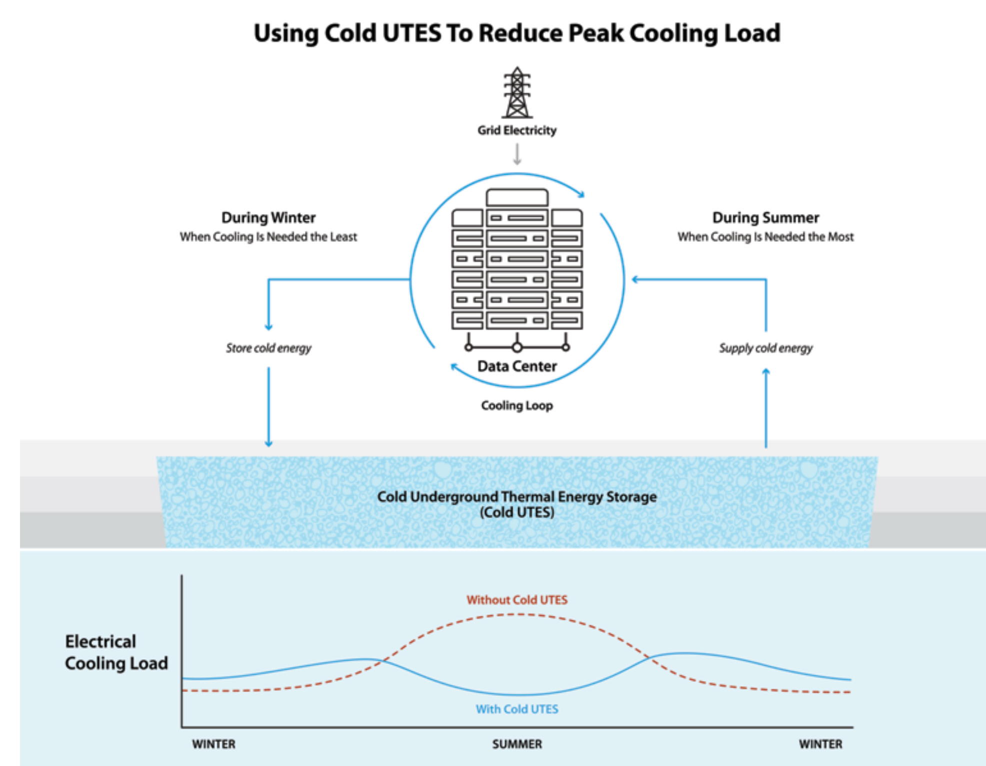

References

Aljbour, J., Wilson, T., and Patel, P. 2024. *Powering Intelligence: Analyzing Artificial Intelligence and Data Center Energy Consumption*. EPRI White Paper no. 3002028905.

Shehabi, A., Smith, S.J., Hubbard, A., Newkirk, A., Lei, N., et al. 2024. 2024 *United States Data Center Energy Usage Report*. Lawrence Berkeley National Laboratory, Berkeley, California. LBNL-2001637.

This page: A schematic of data center cooling system using Cold UTES. *Graphic by Dominique Barnes, NREL*

Left hand page: NREL researcher Dayo Akindipe shows equipment developed as part of an ARPA-E project called "Repurposing Infrastructure for Gravity Storage Using Underground Potential Energy (RIGS-UP)" to NREL and GTO staff and industry partners. *Photo by Joe DelNero, NREL 101023*

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Closed-Loop Geothermal Working Group Evaluates Comprehensive Techno-Economic Modeling for Energy Savings

The Closed Loop Geothermal Working Group (CLGWG), a multi-lab initiative led by NREL, focused on evaluating the techno-economics of closed-loop geothermal systems for power and heating in FY25 to establish suggested parameters for economically feasible designs.

Closed-loop geothermal systems, also referred to as advanced geothermal systems, utilize a heat transfer fluid circulating in a closed-loop configuration through a co-axial ("pipe-in-pipe") or U-loop type subsurface heat exchanger to bring reservoir heat to the surface. Over the years, the CLGWG has modeled U-loop and co-axial system designs, considering various technologies (e.g., vacuum-insulated tubing, multilaterals, enhanced near-wellbore thermal conductivity, and flexible dispatch) and physical phenomena (e.g., non-steady temperature decline, background convective heat transfer, pressure and heat gain/loss, and thermosiphon effect).

In FY25, the group further validated the Slender-Body Theory model, developed by NREL researchers, using recent field data obtained through industry. In continuation of prior work on modeling the effect of reservoir convection on closed-loop systems, the group modeled different reservoir conditions including phase change. Additionally, efforts were extended to evaluate the techno-economic feasibility of U-loop and co-axial systems at 11 select sites, qualitatively classified into three mutually inclusive categories: basin and range (Desert Peak, Roosevelt Hot Springs, Coso), volcanic regions (Newberry, Fenton Hill, Imperial Valley), and sedimentary basins (Eagle Ford, Haynesville, New York Appalachian, West Virginia Appalachian, Denver-Julesburg).

These site-specific results were integrated into **GeoCLUSTER**,[1] an open-source web simulator that enables closed-loop developers, investors, and other stakeholders to analyze closed-loop designs across different surface and subsurface settings. Workshops were held with industry and other stakeholders to present CLGWG results, demonstrate GeoCLUSTER, and collect feedback on modeling efforts.

PRINCIPAL INVESTIGATOR
Jabs Aljubran

IMPACT
Development of open-source tools and comprehensive techno-economic modeling of diverse closed-loop geothermal systems and technologies has established the required parameters for these systems to cost-effectively provide heat and power.

PARTNERS
Sandia National Laboratories, Pacific Northwest National Laboratory

LEARN MORE

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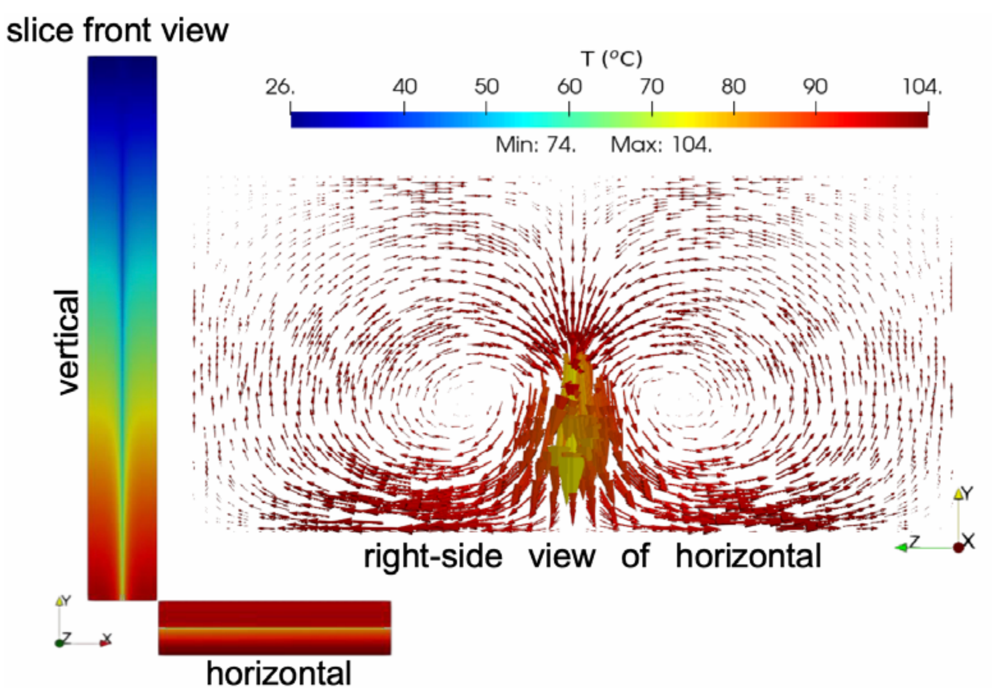


Slice front view showing the temperature gradient after 20 years of operations and right-side view of horizontal section showing the buoyantly driven convection cells on either side of the tube. Co-axial tube (not shown) is in the center of the velocity field, into/out of the page. Length of arrow scales with fluid velocity magnitude. *Figure from Sandia National Laboratories.*

[1] https://apps.openei.org/GeoCLUSTER/

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Value of Information for Geothermal Exploration

Geothermal exploration data collection has experienced a critical expansion in the last few years, providing opportunities for data-driven statistics. Decision analysis is one of these new tools that provides a framework to identify which decision action—such as building a certain size of geothermal facility—has the highest expected economic outcomes (e.g., lowest levelized cost of energy, or LCOE) given the uncertainty of the geothermal resource. For most geothermal resources, the variable is the existence and size of the geothermal resource. Additionally, the metric of value of information (VOI) is defined within decision analysis and reveals which types of information reliably improve the outcomes of these decisions.

NREL developed the **VOI App**[2] to help industry identify which information yields better decision-making to identify geothermal resources. The app currently allows users to input two csv files that represent their positively and negatively labeled data, which is then analyzed to compare the one data attribute co-located at positive versus that same data attribute co-located at negative sites (absence of geothermal resource).

Previous VOI studies have used nominal economic values (e.g. $1 million for positive site, -$1 million for negative site) and focused on the information statistics (reliability).

The project team engaged with industry to ensure that the open-source decision analysis and VOI software is impactful and includes functionality to best represent economic and geologic risk.

At the 2024 Geothermal Rising Conference, Whitney Trainor-Guitton and Nicole Taverna ran a pre-conference workshop titled "Value of Information for Geothermal Exploration" to promote the application. The workshop included three case histories from industry partners covering exploration decisions around EGS, hydrothermal, and district heating.

Based on additional workshop participant and industry partner feedback, the team incorporated GEOPHIRES project economics and completed a manual for understanding how the VOI App works and submitted it to the *Journal of Open-Source Software*.

PRINCIPAL INVESTIGATOR
Whitney Trainor-Guitton

IMPACT
The Value of Information App now has realistic economic outcomes and provides a quantitative tool for geologic risk, including the ability for users to upload their own "imperfect" data.

PARTNERS
Fervo Energy, Geologica, and Arctic Green

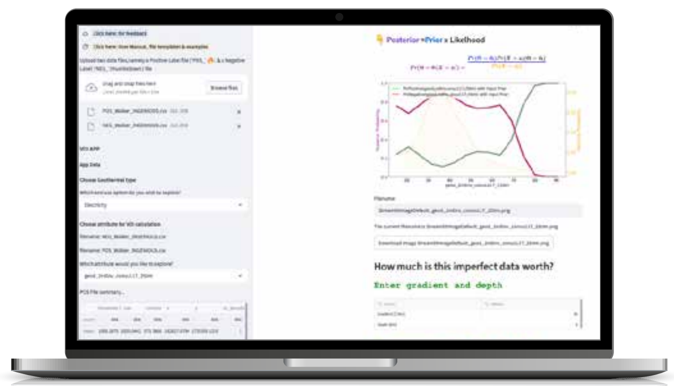
LEARN MORE

bit.ly/4nlvoXK

Workshop participants shared the following:

"Although we are familiar in the oil industry with VOI, reframing the application for geothermal was quite helpful."

"Thank you so much for creating such an awesome app, it was incredibly useful and I see much more use by our company in the future."



Screenshot from the VOI App, which NREL created to help industry stakeholders identify which information yields better decision-making for finding geothermal resources.

Participants of the October 2024 Geothermal Rising pre-conference workshop "Value of Information for Geothermal Exploration." *Photo by Whitney Trainor-Guitton, NREL.*

[2] https://voigeothermalrising.streamlit.app/ & http://voi.geothermal.nrel.gov/

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Geothermal Well Performance Evaluation and Alternative Designs

PRINCIPAL INVESTIGATOR
Geoffrey Kiptoo Mibei

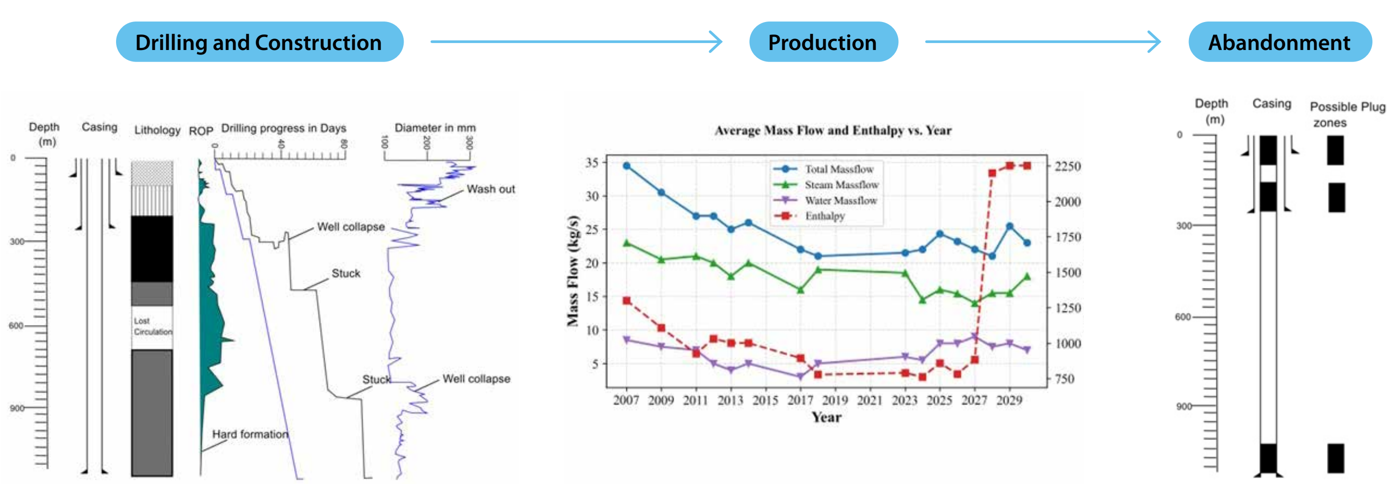
IMPACT
The analysis identifies risks and techno-economics associated with geothermal well drilling, construction, and production to reduce costs and optimize returns.

PARTNERS
Sandia National Laboratories, Oak Ridge National Laboratory, and Brookhaven National Laboratory

The Geothermal Well Lifecycle Evaluation project aims to optimize geothermal wellbores by understanding risks and mitigation for the complete well lifecycle—from drilling to construction, production, and eventual abandonment. Led by Sandia National Laboratories, the project included four national laboratories and tackled well performance analysis and alternative well designs.

The well performance analysis was dedicated to collecting and analyzing data related to the lifecycle of geothermal wellbores. This included gathering information on construction, completion, production, and abandonment phases from both public and private sources. The team developed a techno-economic model to evaluate geothermal well costs using data collected from industry partners. This model used a baseline (business-as-usual or BAU) well design, which was a reference point for comparing the costs and risks associated with various well configurations. The final step in this phase involved conducting a failure mode and risk analysis of the BAU well design. This identified potential failure causes and prioritized risks across the different lifecycle phases under common themes, providing insights that will be fed back into the techno-economic model for further refinement.

The alternative well performance designs phase explored different well designs that could offer improved performance or reduced costs compared to the BAU configuration. Various design configurations were assessed, with a similar failure cause and risk analysis conducted for these alternative designs, comparing their risks to those identified in the BAU design. This analysis helped to determine the cost implications of different design choices and identify mitigation strategies where necessary. This informs the technical feasibility and commercialization of the alternative well designs. The approach considers conventional wells as BAU, while alternative designs include EGS, closed-loop, and repurposed oil and gas wells.



Drilling and Construction Considerations:

- Well collapse
- Hard formation
- Stuck drill string
- Lost circulation

Production Considerations:

- Mass flow decline
- Scaling and corrosion
- Thermal or pressure decline
- Thermal breakthrough

Abandonment Considerations:

- Gas release
- Mechanical failure
- Seepage

This figure illustrates typical geothermal considerations, including spanning drilling, production, and abandonment phases. *Figure by Geoffrey Mibei, NREL.*

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

NREL Geothermal Showcase: Monitoring, Analysis, and Education Around Geothermal Heating and Cooling

PRINCIPAL INVESTIGATOR
Xiaofei Pu

IMPACT
Installation of a full suite of monitoring instrumentation on a geothermal heat pump (GHP) system on NREL's campus enables valuable performance data collection and the development of system performance and optimization models to facilitate future efforts on GHP system design and operation optimization. Data collected can also be used to educate and inspire the next generation of the workforce on geothermal heating and cooling technologies.

PARTNERS
Mountain Energy Partnership, Kopacz Boyer, Rocky Mountain Mechanics, and Geo-Energy Service

In FY25, NREL completed the installation of a suite of monitoring instrumentations on the geothermal heating and cooling system at the lab's Solar Radiation Research Laboratory (SRRL) building. Since 2011, the system has provided heating and cooling thermal stability to the SRRL, a 4,584 ft^2 metrology research laboratory located at NREL's Mesa Top facility with stringent requirements for ambient temperature.

The current monitoring instrumentation for the geothermal showcase includes power metering on 17 components in the geothermal system, flow rate, and temperature measurement on each of the 27 borehole loops, the bulk ground loop and the bulk building loop, 8-10 temperature measurements inside each borehole and each of the 15 monitoring wells in the borehole field. These instruments enable important data collection on system performance characteristics, numerical modeling of the borehole field, and semi-analytical modeling of the ground-coupled heat exchanger. The new data collection also provided critical insights on the design and operation optimization of geothermal heating and cooling systems.

Data collected from the SRRL system is also playing an integral part in NREL's outreach to students, helping to further develop the geothermal workforce pipeline. This work includes displaying live performance data of the SRRL system in NREL's Education Center, which offers programs to students in grades 3-12. This project will be developing a 90-minute curriculum focused on scientific principles and the benefits of geothermal heating and cooling systems.

NREL staff and visitors tour the Mesa Top facility. *Photo by Agata Bogucka, NREL 101398*

Geologic Hydrogen Production by Stimulating Iron-Rich Rocks

PRINCIPAL INVESTIGATOR
Dayo Akindipe

IMPACT
This new research area of geologic hydrogen aims to tap into a vast and less expensive source of natural hydrogen than current manufacturing methods.

PARTNERS
Texas Tech University, Rio Tinto, Lawrence Berkeley National Laboratory, Columbia University, and University of Lyon

Funded by the Advanced Research Projects Agency-Energy (ARPA-E), NREL is implementing first-of-a-kind research with lead Texas Tech University, Rio Tinto, Lawrence Berkeley National Laboratory, Columbia University, and University of Lyon to stimulate hydrogen production in iron-rich mafic and ultramafic rocks via chemical, mechanical, and biological processes. The project aims to enhance the redox reactions that enable hydrogen production beyond natural rates, understand active geochemical interactions between hydrogen, water, and mineral species, and inhibit microbial uptake of produced hydrogen. Researchers are also analyzing the potential market demand for geologic hydrogen in high-prospectivity regions.

In FY25, the team implemented laboratory experiments to determine the rate of hydrogen consumption by methanogens. Thermophilic archaea, *Methanothermobacter thermoautotrophicum* DSM 3590 (MT3590), was used as a model methanogen. Initial data showed hydrogen consumptions rates up to 6 mmol H_2/L/h within four days. The team has also collected live water, cells, and rock samples from an actively serpentinizing site in California. Analysis work on these actual field samples is ongoing, and findings will be reported when they become available.

Other NREL geologic hydrogen projects are discussed in the **Laboratory Investment in Geothermal Research Capabilities** section.

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Superhot EGS Model Updates, Testing, and Open Source Publication

PRINCIPAL INVESTIGATOR
Nicole Taverna

IMPACT
Developed new and validated open-source tools to reduce risk and cost in superhot geothermal projects while enhancing transparency, standardization, and efficiency in exploration workflows.

PARTNERS
Lawrence Berkeley National Laboratory, Mazama Energy, Reykjavik Energy

From Fiscal Year (FY) 2022 to FY2025, GTO funded the DEEPEN (DE-risking Exploration for geothermal Plays in magmatic ENvironments) project—a multi-lab and transnational initiative funded in partnership with Geothermica. DEEPEN aimed to reduce exploration risk and improve resource characterization for supercritical geothermal systems, particularly those associated with magmatic environments.

In FY25, NREL continued pioneering work on discovery and characterization of superhot geothermal resources by applying the DEEPEN play fairway analysis (PFA) to superhot systems in the United States and Iceland. This work resulted in 3D favorability models and conceptual site models for the two sites. These outputs directly informed preparations for drilling at Hengill Volcano in Iceland (IDDP, planned for 2026) and Newberry Volcano in the U.S. (Mazama EGS Pilot Demonstration, planned for 2025).

FY25 work made important improvements to modeling tools—particularly the producibility improving constraints on the reservoir component of the PFA, standardizing PFA workflows, and updating the thermal-hydraulic-mechanical-chemical simulator TReactMech for superhot systems.

Overall, the project advanced tools and methods to reduce cost and uncertainty in superhot geothermal exploration. It focused on:

Building open-source tools for 2D/3D PFA in superhot plays, resulting in a new python library called **geoPFA**,[3]

1. Updating TReactMech to reflect high-temperature, high-pressure fluid behavior,
2. Testing tools at Newberry, Nesjavellir, and
3. Releasing all tools and workflows as open-source resources.

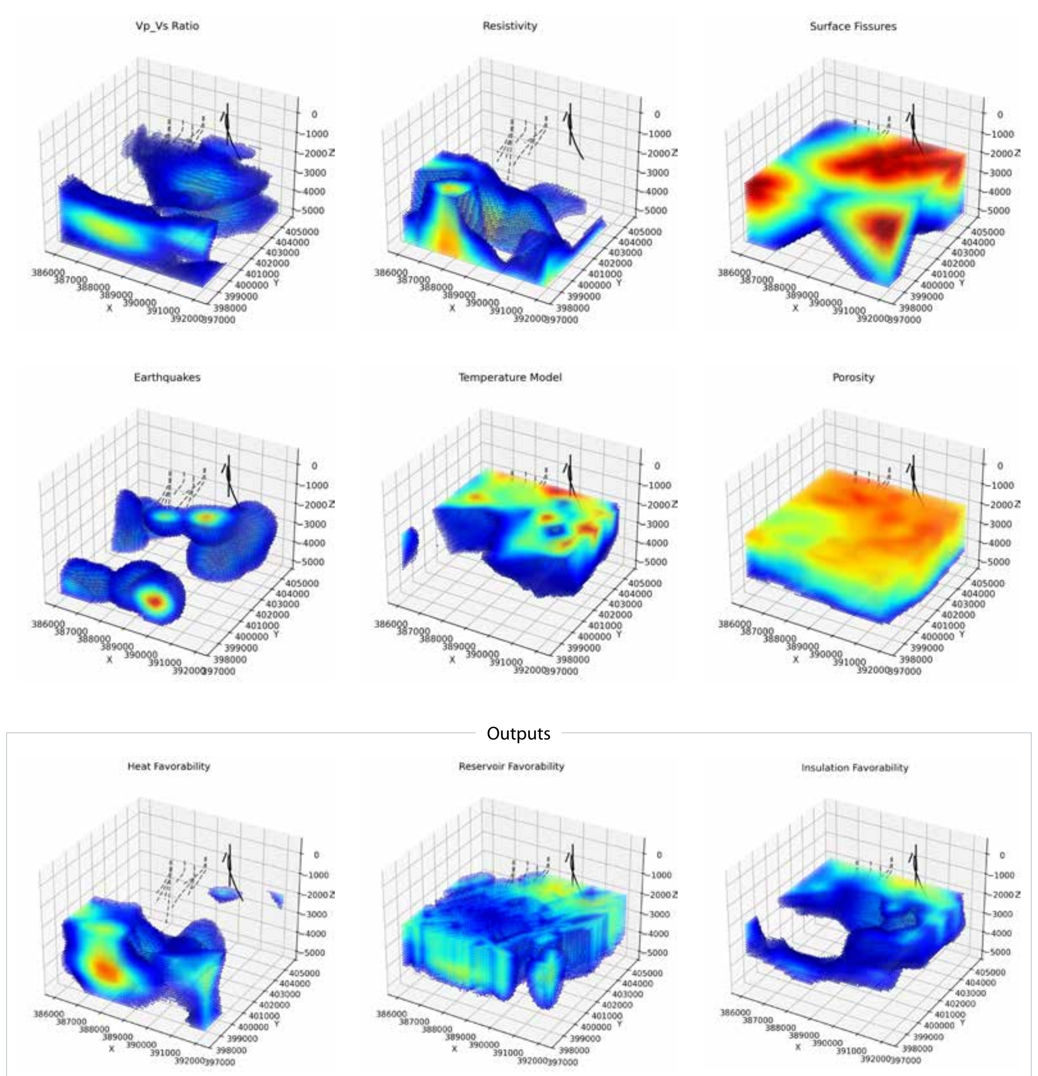


Image of Nesjavellir superhot PFA produced using geoPFA Python library. Includes component favorability models for heat, producibility, and insulation components, along with marginal favorability models used to construct them. *Figure from Taverna et al., 2025*

[3] https://github.com/NREL/geopfa

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

The CHANGE: The Cooling and Heating Transition Acceleration via Network Geothermal Energy

PRINCIPAL INVESTIGATOR
Matt Mitchell

IMPACT
Created improved design and screening tools for geothermal district energy systems.

PARTNERS
Oklahoma State University, Oak Ridge National Laboratory, Lund University, Swedish Geoenergy Center, VIA University, Geologic Survey of Greenland and Denmark, GeoDrilling, Skanska Norway

The Cooling and Heating transition Acceleration via Network Geothermal Energy (**The CHANGE**[4]) is an international consortium of geothermal heating and cooling experts that aims to develop validated design and screening tools for district systems. The project's key objectives are development of thermal energy network (TEN) design tools that enable rapid input and evaluation of building geometry, data, and loads; development of fast and accurate network component models needed for system design and simulation; and development of design algorithms that produce near-optimal TEN designs.

In FY25, NREL worked with project partner Oklahoma State University (OSU) to develop initial design and simulation tools, which the team integrated into the tool "GHEDesigner." This is an important milestone that will allow further model testing and validation in subsequent project years. As part of this effort, OSU developed and tested linearized thermal solver methods to support system design simulations. In parallel, NREL developed a separate thermal solver and collaborated with OSU to test and compare both approaches. OSU also developed a heat pump simulation approach which is needed for TEN system simulation, which NREL has implemented in GHEDesigner. OSU also completed automatic borehole circuiting algorithms to support automated ground heat exchanger system design, with sample layouts illustrating performance and cost tradeoffs. White papers for the linear solver, heat pump simulation, and automatic borehole circuiting algorithms have been developed and will be the basis of conference or journal publications.

The Swedish institution and project partner, Lund University, has also made strong progress in developing models to support system design and validation. The team created an analytical model for one- and two-pipe horizontal pipe configurations that captures heat transfer between buried pipes and the surrounding ground. Derived using advanced mathematics, the model predicts heat losses and gains for buried pipes and will allow accounting for the extra heat storage of the ground surrounding the buried pipes. A full mathematical report has been completed, and a paper is in development. Upcoming work includes generating heat pump performance data used for developing simplified polynomial models and validating the results against manufacturer data. The remaining Swedish and Norwegian partners are involved in collecting overall system data used for validating the design and simulation tools, and Oak Ridge National Laboratory is currently integrating the design tools into their online, web-based screening tools.

Thermo Road Project Site. Data collected from this system will be used for design and simulation tools validation. *Image from Jeffrey Spitler, OSU.*

[4] https://www.geothermica.eu/project/thechange

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Optimizing Retail and Grocery Store Heating and Cooling with TEN GHPs

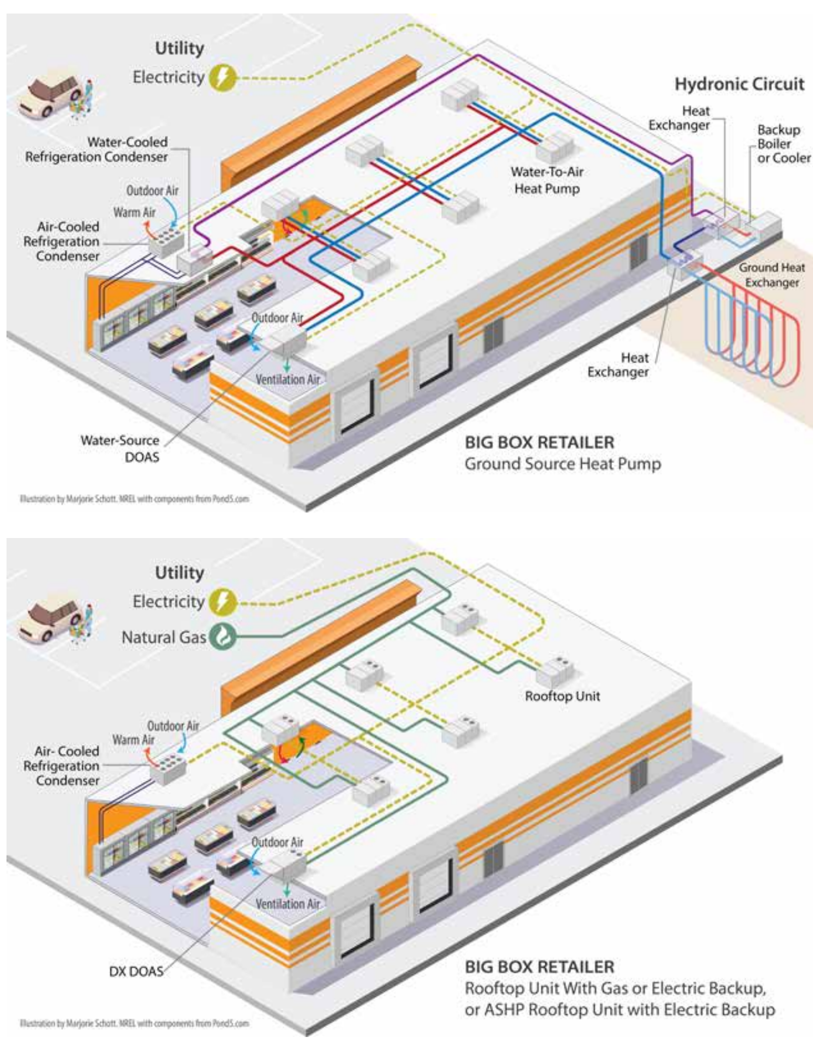
PRINCIPAL INVESTIGATOR
Grant Wheeler, Matt Mitchell

IMPACT
Showcased the potential benefits of geothermal scenarios that directly apply to major retail buildings.

A new project by NREL investigated the potential for applying geothermal heating and cooling technologies, coupled with thermal recovery and storage, at retail chains to optimize space and ventilation heating within a single building in moderate to extreme cold climates.

Grocery and retail spaces are typically heated through gas-fired unitary rooftop units, with fresh air ventilation supplied by gas-fired outdoor air systems. Geothermal heating and cooling coupled with thermal recovery and storage offer unique opportunities to optimize efficiency and resiliency. Two retail giants worked with NREL in FY25 to model these technologies.

NREL developed realistic modeling scenarios for applying thermally networked water-source heat pumps, heat recovery, thermal storage, and geothermal heat exchange in various retail locations to optimize space and ventilation heating within a single building in moderate to extreme cold climates for the stores. The team also performed energy and cost modeling to compare system performance to a baseline heating system type and presented results and TEN GHP scenarios to industry stakeholders, including large retailers and engineering design firms. These initial modeling results identified energy savings from the proposed system designs. NREL has presented initial promising model results and is proposing more work in FY26 with these retail partners to get closer to a pilot.



Typical (below) versus proposed (above) retail grocery store HVAC system. *Figure by Marjorie Schott, NREL, with components from Pond5.com*

DX	direct expansion
DOAS	dedicated outdoor air system
ASHP	air-source heat pump

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Newberry Superhot EGS Demonstration Project

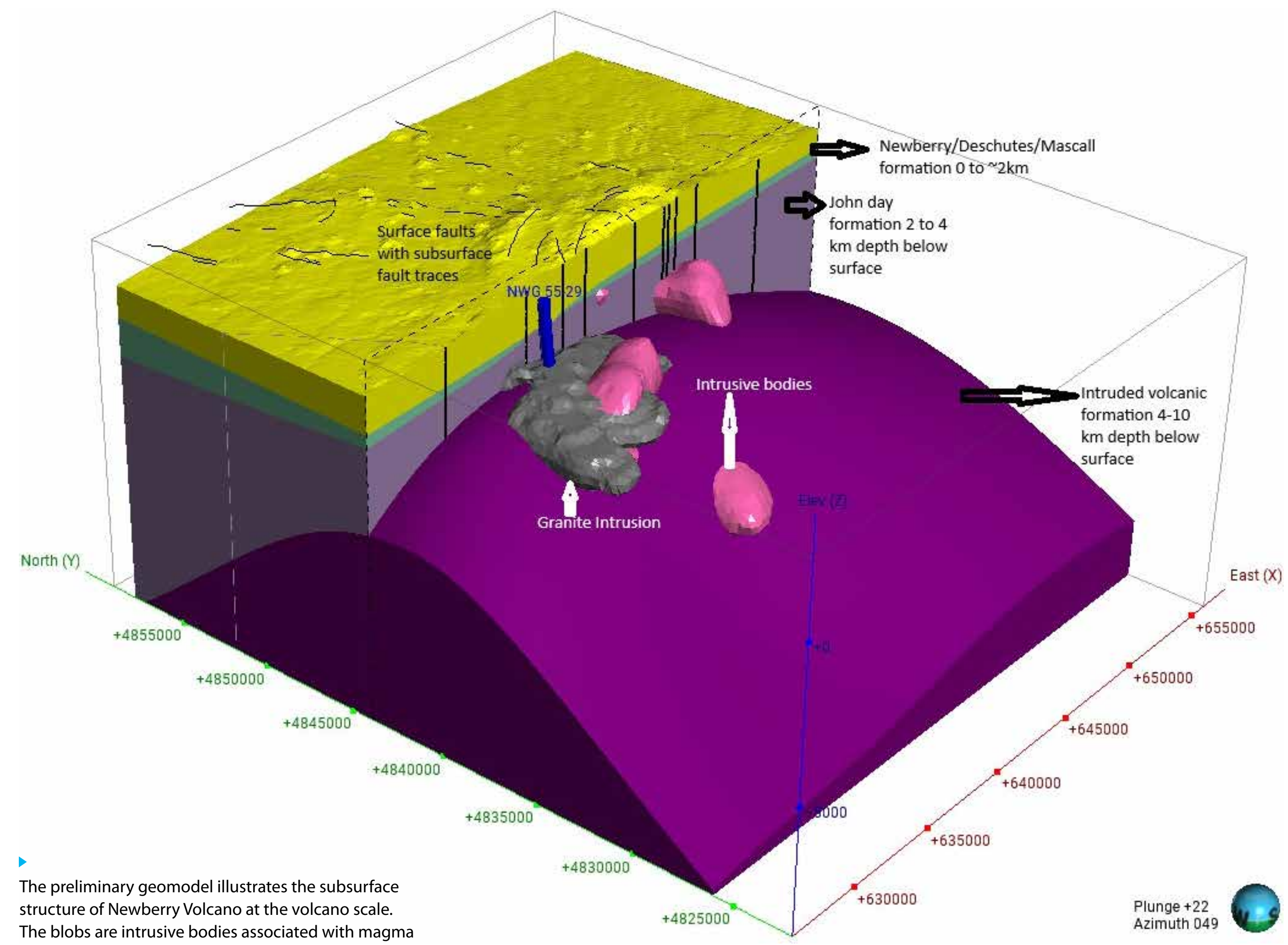
PRINCIPAL INVESTIGATOR
Geoffrey Kiptoo Mibei

IMPACT
Advancing and derisking superhot EGS well drilling and design through updated geomodels integrating lithology, intrusions, temperature and through uncertainty analysis using data across scales (well, reservoir, and volcano scale).

Located at the Newberry Volcano in Oregon, the Newberry Superhot EGS Demonstration project aims to target and demonstrate EGS in superhot rock, at temperatures exceeding 400°C. Energy extracted from this resource is expected to have several times the power density of conventional geothermal systems.

In FY25, the NREL project team mapped the subsurface intrusions (magma, partial melt, and plutons) beneath Newberry Volcano. Magmatic intrusions have been identified west of the Newberry Caldera through resistivity and gravity surveys and distinguished from other types of intrusions, helping locate the hottest rocks in the subsurface. Accurately mapping the location of the supercritical temperature zone helps ensure high energy density output and reduces the number of wells required.

At the time of this report, a drilling rig is onsite to stimulate an established well and to drill a sidetrack well, generating critical resource data. NREL is contributing to the project's resource conceptual modeling efforts, building on the previous model developed during the DEEPEN project (see pg. 8). The goal is to refine the geologic model from volcano scale to reservoir scale, and ultimately to wellbore scale. The models will inform production as well as interactive 3D models and videos that will be developed to communicate project insights to a broader public audience.



The preliminary geomodel illustrates the subsurface structure of Newberry Volcano at the volcano scale. The blobs are intrusive bodies associated with magma intrusions and partial melt bodies associated with high-temperature zones. Black traces represent geologic fault structures. *Figure by Geoffrey Mibei, NREL*

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Wells of Opportunity

NREL researchers are involved in two projects awarded under GTO's Wells of Opportunity (WOO) initiative that explore the feasibility of utilizing existing oil and gas wells for geothermal energy. These two projects—located in oil and gas basins in Nevada and Oklahoma—showcase that geothermal energy production at these sites is technically and economically feasible and can save millions of dollars in drilling costs.

Co-Production With Oil Operations in Blackburn, Nevada

In Nevada, NREL is collaborating with partner Gradient Geothermal, Inc., to evaluate geothermal energy generation through co-production with oil operations at the Blackburn Oil Field in Eureka County. This project has demonstrated the technical viability of harnessing geothermal energy from the substantial volumes of hot water historically co-produced at the field.

From 1982 to 2022, Blackburn Field produced 4.3 million barrels of oil and 43.5 million barrels of water, with the annual water cut rising to nearly 99% in recent years. This high water-to-oil ratio, along with the naturally fractured Nevada dolomite reservoir and elevated geothermal gradients, presented a strong case for geothermal co-production. The Devonian steady-state reservoir has historically produced fluid at 240°F (115.6°C), observed at the wellhead without documented pressure drawdown or thermal breakthrough.

In FY25, NREL led advanced geological and reservoir modeling to evaluate co-production potential. A 3D conceptual model was developed using both public and proprietary historical data, legacy subsurface exploration from initial field development, and detailed lithological and thermophysical characterizations. The team also analyzed heat and fluid flow over a simulated 10-year time period. Thermophysical and flow properties were calibrated using historical well logs and field data to represent Blackburn's subsurface conditions.

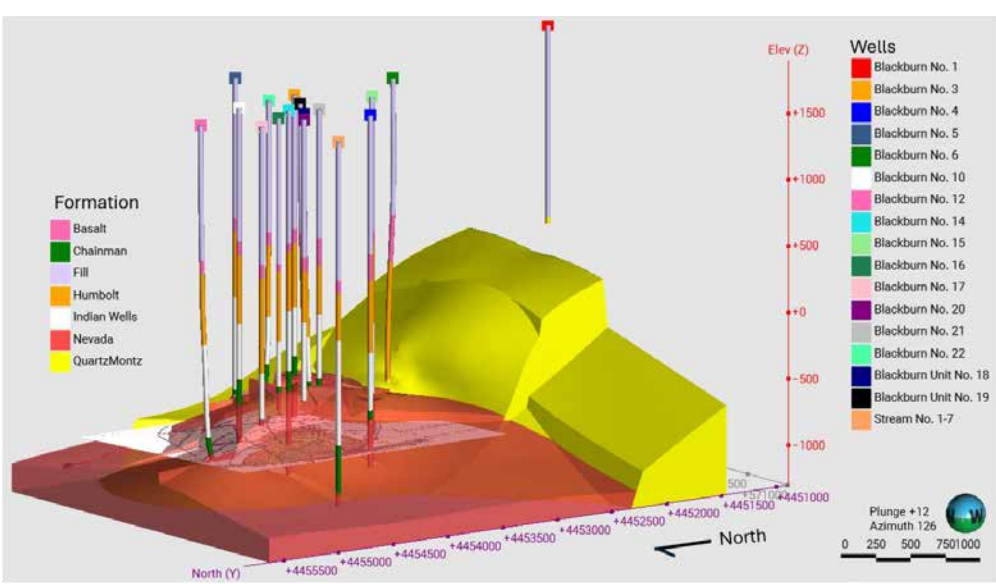
Modeled reservoir production performance suggested that a combined geothermal–oil production strategy can extend the economic life of mature oil fields while contributing to energy generation. The project has successfully transitioned from modeling and feasibility analysis into the preparatory stages of field deployment, positioning the project to begin pilot deployment steps to enable co-produced geothermal resources for domestic, dispatchable power in Nevada.

PRINCIPAL INVESTIGATOR
Abra Gold

IMPACT
The project explores reliable, year-round power generation from a domestic and dispatchable geothermal resource to extend the productive life of mature oil fields.

PARTNER
Gradient Geothermal, Inc.

LEARN MORE
bit.ly/4luPjDk



GeologicModel: 3D geological model of the reservoir rock (Nevada dolomite) and basement rock (Quartz monzonite) at the Blackburn Oil Field, with formation tops data pictured as sticks. *Figure by Abra Gold, NREL.*

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Wells of Opportunity

Geothermal Energy From Inactive Oil and Gas Wells in Tuttle, Oklahoma

In Tuttle, Oklahoma, NREL is partnering with the University of Oklahoma, Southern Methodist University, and Blue Cedar Energy to use four existing oil and gas wells for geothermal energy production to supply heating and cooling demand to a primary school, a secondary school, and 250 nearby single-family homes. These users are only a mile away from the targeted wells, which tap ~90°C geothermal fluids from around 3 kilometers below the ground surface.

In FY25, the team published results showing that geothermal energy production is technically and economically feasible to supply the district thermal loads over a 30-year lifetime. By repurposing existing oil and gas wells, $7 million in drilling costs can be saved, yielding a levelized cost of heat of $71/megawatt-hour (MWh). When including the revenue from supplying the regional base heating load, $71/MWh is further reduced to $54.6/MWh. NREL's team also analyzed the impact of the geothermal district energy system on the environment, and on grid flexibility and resilience. Results suggested up to 94.7% reduction in electricity consumption compared to a non-geothermal base case (an electrified heating system and air source heat pump), with annual energy savings reaching $803,000 per year.

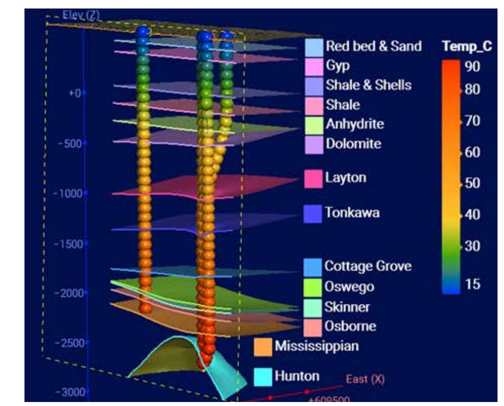
Grid-responsive, flexible operation further reduced wholesale electricity costs by 53%–56%. Grid-responsive, flexible operation reduces electricity consumption during periods of high grid costs by shifting more load to peaking gas boilers. The analysis evaluated both the reductions in electricity consumption and the corresponding increase in boiler usages when comparing grid-responsive and non-responsive operation.

Ultimately, these findings and FY25 publications illustrate the feasibility of geothermal energy production using inactive oil and gas wells for the Tuttle district energy system while demonstrating the positive impacts that reusing this type of existing infrastructure can have on cost savings and grid flexibility.

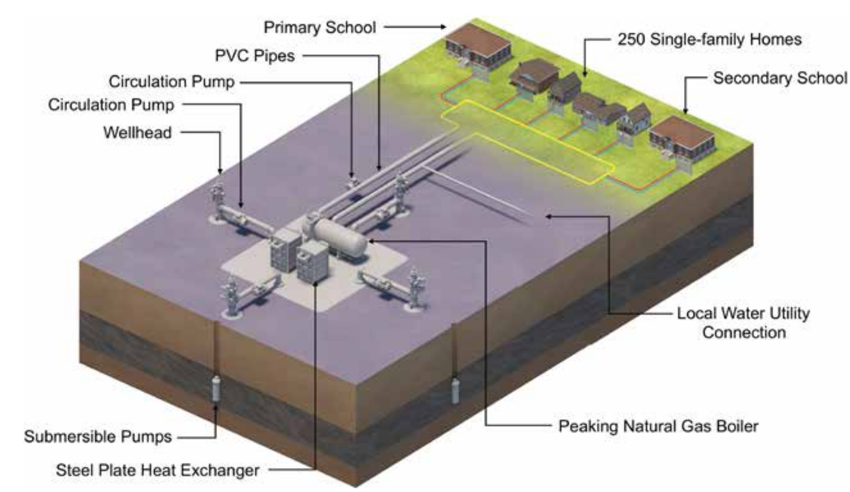
PRINCIPAL INVESTIGATOR
Hyunjun Oh

IMPACT
Outcomes highlight repurposing existing oil and gas infrastructure for geothermal energy production will bring future economic benefits, as well as enhanced grid value.

PARTNERS
University of Oklahoma, Southern Methodist University, Blue Cedar Energy



Deposit contact surfaces with the wellbore temperature distribution. *Figure by NREL, published in Oh et al. 2024*



Overview of geothermal district heating system in Tuttle, Oklahoma. *Figure by Besiki Kazaishvili/NREL, published in Marroquin et al. 2025*

LEARN MORE

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TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

EGS Ground Truthing at Cornell: Techno-Economic Analysis, Modeling, and Scalability

PRINCIPAL INVESTIGATOR
Hannah Pauling

IMPACT
Demonstrated the technical and economic feasibility of deep geothermal district heating in the northeastern United States, identifying up to 60 GWth of cost-competitive capacity and substantial local job creation potential. These results support future deployment of resilient heating solutions in dense, high-demand communities.

PARTNER
Cornell University

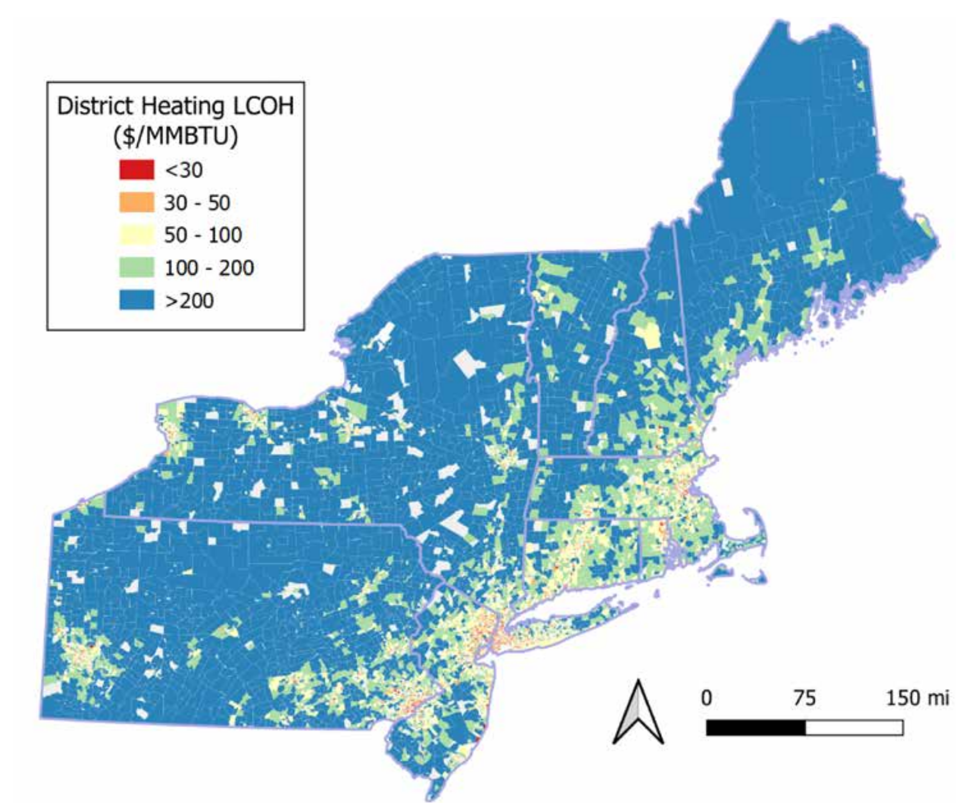
LEARN MORE
bit.ly/3GqWSf0

In FY25, NREL completed the final phase of a multiyear collaboration with Cornell University in support of the Earth Source Heat deep direct-use geothermal project. This effort focused on techno-economic evaluation, reservoir modeling, and the regional scalability of deep geothermal systems for campus- and community-scale heating in the northeastern United States.

In previous years, NREL developed and applied advanced reservoir simulation tools and upgraded techno-economic models—GEOPHIRES and MEnU—to analyze borehole data from Cornell's exploratory well and assess the cost-competitiveness of deep direct-use systems. These tools were integrated with NREL's Distributed Geothermal Market Demand (dGeo) model to conduct a regional feasibility study.

This project demonstrated the strong socio-techno-economic potential of EGS-powered district heating in the northeastern United States. The analysis, conducted at the census-tract level across nine states, identified up to 60 GWth of capacity with levelized costs of heat (LCOH) below $50/MMBtu, concentrated in dense urban areas with high thermal demand. If deployed at scale, such systems could generate tens of thousands of construction jobs and drive billions of dollars in capital investment, primarily through drilling and district energy infrastructure.

The study confirmed that EGS-based deep direct-use systems are not only feasible for individual campuses like Cornell's, but also scalable to broader regional applications—particularly in cold climates and high-demand communities. NREL's FY25 activities supported final model refinement, public data release via the Geothermal Data Repository, and dissemination of findings through the 2025 Stanford Geothermal Workshop. These efforts concluded NREL's contributions to a project that provides a compelling case for expanding geothermal district heating beyond traditional geothermal hotspots.



Levelized cost of heat (LCOH) in $/million British thermal units (MMBtu) for EGS-based geothermal district heating systems by census tract. *Graphic by Koenraad Beckers, NREL*

TECHNOLOGIES AND RESOURCES RESEARCH PILLAR

Geothermal Resource Potential of Alaska: Improved Estimates Through Local Collaboration, Updated Datasets, and Modeling

PRINCIPAL INVESTIGATOR
Estefanny Davalos Elizondo

IMPACT
Advances the understanding of Alaska's geothermal resource potential, enabling the identification of viable sites for energy development.

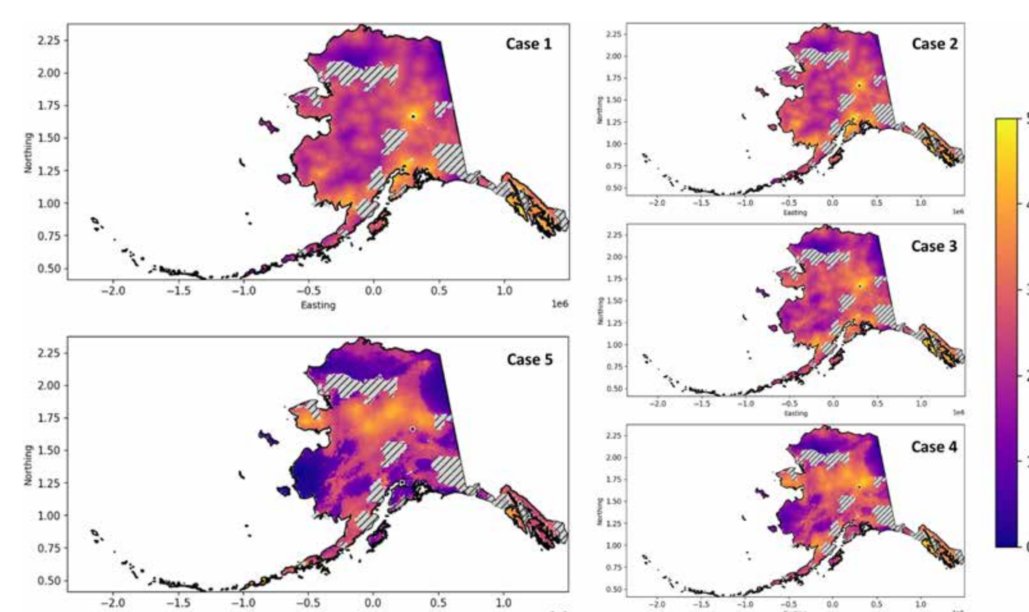
PARTNER
AECOM, Alaska Division of Geological and Geophysical Surveys, University of Alaska Fairbanks/Alaska Center for Energy and Power, University of Alaska Anchorage, U.S. Geological Survey (including the Alaska Volcano Observatory), Alaska Energy Authority, U.S. Army Corps of Engineers, DOE's Arctic Energy Office, Alaska Oil and Gas Commission, and Tribal organizations.

In FY25, NREL made significant strides in enhancing geothermal resource characterization in Alaska, one of the most geologically promising yet historically underexplored regions in the United States. Due to limited exploration and sparse data, Alaska has frequently been overlooked in national geothermal deployment studies. To directly address these challenges, NREL integrated a wide range of geothermal resource datasets, leveraging advanced modeling techniques to significantly improve the state's thermal Earth model.

Key accomplishments in FY25 include the refinement of Alaska's thermal model through the application of a physics-informed graph neural network interpolation algorithm, which greatly enhanced subsurface resolution and temperature accuracy. This advanced model was built upon an extensive foundation of previously compiled datasets, while also incorporating new subsurface resource data. NREL also developed and updated a comprehensive geospatial database encompassing critical subsurface information, such as well temperature logs, thermal conductivity, and fault systems, alongside surface conditions like permafrost extent and soil properties, as well as demand-side factors including heating and cooling demand, population centers, community relocation plans, and other relevant variables.

A critical driver of the project's success has been the Alaska Geothermal Gap Analysis Working Group, listed at right as partners. This collaborative group played an essential role in shaping the project's direction by providing expert guidance, identifying priority regions for study, prioritizing data collection efforts, and ensuring broad stakeholder engagement and diverse perspectives.

This project identified previously overlooked medium-temperature geothermal resource zones, particularly in areas with favorable geological conditions. These zones show strong potential for both electricity generation and direct-use applications, especially in remote communities and emerging population centers. The project's broader impact lies in its contribution to a long-term roadmap for geothermal resource development in Alaska.



Spectrum of deep geothermal favorability maps generated using the **geoPFA**[3] tool (Cases 1–5). Brighter colors indicate higher favorability. Maps are labeled by case number: Case 1 (economically dominated) through Case 5 (geologically dominated). Intermediate cases (2–4) highlight regions where geologic and economic favorability overlap, providing a balanced view of near- to medium-term opportunities. *Graphics by Estefanny Davalos Elizondo and Scott Mello, NREL*

MARKET ACCELERATION PILLAR

Upcoming Analyses

U.S. Geothermal Market Report Update Underway

NREL is currently finalizing an update and expansion of the *2021 U.S. Geothermal Power Production and District Heating Market Report*. The update will provide an in-depth look at the state of geothermal energy in the United States, capturing the growth of the industry over the past four years and includes a new discussion of geothermal heating and cooling applications, as well as next-generation technology breakthroughs.

Funded by DOE's Geothermal Technologies Office and developed with support from Geothermal Rising, the report aims to provide policymakers, developers, researchers, engineers, financiers, and other stakeholders with a broad update on the state of the industry in the United States. Topics will include conventional geothermal electricity generation, EGS, closed-loop geothermal, heating and cooling, direct use, storage, TENs, policy impacts, flexible and secure grid support, and emerging technologies like superhot, mineral extraction, and co-production with oil and gas.

PRINCIPAL INVESTIGATOR
Dayo Akindipe

IMPACT
Captures the growth of the geothermal industry across power, heating, cooling, storage, and more, and highlights emerging technologies to watch in the next 5 to 10 years.

PARTNER
Geothermal Rising

2025 Analysis Identifes Key Geothermal Workforce Hurdles and Opportunities

The NREL-led *Geothermal Workforce Assessment: Current Status and Future Trends* is underway, examining effective recruitment, training, and hiring practices necessary for a workforce ready to meet industry needs.

This foundational, national-level assessment focuses on analyzing workforce opportunities and challenges across geothermal power generation and geothermal heating and cooling. This assessment evaluates both the current and future workforce needs of the industry by analyzing workforce supply and demand and helps identify critical workforce development-related challenges and emerging opportunities to mitigate future negative impacts.

Multiple research methods are being used, including a literature review, semi-structured interviews with more than 33 industry stakeholders and companies, an occupational mapping exercise, and the development of a national database of relevant education and training programs. Additionally, workforce projections were modeled using the Workforce Impacts and Regional Economic Development (WIRED) tool to estimate job creation under various future deployment scenarios. A public version of the analysis is under development.

PRINCIPAL INVESTIGATOR
Brinn McDowell

IMPACT
This foundational workforce assessment examines the workforce supply and demand across three geothermal technology groupings.

MARKET ACCELERATION PILLAR

GeoBridge, a New Launch Point for Geothermal Information

The geothermal community is home to numerous tools, events, and organizations dedicated to sharing knowledge. However, many of these tools can be difficult to find—their resources undiscoverable by search engines, available only to members, or hidden behind pay walls. GeoBridge, a new DOE initiative developed by NREL, is designed to bridge gaps in information and connect the geothermal stakeholders to essential online resources.

This new tool aspires to expand the pool of geothermal stakeholders by providing geothermal information and community resources in one place. It makes these resources easier to access for the broader geothermal community as well as those looking to join, such as entrepreneurs or innovators in adjacent industries looking to expand into geothermal energy.

GeoBridge covers a variety of topics ranging from basic geothermal knowledge to career information, classroom resources, geothermal innovations, tools, and more—all with curated content aimed at building a bigger, more knowledgeable, more connected geothermal community. Since its launch in October 2024, GeoBridge has connected thousands of users to reliable, impartial information about geothermal technologies, opportunities, industries, and experts.

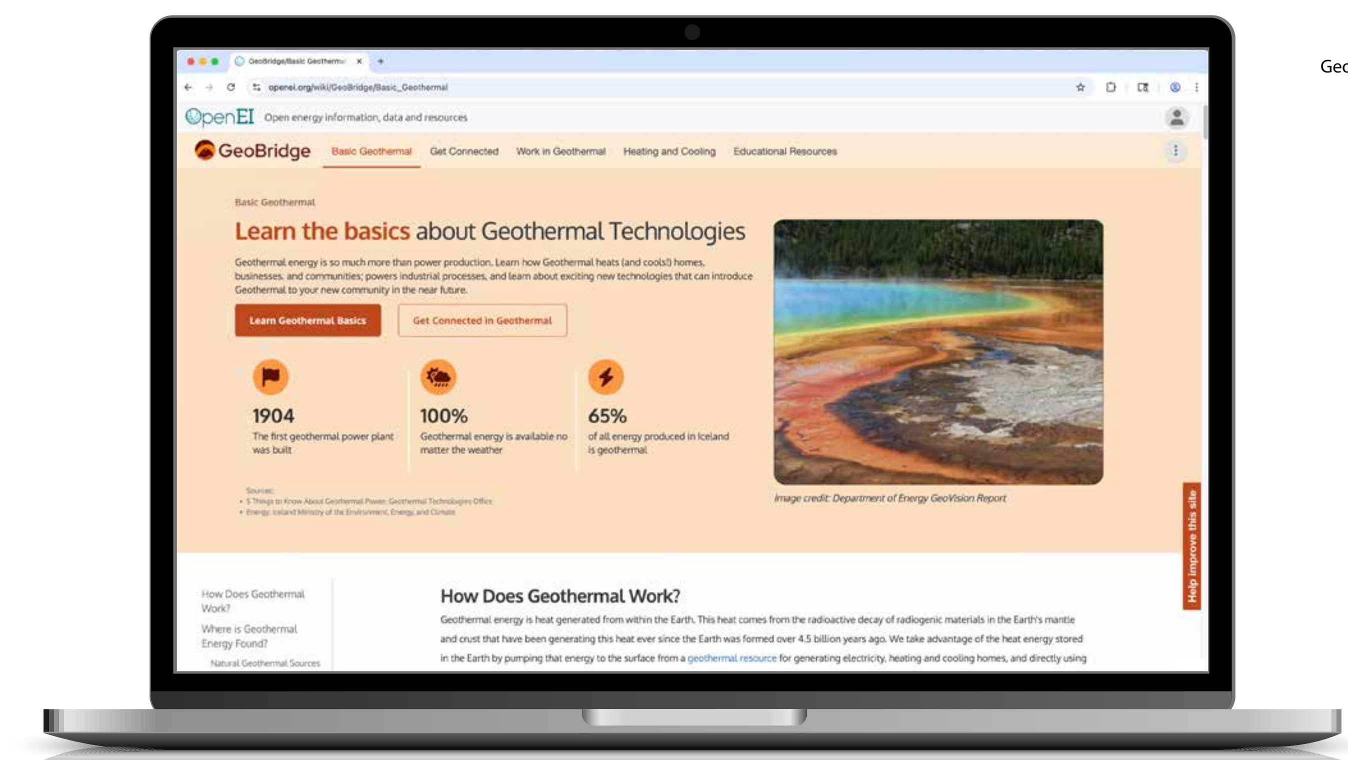
GeoBridge was launched with an initial set of content at the Geothermal Rising Conference (GRC) in 2024. Since then, the response has been overwhelmingly positive, validating that there is a sustained demand for the information on GeoBridge. In FY25, the team doubled the size and scope of the portal, incorporated feedback and suggestions from users, and added tools to make it easier to navigate, query, and find geothermal resources while keeping information updated and relevant.

PRINCIPAL INVESTIGATOR
Jon Weers

IMPACT
GeoBridge provides answers to some of the most pressing questions in geothermal, covering everything from home heat pump installation to careers in geothermal, educational tools, and cost savings opportunities for businesses.

PARTNER
GeoBridge Advisory Group

LEARN MORE
bit.ly/3TFB2Ya



Screenshot of the GeoBridge homepage. *Graphic by NREL*

MARKET ACCELERATION PILLAR

Geothermal Energy Atlas Replaces Geothermal Prospector Tool

The **Geothermal Energy Atlas**[5] launched in FY25 as a publicly accessible, web-based platform that empowers a broad range of stakeholders to discover, understand, and act on complex geothermal geospatial data. Developed by NREL, the Geothermal Energy Atlas fills a critical gap left by the 2022 retirement of the Geothermal Prospector tool.

The Geothermal Energy Atlas was designed in direct response to early-stage user and market research conducted by NREL, which identified a growing need among research scientists, geologists, and energy analysts to easily access and interpret geothermal datasets. These users, spanning federal agencies, startups, nonprofits, utilities, and academic institutions, consistently noted challenges in accessing curated, decision-ready data to inform feasibility assessments, site selection, and broader geothermal deployment strategies.

Throughout FY25, the Geothermal Energy Atlas team expanded the platform's capabilities by incorporating new datasets and integrating modeling results to support the full spectrum of geothermal use cases, including power generation, direct-use heating, and district-scale geothermal power generation and geothermal heating and cooling technologies. The integration of these enhancements reflects GTO's commitment to enabling more informed, data-driven decisions across the geothermal ecosystem and to supporting the scale-up of both conventional and emerging geothermal technologies.

PRINCIPAL INVESTIGATOR
Nicholas Gilroy

IMPACT
The new Geothermal Energy Atlas will empower users to discover, understand, and act on complex geothermal spatial data.

LEARN MORE
bit.ly/4o10O68

State-Level Collaboration on Geothermal Energy Helps Understand Stakeholder Concerns and Barriers to Development

As geothermal energy expands across the United States, connecting with a variety of stakeholders at the state level and building trust in communities are critical steps toward developing lasting relationships and raising awareness about the technology. As part of this effort in FY25 and into FY26, NREL co-hosted a series of workshops and virtual educational webinars in multiple regions in Colorado to understand the current relationship stakeholders have with geothermal, as well as to provide educational resources and awareness of the technologies. In FY26, the NREL team will focus on working with Colorado stakeholders to identify barriers and opportunities related to geothermal development from their perspectives.

This effort builds on the lessons learned and successes from previous engagements in Alaska and Hawai'i; the concept of state-level collaboration has been a unique effort seeking to address common misconceptions and concerns surrounding all types of geothermal technologies through direct engagement with stakeholders, listening sessions, and the creation of educational materials. The FY25 initiative will continue into FY26 and will include multiple regional events in Northwest Colorado, the Western Slope, Southwest Colorado, the Central Mountains, and the Front Range. For this effort, the NREL team has coordinated with the Colorado Energy Office to create the Colorado Geothermal Council. The Council includes over 50 members representing state agencies, industry, decisionmakers, nonprofits, and Tribal representatives who self-identify as geothermal stakeholders in Colorado with an interest in increasing education and awareness.

PRINCIPAL INVESTIGATOR
Faith M. Smith

IMPACT
Connecting with state-level energy and environmental stakeholders interested in geothermal technologies allows for more open and transparent engagement and education. This effort emphasizes hearing various perspectives related to geothermal energy as well as increasing geothermal education and awareness at the local level. Increased awareness and education helps inform decisionmakers, community members, and energy stakeholders while reducing nontechnical barriers, which can delay geothermal deployment.

PARTNERS
The Colorado Geothermal Council includes over 50 individuals from varying organizations and positions. The core list of supporters includes but is not limited to: Colorado Energy Office, Colorado's Carbon and Energy Management Commission, Colorado School of Mines, and Colorado's Department of Natural Resources.

[5] https://maps.nrel.gov/geothermal-energy-atlas/

MARKET ACCELERATION PILLAR

Geothermal Data Repository Adopts AI Research Assistant "AskGDR"

The **Geothermal Data Repository (GDR)**[6] enables research, collaboration, and transparency by providing free access to geothermal data generated from projects funded by GTO. GDR protects DOE's investment in research and development through proper data management and the open transfer of knowledge, fueling innovation, reducing duplication of effort, and promoting scientific discovery in the geothermal sector.

The GDR was developed by NREL in 2012 in accordance with DOE's 2011 Strategic Plan, which stated that "DOE's success should be measured not when a project is completed or an experiment concluded, but when scientific and technical information is disseminated." Built from the ground up to share information, the GDR shares its metadata with a network of data sharing partner sites, including Data.gov, OSTI's DOE Data Explorer, Thompson Reuters, Google Datasets, and more. All data submitted to the GDR automatically appear in the content and searches of these sites, exponentially increasing the impact of data from GTO research and development activities. The GDR has over 1,320 datasets and more than 760 terabytes (TB) of data from 126 different organizations.

In FY25, several updates were made to the GDR. A new AI research assistant called AskGDR was launched at the 2024 Geothermal Rising Conference, and the team has continued to analyze AskGDR's use and improve its functionality over the fiscal year. The team also released Data Foundry 2.0, which now allows for programmatic access to data stored within private cloud-based data lakes, while providing the same levels of security and access control. Data Foundry's new private data lakes enable researchers to collaborate on thousands of files simultaneously.

The GDR is an important resource to the geothermal scientific community. Data stored on the GDR are downloaded hundreds of thousands of times per month by universities, private organizations, industry professionals, and government agencies.

PRINCIPAL INVESTIGATOR
Jon Weers

IMPACT
Enabling research, collaboration, and transparency by providing universal access to geothermal data.

LEARN MORE
bit.ly/40i84RT
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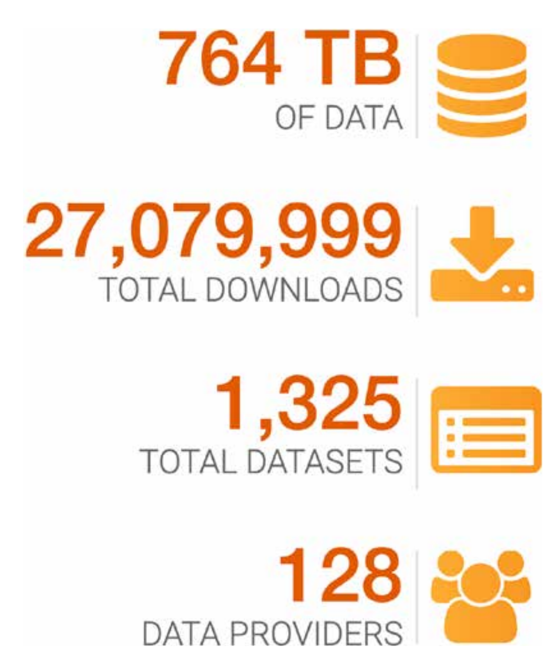


GDR stats. *Figure from GDR website*

AskGDR flow. *Figure from Jon Weers, NREL*

[6] https://gdr.openei.org/

MARKET ACCELERATION PILLAR

"What Is at the Bottom of a Geothermal Well?" Storymap Takes Viewers Underground

An NREL-developed, GTO-envisioned application titled **"What is at the bottom of a geothermal well?"**[7] launched as a publicly accessible web resource in FY25 to bring geothermal energy into clearer focus for general audiences, developers, and policy makers. Through engaging narratives, striking visuals, and memorable trivia, the platform has bridged a gap in public understanding by making the unseen world beneath our feet both relatable and compelling.

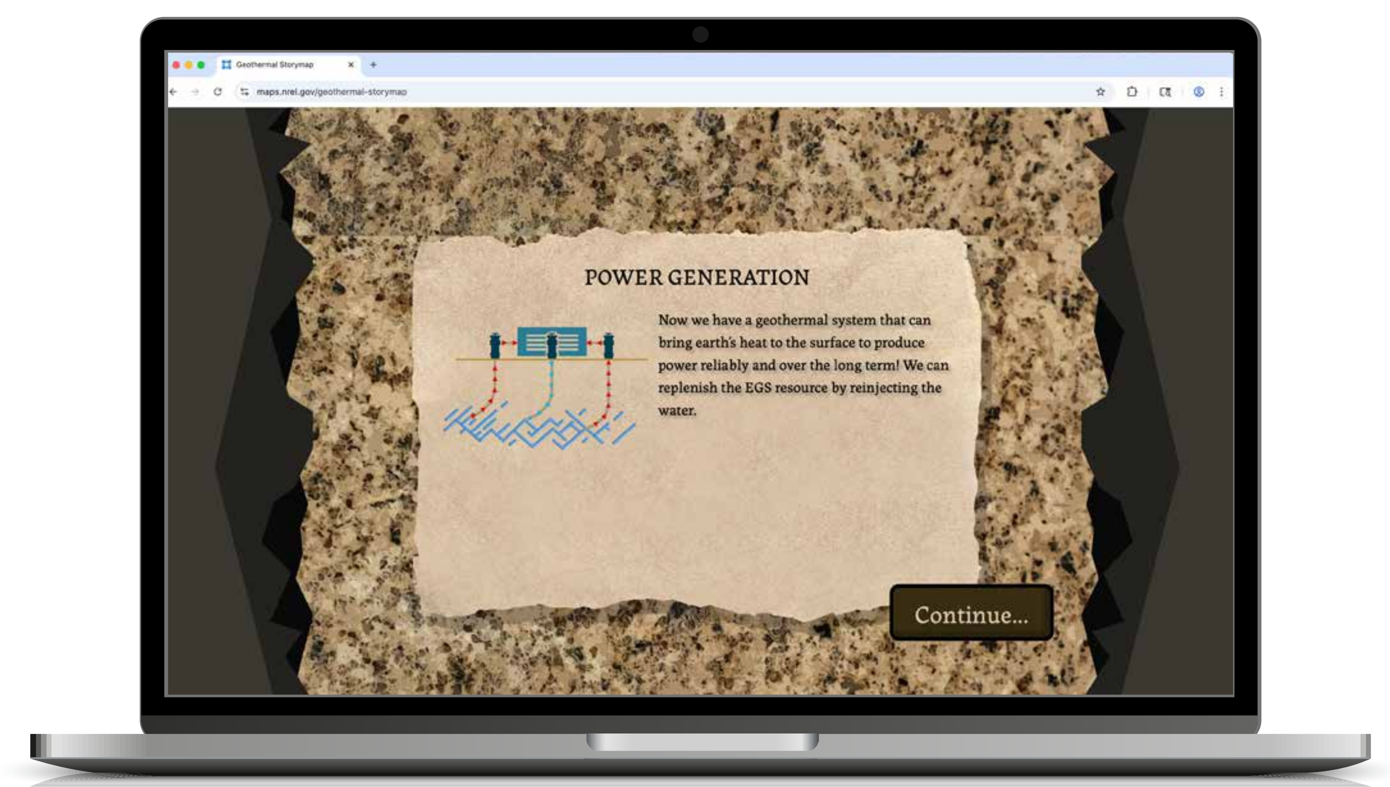
This project tackles a fundamental communication barrier in the geothermal energy space: how to represent a resource that operates entirely underground and cannot be captured through traditional imagery. By visualizing geothermal systems at depth, this project demystifies the subsurface and helps users conceptualize the scale, safety, and potential of this hidden energy source.

Geothermal energy has faced nontechnical hurdles to broader adoption, particularly around public perception and community acceptance. In response, GTO funded this project to offer a transparent, visually rich experience that contextualizes geothermal activity and clarifies its real-world impacts. More than just an educational resource, this project represents a model for how creative communication can support the deployment of complex technologies.

PRINCIPAL INVESTIGATOR
Nicholas Gilroy

IMPACT
As geothermal energy continues to expand its role in the energy landscape, this project stands as a reminder that public understanding is just as critical to success as the technologies themselves.

LEARN MORE
bit.ly/4ocekUB



StoryMap screenshot. *Figure by NREL*

[7] https://maps.nrel.gov/geothermal-storymap

MARKET ACCELERATION PILLAR

Subject Matter Experts and Oil and Gas Stakeholders Collaborate Through GEODE

The Geothermal Energy from Oil and Gas Demonstrated Engineering (GEODE) project is a groundbreaking GTO-funded initiative aimed at accelerating geothermal energy development by integrating technical expertise, practices, and data from the oil and gas sector. GEODE, led by Project InnerSpace and the Society of Petroleum Engineers, establishes a structured framework for cross-sector collaboration, focusing on shared challenges and opportunities between the geothermal and oil and gas industries. In FY25, it brought together a wide range of stakeholders across government, academia, national laboratories, and private industry.

GEODE is structured into several focused "Facets," each including one or more working groups tackling a critical area of geothermal development. NREL researchers have participated in several working groups. Facet 1 centered around Technology Transfer from oil and gas, where NREL contributed to discussions around modeling and simulation, as well as drilling and completions. NREL also trained a generative AI large language model to facilitate access and streamline analysis in the Capabilities Database that the GEODE consortium is developing to map out the competencies, expertise, and facilities at national laboratories and in academia.

In addition, NREL contributed to Facet 4, which focused on Workforce Analysis, Training, and Education.

NREL chaired the working group in Facet 2, focused on subsurface and operational data for geothermal resource exploration and characterization. Facet 2 roadmapping brought together geoscientists, reservoir engineers, and data scientists to improve how the geothermal industry identifies, evaluates, and models subsurface resources. Efforts were centered on identifying and addressing gaps in publicly available subsurface data, and designing a state-by-state framework to generate a high-resolution heat flow map across the United States. Facet 2 ultimately aims to de-risk geothermal exploration by making subsurface information more accessible, standardized, and machine-readable—laying the groundwork for a new generation of data-driven geothermal development across the United States.

PRINCIPAL INVESTIGATOR
Nicole Taverna

IMPACT
Leveraging best practices and knowledge from oil and gas to help expand the use of geothermal technology across sectors.

PARTNERS
Project InnerSpace, Society of Petroleum Engineers

First quarterly brainstorming meeting for GEODE Facet 2 at NREL. *Photo by James Bosch, NREL*

MARKET ACCELERATION PILLAR

Retrieving Local Groundwater Permitting Guidelines using AI

PRINCIPAL INVESTIGATOR
Whitney Trainor-Guitton

IMPACT
Developing an autonomous workflow using AI to help track the changes in local ordinances that affect geothermal development could provide a cost-effective and consistently improving methodology to support the industry.

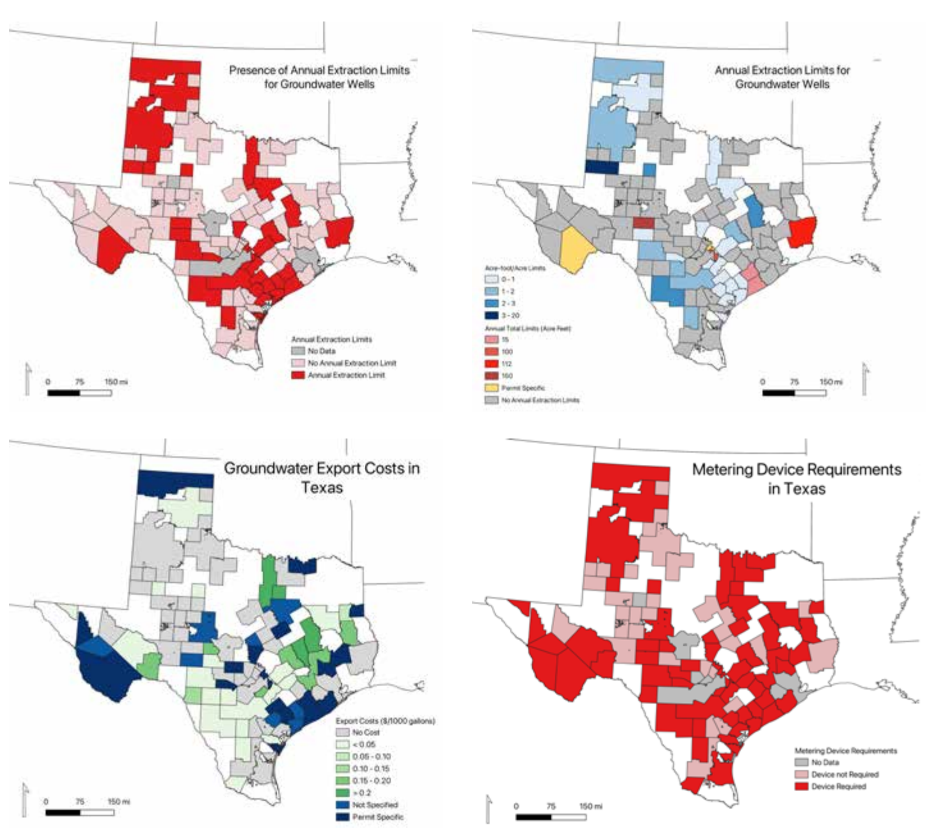
An NREL team is harnessing the power of AI to scrape the web for water availability and policy information related to EGS operations to test the validity of AI algorithms for geothermal.

Gathering geographically expansive and unstructured information on regional, state, or local ordinances that could affect EGS development is time-consuming and difficult because ordinances are rapidly changing, requiring repeated labor-intensive efforts. Web scraping with AI-powered large language models may provide a reproducible and rapid method for updating local regulations, which then can be included in different scenarios modeled in NREL's **reV**[8] model.[9]

This new project is using large language models and retrieval-augmented generation as a pilot to find and categorize information detailing groundwater well permitting as it relates to geothermal energy in Texas. The large language model extracts unstructured data from text documents, which is then fed through a decision tree to validate the information. The retrieval-augmented generation was then used to capture more detailed information, such as spacing and metering requirements, drought management plan, permit timelines, maximum water extraction limits, permit requirements, and more.

The AI outputs are verified by previous NREL research characterizing the policy impacts, helping researchers understand how effective web scraping of HTML material and decision tree algorithms are at organizing the geothermal-relevant web content.

Researchers have produced preliminary maps groundwater guidelines for almost 100 water conservation districts with plans to expand this work geographically next year.



Preliminary maps: Using one of OpenAI's GPT models and prompts around current groundwater extraction guidelines, NREL researchers retrieved the status of 95 groundwater districts in Texas. Maps here depict where annual extraction limits exist (upper left), the magnitude of extraction limits (upper right), export costs (lower left) and metering devices (lower right) for groundwater exist. Please note: White areas indicate absence of water conservation district, and maps reflect information in different units. *Graphic by Slater Podgorny, NREL*

[8] https://www.nrel.gov/gis/renewable-energy-potential

[9] The reV model assesses renewable energy resources and their geospatial intersection with grid infrastructure and land use characteristics. https://docs.nrel.gov/docs/fy19osti/73067.pdf

MARKET ACCELERATION PILLAR

Feasibility Study Shows Geothermal District Energy Systems Could Meet Demand in Romania

PRINCIPAL INVESTIGATOR
Shanti Pless

IMPACT
Promotes awareness of geothermal energy and industries across the United States and Europe, while amplifying geothermal energy as a tool and critical technology in the energy space.

NREL provided technical assistance to the city of Bucharest, Romania, for the development of a geothermal district energy system. NREL's role included collecting data to help determine the feasibility of a geothermal district energy system (GeoDES) or TEN designed to meet the thermal energy demand of the city. Much of Bucharest is served by an existing natural gas-fired district energy system distributing hot water. The system could be extended through the addition of geothermal wells (coupled to a heat pump) as a heat source. Such a configuration could operate in a highly efficient way, and would reduce the system's exposure to the price volatility of natural gas, provide required district heating temperatures, and minimize additional distribution costs. These energy networks allow for multiple energy sources and sinks, with the physical infrastructure of TENs mimicking that of existing natural gas systems. This means that the existing workforce in the city that is familiar with the natural gas system can install and implement the TENs system without a major overhaul, providing jobs to utility workers.

Ultimately, NREL's research team collected data from Romanian sites, targeting the subsurface, surface, and demand factors of the area along with energy sources and sinks in each area and geological suitability. This information allowed the team to simulate and analyze geothermal integration with other energy sources for renovated and new district energy systems. The findings have been summarized into a report for the city to consider how to best support their energy needs. In addition, this work serves as a model to educate others on meeting the heating needs of medium-sized cities, which can then be replicated within the United States and with other partner countries.

Thermal substation with heat exchangers to buildings. *Photo by Shanti Pless, NREL*

MARKET ACCELERATION PILLAR

FedGeo Partnership Brings Geothermal Heating and Cooling to Federal Sites

PRINCIPAL INVESTIGATOR
Matt Mitchell

IMPACT
Providing technical support for federal sites implementing geothermal heating and cooling promotes adoption and can reduce federal costs.

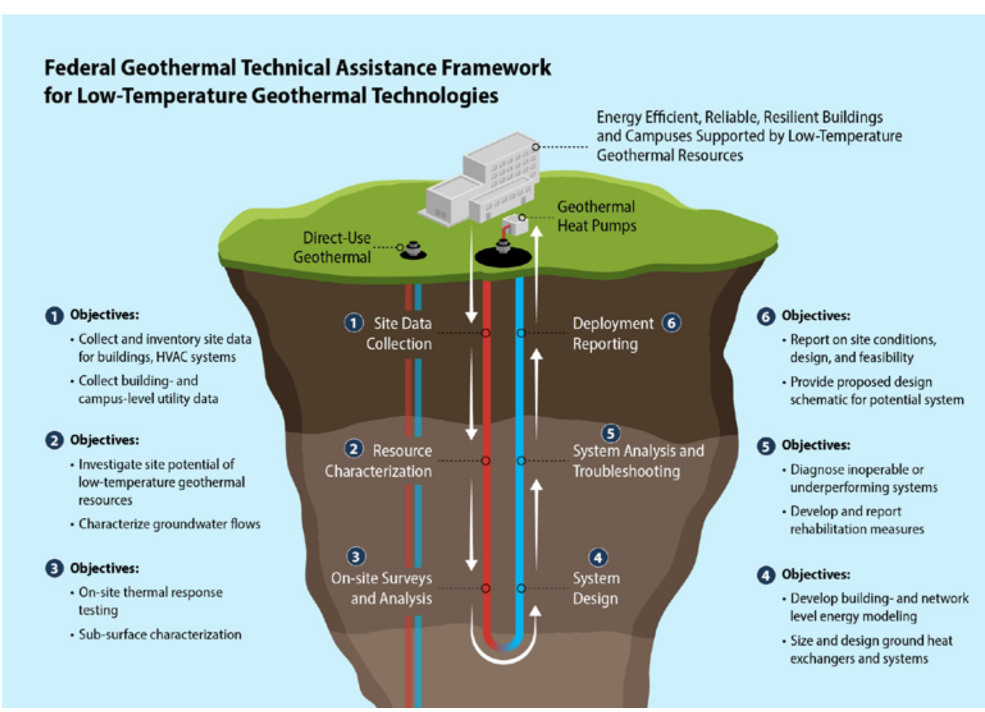
PARTNERS
Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, Oklahoma State University, University of Wisconsin–Madison, Illinois Geologic Survey

The federal government operates more than 300,000 buildings and spends billions of dollars annually on energy costs. To reduce these costs, NREL is partnering with federal facilities through the Federal Geothermal Partnership (FedGeo Partnership) to establish a long-term technical assistance pathway related to low-temperature geothermal technology, including GHPs, district and community heating and cooling systems, and hybrid systems that include geothermal resources.

This project, under the leadership of Oak Ridge National Laboratory, brings together NREL, other national laboratories, industry, and academia, to establish a technical assistance pathway for federal organizations to obtain help analyzing, designing, and deploying geothermal technologies for heating and cooling.

In FY2024, the FedGeo team conducted a comprehensive feasibility study to evaluate the implementation of geothermal heating and cooling systems at two locations: the U.S. Army Garrison Detroit Arsenal in Michigan and the U.S. Military Academy at West Point. The techno-economic analysis indicated that retrofitting existing heating, ventilating, and air conditioning (HVAC) systems in selected buildings with GHP technology could lead to significant reductions in energy costs. The study included detailed site assessments and offered recommendations to enhance economic viability and system performance through thermal load balancing and improvements to building envelopes.

In FY25, similar principles and lessons learned are being applied to two additional sites: Fort Gordon in Georgia and the Mansfield Federal Courthouse in Butte, Montana. At Fort Gordon, NREL is developing and validating a hydraulic model of the geothermal pumping system to diagnose existing operational challenges, optimize system performance, and support more efficient management of the borefields. At the Mansfield Federal Courthouse, NREL is collaborating with the University of Wisconsin–Madison to conduct subsurface explorations of the nearby Steward mine shaft. This effort aims to assess the site's feasibility for geothermal development through drilling access, deployment of sensing equipment, and documentation of subsurface conditions.



The FedGeo partners collaborate to create a framework that enables the deployment and future growth of geothermal technologies at federal facilities.
Graphic by NREL

MARKET ACCELERATION PILLAR

Case Study Yearbook Highlights the Versatility of Geothermal Heating and Cooling Technologies

PRINCIPAL INVESTIGATOR
Xiaofei Pu

IMPACT
Case studies highlight the advantage and wide applicability of geothermal heating and cooling technology across the United States in providing heating and cooling.

Providing homeowners and business owners interested in installing geothermal heating and cooling systems with accurate information on real-life systems in a variety of U.S. areas is crucial to promote adoption, but this information can be difficult to access. To address this gap and showcase the wide applicability of geothermal heating and cooling technology, GTO funded NREL to work with installers and owners to create a series of case studies that help interested parties learn how these systems might work for them.

Building on **19 case studies released in FY24**,[10] NREL continued to amplify outreach on these materials to industry and local stakeholders in FY25. The team also prepared five additional case studies for publication, expanding to new regions in the United States and new building types. These new case studies included a school district in West Virginia, a grocery store in Oklahoma, a Kentucky airport, a housing development associated with a film studio in Georgia, and a college in New Mexico. Continued outreach and publication of such case studies is important to highlight geothermal for its energy efficiency, cost savings, wide applicability, and stable performance in providing heating and cooling to a variety of building types, sizes, and climate zones.

NREL published 19 case studies describing sites that use geothermal heating and cooling for their facilities.
Graphic by Dominique Barnes, NREL

[10] https://www.energy.gov/eere/geothermal/geothermal-heat-pump-case-studies

NREL has been working on upgrading geothermal analysis tools for the past three years, including the programs profiled here across both power (green) and heating and cooling (blue) at the site-specific and nationwide levels. *Graphic by Dominique Barnes, NREL*

GRID INTEGRATION PILLAR

Geothermal Analysis Portfolio Sees Major Upgrades to Increase Geothermal Representation in Modeling Tools

For the past several years, NREL researchers have been improving geothermal representation across a variety of NREL's flagship modeling and analysis platforms. Early work ensured modeling and dataset improvements were made, and that baseline deployment benefits and analyses were understood. In FY25, the portfolio built upon the development of modeling tools to be able to analyze multi-scale and multi-sector impacts and what geothermal power, heating and cooling, and storage could do for the grid.

The modeling upgrades span nine different software programs and integrate together to allow researchers to acurately predict costs and performance, design integrated geothermal systems, model and analyze grid impacts of geothermal technologies, and more. This body of work has ensured geothermal technologies are now represented in key studies conducted both by NREL and by external stakeholders.

LEARN MORE

bit.ly/4lZpc6F

GRID INTEGRATION PILLAR

Geothermal Analysis Portfolio Summary

Major Upgrades Increase Geothermal Representation in Modeling Tools

GEOTHERMAL POWER

By design, these three models utilize Annual Technology Baseline costs for consistent analyses across the scales.

The Geothermal Electricity Technology Evaluation Model (GETEM) is an Excel-based tool for estimating the performance and costs for geothermal power technologies. It is used to optimize power plant sizing and estimate future costs of geothermal electricity based on current deployment and technology improvement scenarios. GETEM is now integrated into NREL's System Advisor Model (SAM).

The Renewable Energy Potential (reV) model is a geospatial modeling platform used to calculate capacity, generation, and cost while considering grid infrastructure and land-use characteristics. The reV model calls GETEM for each hypothetical geothermal power plant location at the national scale—allowing for geothermal potential to be represented at the same detailed resolution as other renewable energy technologies.

The Regional Energy Deployment System (ReEDS) is NREL's flagship capacity planning model for the power sector. ReEDS ingests site-based geothermal capacity and economics from GETEM and reV to compare to other energy sources and determine future grid needs.

GEOTHERMAL HEATING AND COOLING

On a building or network of buildings scale:

URBANopt™ (Urban Renewable Building and Neighborhood optimization) can model the physics for one building or a network of buildings, sizing how many GHPs you might need to meet the space heating and cooling for your site.

REopt™ (Renewable Energy Integration and optimization) can be co-simulated with URBANopt to provide life cycle costs of a geothermal-based district energy system. REopt allows for comparing a single-heat pump system with other energy options for a single site based on costs, resiliency, energy usage, etc. Future work will expand REopt's capabilities to geothermal power.

On a national scale:

ComStock™ and ResStock™ offer a probabilistic representation of the U.S. national building stock and can now represent GHP options at a national scale.

dGeo simulates the adoption of GHPs and district heating systems, analyzing economic favorability on a nationwide scale.

BOTH GEOTHERMAL POWER + HEATING AND COOLING

GEOPHIRES is a techno-economic simulator for evaluating the thermal performance and cost-competitiveness of both geothermal plants for electricity and heating and cooling applications.

ReEDS[11] (power) and **dGeo** (heating/cooling) can feed simulation results to each other to analyze how nationwide adoption of heating and cooling technologies may impact the electric grid.

ISLANDED GRIDS

The Engage™ modeling tool has been updated for islanded grids to examine all energy technologies, including geothermal.

[11] https://www.nrel.gov/analysis/reeds/

GRID INTEGRATION PILLAR

Model Upgrades

Community-Scale District Techno-Economic Analysis With dGeo

dGeo[12] is an agent-based modeling tool used to investigate the nationwide potential of deep and shallow geothermal-coupled heating and cooling systems for individual buildings and districts. It can model three technologies: individual GHPs, ambient-temperature TENs, and direct-use geothermal district heating. A 3-year project concluded this year that made major updates to the model, including the analysis of ambient-temperature TENs with geothermal boreholes for mixed residential and commercial districts, updates to underlying data tables and inputs, and a connection with NREL's ReEDS model to understand the electric grid impacts of geothermal heating and cooling adoption. Recent data updates include integrating the latest Stanford Temperature Model maps for subsurface temperature and thermal conductivity predictions and updating building load profiles based on the latest ComStock release. The upgraded dGeo tool is designed to perform high-level simulations of distributed geothermal systems at the census tract level across a large region (such as an entire state or nationwide) to screen locations and identify promising sites for development.

dGeo

ABOUT
- Heating and Cooling
- Nationwide

PRINCIPAL INVESTIGATOR
Juliet Simpson

The Geothermal Electricity Technology Evaluation Model (GETEM)

In FY25, **GETEM in SAM**[13] was validated using the 18 Annual Technology Baseline (ATB) scenarios. The validation work showed excellent agreement between GETEM in SAM and Excel-based GETEM on performance metrics (e.g., brine effectiveness and power output). The cost validation effort (still ongoing) shows adequate alignment between the two models with SAM generally overpredicting LCOE and CAPEX. The team will continue to work on improving the accuracy of the GETEM in SAM model to match the legacy Excel-based GETEM. A workflow for closed-loop implementation in SAM was developed in readiness for proposed FY26 work on implementing closed-loop geothermal systems techno-economic modeling in SAM.

GETEM

ABOUT
- Power Generation
- Site Specific

PRINCIPAL INVESTIGATOR
Dayo Akindipe

Integrating Geothermal Technologies into Engage Facilitates Accurate Capacity Expansion Modeling in Hawai'i

Engage[14] is an accessible, free-to-use and collaborative long-term capacity planning and operational simulation model. It is a web application that covers single and multi-carrier systems at different and mixed scales. Building on prior work—templating geothermal technologies and integrating GEOPHIRES—in FY25 NREL developed constraints for more precise operational modeling of geothermal and other technologies, along with an automated workflow for testing model solutions in operational simulation. New constraints include startup and shutdown costs, minimum run times and down times, and efficiency curves for generation, transmission, and storage. These constraints have not previously been used in planning modeling as they were too computationally intensive. NREL is supporting the use of Engage to facilitate the Hawai'i State Energy Office's regulatory review of Hawaiian Electric's Integrated Grid Planning scenarios, including screening advanced scenarios that model specific technologies.

engage

ABOUT
- Power Generation
- Site Specific

PRINCIPAL INVESTIGATOR
Tom Harris

[12] https://www.nrel.gov/analysis/dgen/index
[13] https://sam.nrel.gov/
[14] https://www.nrel.gov/state-local-tribal/engage-energy-modeling-tool

GRID INTEGRATION PILLAR

Model Upgrades

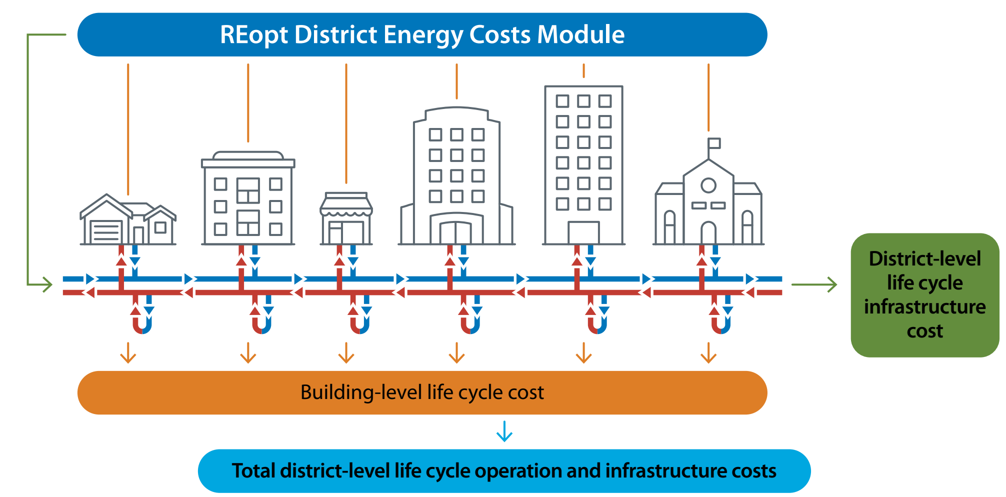
Adding GHPs to REopt

In FY25, the **REopt**[15] team expanded REopt's GHP Module to offer users more modeling flexibility in analysis of their GHP-ground heat exchanger (GHE) systems. Last fiscal year, the REopt team developed a new District GHP Module which allows for co-simulation between URBANopt and REopt for life cycle cost analysis of district GHP systems. REopt's District GHP Module leverages REopt's life cycle cost analysis capabilities and URBANopt's capabilities to physically model district energy systems. The District GHP Module takes URBANopt outputs including the sizes of GHPs and GHEs, building areas, and building- and district-level electricity consumption profiles to estimate life cycle cost of the URBANopt's district GHP system (see figure). In FY25, the REopt team added another new capability to the REopt's GHP Module to allow users to constrain the sizes of their GHPs and/or GHEs to reduce the total costs of replacing their heating and cooling systems with GHP or meet the physical limitations of their sites. Two case studies of a small office building in cold climate Alaska and a hotel in warm climate Georgia were conducted to validate new developments. The results from these case studies emphasize the importance of allowing users options to more flexibly model their systems and inform them of more cost-effective GHP-GHE sizing scenarios.

REopt Renewable Energy Integration and Optimization

ABOUT
- Heating and Cooling
- Site Specific

PRINCIPAL INVESTIGATOR
An Pham



Life cycle cost analysis of a district GHP system in REopt.
Graphic by Dominique Barnes, NREL

Low-Temperature HCA GEOPHIRES Upgrades

In FY25, the **GEOPHIRES**[16] codebase was updated to improve accuracy, usability, and interoperability with other DOE-supported tools, including GETEM, SAM, and the ATB. GEOPHIRES was mapped to SAM inputs, and a new workflow using PYSAM enables integration of the SAM Single-Owner Power Purchase Agreement model directly within GEOPHIRES. Cost correlations were enhanced with updated drilling cost curves based on Akindipe and Witter (2025).[17] These updates were validated through a case study of a large-scale EGS project modeled on Fervo's Cape Station, demonstrating alignment between GEOPHIRES and SAM financial outputs. To support adoption, the team also updated the GEOPHIRES user guide and added new training materials designed for both new and experienced users.

GEOPHIRES

ABOUT
- Power Generation
- Heating and Cooling
- Site Specific

PRINCIPAL INVESTIGATOR
Hannah Pauling

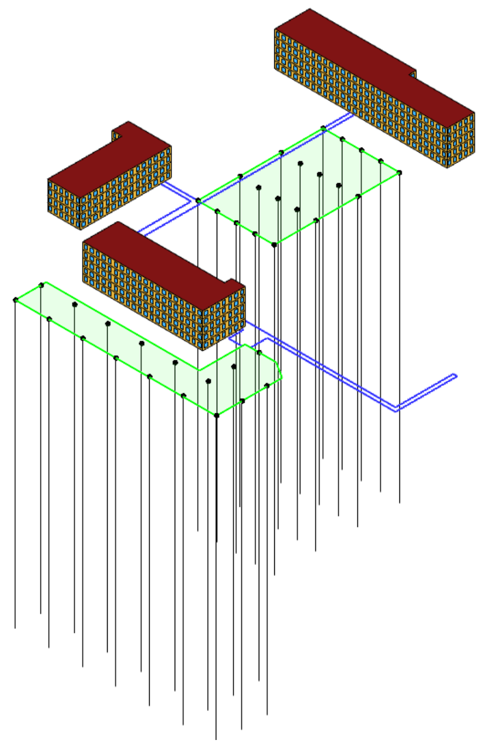
[15] https://www.nrel.gov/reopt/
[16] https://github.com/NREL/GEOPHIRES-X
[17] https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2025/Akindipe.pdf

GRID INTEGRATION PILLAR

Model Upgrades

URBANopt Community Systems

In FY25 the NREL **URBANopt**[18] team focused on continuing developing open-source tools that support the design and analysis of community-scale GHP systems. NREL advanced URBANopt's modeling capabilities with support for branched ground heat exchanger configurations, life cycle cost analysis via REopt integration, and the ability to model waste heat connected to the TEN. A case study was also conducted in partnership with Salas O'Brien LLC, an engineering and technical services firm with experience in designing GHP TEN systems, and Ladybug Tools LLC, a company that is integrating URBANopt GHP capabilities into other tools and workflows used by practitioners and researchers (Dragonfly plugin for Rhino/Grasshopper). The case study focused on testing the tools to model portions of the Colorado Mesa University community GHP system. This provided critical user feedback that informed improvements to energy transfer station modeling, system outputs, and workflow usability. Additional updates included development of backend architecture to support user-designed GHEs. These updates further URBANopt's value to the industry by improving usability, flexibility, and real-world applicability.



View of portions of the Colorado Mesa University campus used for modeling case study. Building, ground heat exchanger, and underground piping size, geometry, and locations are approximate. *Image from Chris Mackey, Ladybug Tools LLC*

URBANOPT

ABOUT
- Heating and Cooling
- Site Specific

PRINCIPAL INVESTIGATOR
Matt Mitchell

GHPs for U.S. Building Stock

This project evaluates the technical and economic feasibility of mass adoption of geothermal heating and cooling systems in the U.S. commercial and residential building stock. **ComStock**[19] and **ResStock**[20] are open-source tools that estimate annual subhourly building load data to enable transparent, data-driven decision-making for advancing energy efficiency and affordability. This project combines the capabilities of highly granular physics-based building energy modeling with ground heat exchanger modeling from GHEDesigner. ComStock and ResStock serve over 8,000 users spanning industry, utilities, consultants, manufacturers, national laboratories, and other sectors. These analyses provide crucial insights for grid and resilience planning, consumer cost reduction, utility program design, R&D and manufacturing tech prioritization, and more.

ComStock ResStock

ABOUT
- Heating and Cooling
- Nationwide

PRINCIPAL INVESTIGATOR
Marlena Praprost

[18] https://www.nrel.gov/buildings/urbanopt
[19] https://www.nrel.gov/buildings/comstock
[20] https://www.nrel.gov/buildings/resstock

GRID INTEGRATION PILLAR

Model Upgrades

PRINCIPAL INVESTIGATOR
Matt Mitchell

EnergyPlus for Enhanced GHP Modeling

EnergyPlus®[21] is DOE's primary building energy simulation engine and is used widely across industry, academia, and research institutions. This project focuses on improving how EnergyPlus models and sizes ground heat exchangers. During the project, the NREL team has integrated a more stable and accurate ground heat exchanger model, which was originally developed in Python, into the EnergyPlus codebase to replace a less accurate legacy ground heat exchanger model that would occasionally produce erroneous results. In parallel, NREL has establishing a workflow linking EnergyPlus to GHEDesigner to enable automated borefield sizing natively from the EnergyPlus simulation, rather than relying on external third-party, proprietary tools, which required users to manually transfer data between the programs.

GHEDesigner Enhancements for GHP Design/Sizing

PRINCIPAL INVESTIGATOR
Matt Mitchell

GHEDesigner[22] is an open source ground heat exchanger (GHE) design and simulation tool which was originally developed by Oklahoma State University and Oak Ridge National Laboratory. Since then, beginning in FY23, NREL had led development to support broader integration with tools like EnergyPlus, URBANopt, and REopt. In FY25, GHEDesigner underwent a major refactoring to improve code maintainability, robustness, and scalability, including the creation of a new borehole resistance library (BHResist) and updates to support new modeling approaches. The input schema was tightened for stronger validation, and the core codebase was modernized with Python dataclasses, type annotations, and clear exception handling. Collaboration with Oklahoma State University also advanced improved system sizing and simulation methods.

Geothermal Power Analysis in reV

The **reV**[23] geothermal team published several key analyses that quantified the geothermal technical potential and included several key partners informing the technical, cultural, and environmental exclusions.

Trieu Mai, Anthony Lopez, Melinda Marquis, Michael Gleason, Anne Hamilton, Whitney Trainor-Guitton, Jonathan Ho, and Shashwat Sharma. 2025. *Land of Opportunity: Potential for Renewable Energy on Federal Lands*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-91848. **https://www.nrel.gov/docs/fy25osti/91848.pdf**.

Trainor-Guitton, W., Pinchuk, P., Olsson, R., & Maclaurin, G. (2025). Renewable Energy Potential Model: Hawaii Geothermal Supply Curves. [Data set]. Geothermal Data Repository. National Renewable Energy Laboratory. **https://doi.org/10.15121/2516750**.

Whitney Trainor-Guitton, Karthik Menon, Pavlo Pinchuk, Sophie Min Thomson, Nicole Hart-Wagoner, Chao Lu, Eli Mlawsky, Mark Coolbaugh, Cary Lindsey, James Faulds, "Hidden" hydrothermal technical potential & technoeconomics: Revealing permeability & fluids with more data, Geothermics, Volume 133, 2025. **https://doi.org/10.1016/j.geothermics.2025.103473**.

Menon, Karthik, Whitney Trainor-Guitton, Sophie-Min Thomson, Pavlo Pinchuk, Nicole Taverna, Reid Olson, and Galen Maclaurin. 2025. "Comparison of geothermal potential from two temperature models." Presented at 50th Workshop on Geothermal Reservoir Engineering, Stanford, California, February 10-12, 2025. National Renewable Energy Laboratory, Golden, Colorado. **https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2025/Menon.pdf**.

reV

ABOUT
- Power Generation
- Nationwide

PRINCIPAL INVESTIGATOR
Whitney Trainor-Guitton

IMPACT
By utilizing the reV workflow, GETEM calculations were provided both at spatially resolved and exhaustive locations throughout domains of each study.

[21] https://energyplus.net/
[22] https://pypi.org/project/ghedesigner/
[23] https://www.nrel.gov/gis/renewable-energy-potential

GRID INTEGRATION PILLAR

EXERGETIC: Assessing the Value of Geothermal Grid Integration

Using NREL's Advanced Research on Integrated Energy Systems (ARIES) infrastructure, researchers developed a geothermal-based real-time digital co-emulation environment, EXERGETIC. The purpose of this unique capability is to assess the benefits of geothermal and hybrid geothermal systems for the electric grid, including stability, flexibility, and grid services.

Building on the technical and economic analysis of geothermal hybrid systems from FY24, EXERGETIC expanded ARIES's capabilities in FY25. This expansion allows for more comprehensive analysis and demonstration of geothermal and hybrid geothermal systems by:

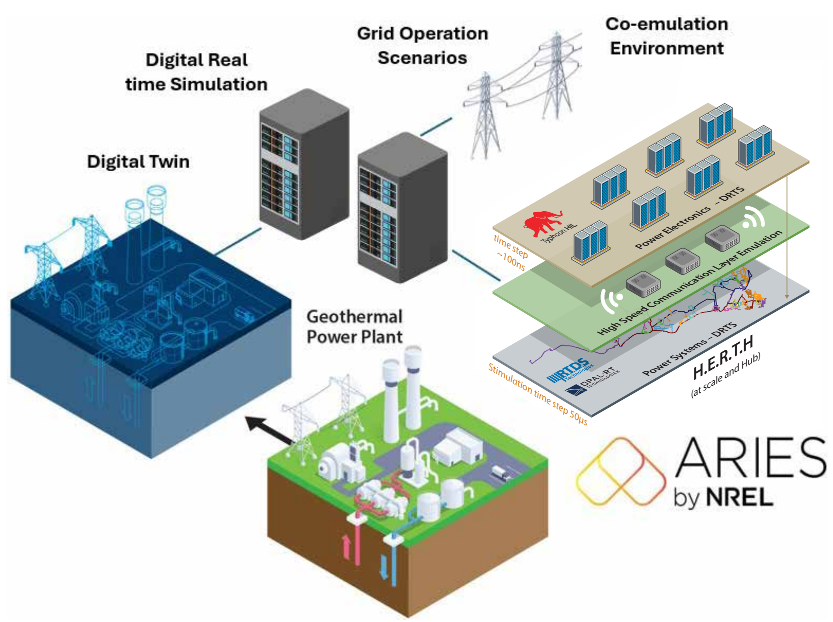
1. Enabling the evaluation of the dynamic response and flexible operation of hybrid geothermal systems under grid-connected scenarios.
2. Supporting scalability analysis for geothermal plants, from laboratory scale (up to 1 MW) to commercial plant levels (up to 100 MW).
3. Allowing the assessment of the capabilities of geothermal systems to participate in the grid services market by providing critical services like grid load following and voltage regulation.

PRINCIPAL INVESTIGATOR
Julian Osorio

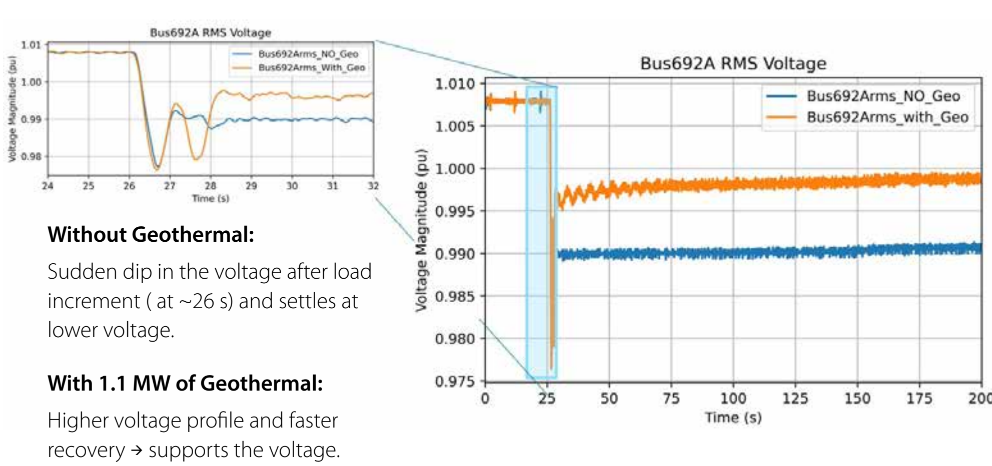
IMPACT
Increases geothermal competitiveness by demonstrating new grid-service capabilities that would lead to higher efficiency and lower operational costs.

De-risk geothermal and geothermal hybrid system development and deployment through a robust MW-scale demonstration at NREL ARIES.

PARTNERS
Florida State University, Clemson University, TECO Westinghouse



EXERGETIC real-time digital co-emulation environment at NREL ARIES. *Graphic by NREL*



Impact of 1.1-MW geothermal integration on voltage. *Graphic by Julian Osorio, NREL*

GRID INTEGRATION PILLAR

FLXenabler Demonstrates Electricity Savings of UTES with Geothermal Heat Exchangers and District Systems

The FLXenabler project, led by Norwegian research institution SINTEF, is a 3-year (2023–2026), multinational research initiative that is evaluating the flexibility that geothermal heating, cooling, and storage can bring to integrated energy systems. The main project objective is to develop an implementable modeling framework to demonstrate the impact of sector coupling and integration of geothermal heating and cooling technologies and thermal energy storage in the United States and Europe.

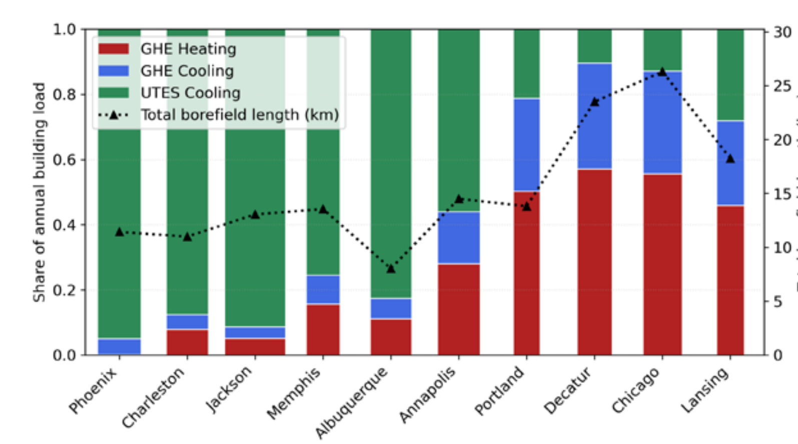
The team developed a transferable techno-economic workflow for district energy systems that couples a ground heat exchanger (GHE) borefield with underground thermal energy storage (UTES). The workflow was demonstrated for 10 cities in the United States (top figure below). Compared to conventional cooling methods, it saves on electricity use (shown in the bottom figure below), thus making the electric grid more resilient.

FLXenabler findings demonstrate the benefits of district energy systems, such as cost-stabilization amid volatile energy prices and external uncertainties.[24] For heating, district systems yield significant cost savings compared to individual solutions, driven by fuel flexibility and the use of local renewable energy sources. For cooling, district systems also show advantages, particularly for larger buildings. Additionally, district systems exhibit considerable flexibility on the heating side, as evidenced by variations in electricity consumption.

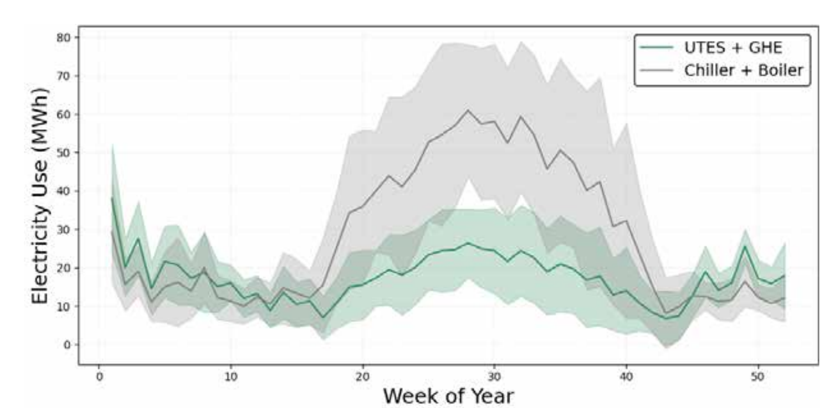
PRINCIPAL INVESTIGATOR
Whitney Trainor-Guitton

IMPACT
FLXenabler shows how geothermal resources can provide heating and cooling flexibility while reducing stress on the grid and allowing consumer choice.

PARTNERS
United States Geological Survey, SINTEF (Norway), Technical University of Vienna



Annual building-side load partition (bars; width proportional to total annual building load) and total drilled borefield length (black line) by city (ordered by decreasing mean ambient temperature). For each city, building-side GHE heating/cooling bars are unequal in length because they include heat-pump compressor work; the ground-side loads used for GHEDesigner sizing are balanced by construction. *Graphic by Scott Mello, NREL*



This visualization compares average district electricity demand for the hybrid geothermal district energy system versus a conventional natural gas boiler plus electric chiller loop. Replacing chiller compressors with low-lift groundwater pumping cuts annual energy and summer peaks, with the greatest grid relief in the hottest cities. The strongest economic and electrical benefits are seen in cooling-dominant climates. *Graphic by Scott Mello, NREL*

[24] https://doi.org/10.1016/j.enconman.2025.119979

GRID INTEGRATION PILLAR

Underground Thermal Energy Storage Can Provide Seasonal Storage and Grid Cost Savings

PRINCIPAL INVESTIGATOR
Jonathan Ho

IMPACT
Identified the potential for underground thermal energy storage for grid and heating and cooling applications in the United States.

This FY25 NREL project advances the understanding of geothermal underground thermal energy storage (UTES) by identifying the value of long-duration, seasonal storage to grids. This project explored the value of both established demand-side UTES for heating and cooling as well as supply-side applications in geothermal power generation that are in earlier phases of commercialization.

Researchers identified UTES storage potential, durations, and efficiencies for heating and cooling applications, building upon ongoing research including FLXenabler (see page 33). The team also identified potential technology configurations for adding UTES to geothermal power plants and analyzed the added value and benefits from having UTES through a ReEDS value analysis. Cost targets relative to the duration of storage potential were also added to the studied UTES technologies.

In most locations studied within the United States, demand-side cold storage results in both electricity demand reductions and grid cost savings, and in all locations, hot storage provided grid cost savings.

Supply-side UTES cost targets were developed based on added plant revenue to aid in technology development and deployment. Storage duration was identified as the key driver of UTES value in hybrid geothermal generation plants, with higher value from long-duration and seasonal storage.

GRID INTEGRATION PILLAR

Engaging With Utilities Creates Better Understanding of Geothermal Value, Opportunities, and Representation

PRINCIPAL INVESTIGATOR
Whitney Trainor-Guitton

IMPACT
Providing utilities with critical information related to geothermal deployment decision-making will help in expanding use of this technology.

PARTNER
EPRI

PUBLICATION
Geothermal Rising Paper (October 2024) Advancing Understanding of Geothermal Representation in the Power Sector to Accelerate Deployment

LEARN MORE

bit.ly/4gmiB5d

Interest in geothermal's contributions to the U.S. power sector has grown considerably, evolving from being considered a niche technology to being recognized as a viable source of grid-balancing power.

Many utilities do not have in-house expertise to evaluate geothermal technologies and their potential role in helping to stabilize the grid. To date, geothermal is rarely included in capacity expansion models, which utilities use in their planning activities and resource/technologies prioritization.

To this end, NREL is working with the Electric Power Research Institute (EPRI) on a GTO-funded research project to improve understanding of geothermal opportunities, value, and risks among the power industry to help accelerate geothermal deployment.

In September 2024, NREL and EPRI ran a virtual workshop on geothermal value, opportunities, and representation for EPRI members. NREL researchers Diana Acero-Allard and Whitney Trainor-Guitton helped organize and run the workshop, which featured 16 technical panelists covering a range of topics, including conventional geothermal risk, emerging technologies, and understanding how to represent geothermal in resource planning. Panelists included NREL engineer Jonathan Ho and NREL researchers Koenraad Beckers and Dayo Akindipe.

The event drew 95 participants, primarily from utilities. This included resource planners in charge of higher-level analysis, such as financial modeling and building future portfolios with energy efficiency goals. Others make technical assessments of emerging technologies and research and development efforts. NREL's collaboration with EPRI prepared utility resource planners and technical specialists to add or expand their companies' involvement in geothermal.

In FY25, NREL completed this project by publishing a paper describing the approach and preliminary findings of this work, focused on two topics:

1. Expanding the degree of understanding among utilities and related groups, specifically around geothermal for power generation, and
2. Improving representation of geothermal power technologies in capacity expansion models.

Photo from Getty 106691138

SECTION 2

Laboratory Investment in Geothermal Research Capabilities

Two-year Core LDRD Project on Geologic H_2 Production Adds Key Capabilities in Subsurface Research

PRINCIPAL INVESTIGATOR
Xiaofei Pu

Funded by NREL's Laboratory Directed Research and Development (LDRD) program, this project aims to (1) advance understanding of the geochemical and microbiological processes related to natural and geologic hydrogen production, (2) set up geological system-informed design and cost optimization tools for both natural hydrogen exploration and stimulated geologic hydrogen production, and (3) perform broad-reaching industrial partner engagement to understand the commercialization approaches, barriers, and priorities to formulate strategy to move technology development forward in this emerging technological space.

The team of geologists, geochemists, microbiologists, and system analysis experts are focusing on building NREL capabilities and addressing key research questions in three areas:

GEOCHEMICAL EXPERIMENTS

- Set up in-house experimental capability to study the hydrogen generating water-rock reactions (serpentinization)
- Compare hydrogen production rates of different iron-rich rocks and minerals
- Compare reaction rates with varying conditions, such as temperature, water chemistry, and water to rock ratio.

MICROBIAL HYDROGEN CONSUMPTION INHIBITOR SCREENING

- Identify model strains of hydrogen-consuming microbes
- Determine baseline hydrogen-consumption rate in lab conditions
- Test various biochemical inhibitors for microbial hydrogen consumption.

ANALYSIS, STRATEGIES, ENGAGEMENT

- Leverage H_2I and GETEM tools to develop geoH_2 cost optimization model framework
- Integrate geoH_2 with industrial innovation
- Engage with industry, academia, and decision makers.

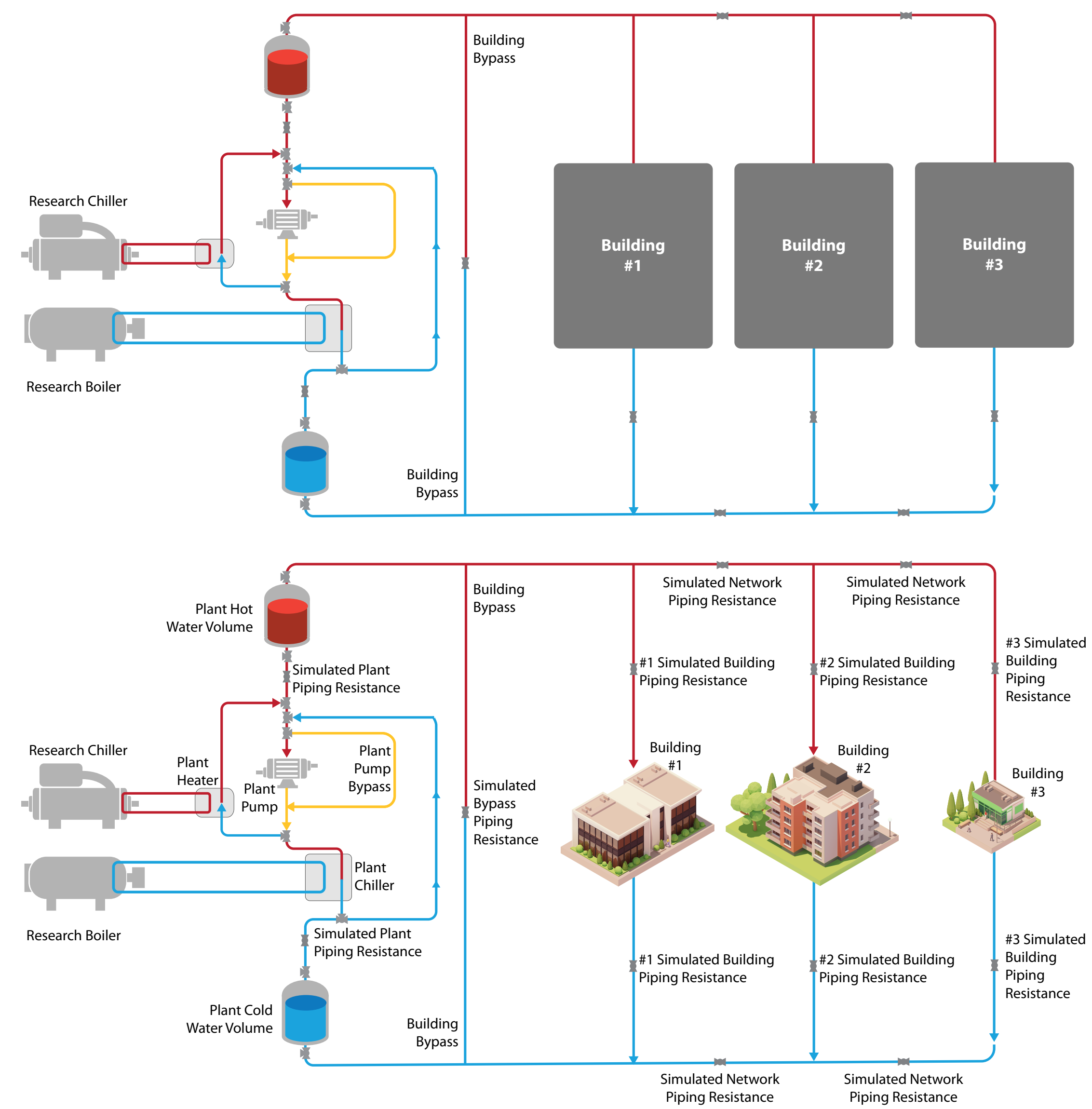
ATTEN: Preparation Continues for Thermal Test Network To De-Risk Advanced Thermal Energy Systems

PRINCIPAL INVESTIGATORS
Amy Allen and Nicholas Long

The Advanced Thermal Test and Emulation Network (ATTEN) is a laboratory-scale thermal test network that will be located in NREL's Energy Systems Integration Facility (ESIF). ATTEN consists of an ambient-temperature water loop serving an emulated building load, with the load conditioned by a real set of water-to-water heat pumps. The ambient loop is conditioned by heat exchangers with ESIF's existing heating hot water and chilled water systems, which will also be used to emulate the building load. The building load will be emulated in a hardware-in-the-loop configuration using NREL's Alfalfa simulation platform. Alfalfa generates a signal representing the building load in an energy model at a particular timestep, and the building load loop is controlled to represent that load.

Work in FY25 focused on design of the ATTEN, and it is anticipated to be installed in 2026. The ATTEN will be used for research focusing on de-risking advanced district thermal energy systems, including through model validation, validation of controls sequences, and evaluation of potential for beneficial electrical load shifting.

Schematic of proposed Advanced Thermal Test and Emulation Network. *Graphic by Marjorie Schott, NREL.*



SECTION 3

Strategic Partnerships

U.S. Department of the Interior: Bureau of Land Management

NREL built upon the longstanding partnership with the Bureau of Land Management (BLM) in FY25 by providing subject matter expertise to BLM on multiple geothermal topics. Examples of projects include development of geothermal training materials for BLM personnel and development of tools, data, and guidance materials to support BLM's oversight and permitting of geothermal projects utilizing federal resources, along with geothermal-related factsheets summarizing geothermal projects on public lands and a 2025 **conference paper on a data-centric methodology for producible geothermal well determinations**.[25]

GA Drilling Collaboration in Houston, Texas, and Bratislava, Slovakia

NREL has partnered with GA Drilling, a geothermal drilling company that specializes in deep geothermal drilling technology, to advance the technology readiness level of a novel high-temperature downhole electric generator and to integrate it with a novel drilling system for full-scale field testing.

Under a previous ARPA-E project (RePED 250), NREL designed and demonstrated the exceptional performance of this high-temperature downhole generator technology for geothermal drilling at downhole ambient temperatures up to 250°C. This work is now being continued under a DOE Office of Technology Commercialization award, where NREL will leverage GA Drilling's expertise and integrate the generator into their PLASMABIT Hybrid drilling solution. Through this partnership, NREL and GA Drilling aim to enable novel high-energy drilling methods that will improve drilling rates in hard, hot, geothermal rock types.

TDA Research

NREL is partnering with TDA Research to investigate geothermal power cycle modifications to yield continuous heat at a temperature range of 80°C to 130°C for TDA Research's proprietary technology. Baseload geothermal plant designs can be modified to maintain some electricity generation while also delivering heat in that temperature range.

NREL researchers are analyzing modifications to binary cycles that extract heat from 130°C to 80°C and are estimating the cost of heat in terms of forfeited electricity generation for these scenarios versus a baseline case where no heat is extracted.

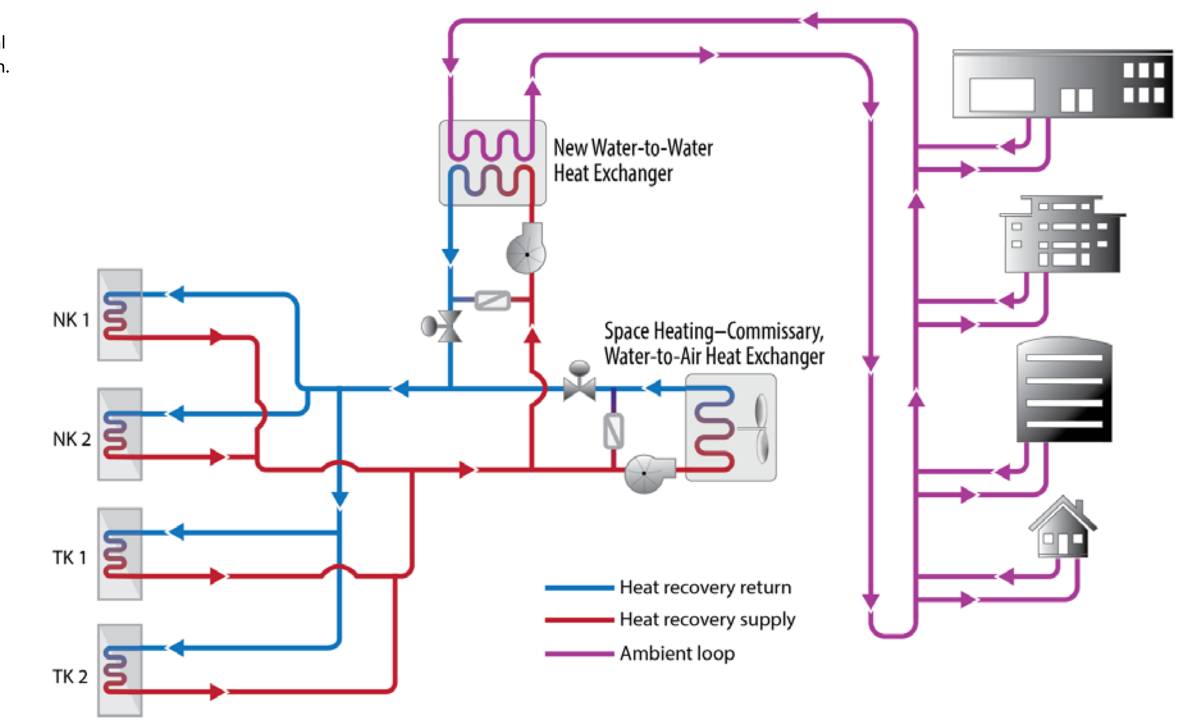
Technical Analysis of Thermal Microgrids at DoD Installations

NREL is carrying out feasibility studies of thermal microgrids at two U.S. Department of Defense (DoD) installations in Germany for DoD's Environmental Security Technology Certification Program (ESTCP). The systems are single-pipe ambient loops with distributed water-to-water heat pumps that condition connected buildings and provide domestic hot water.

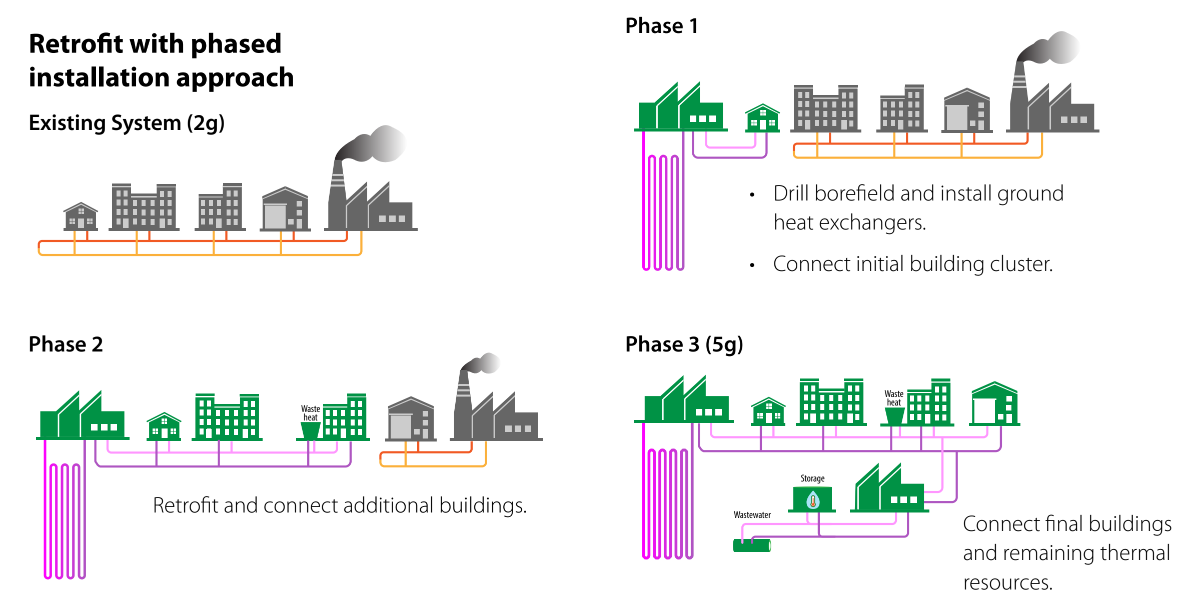
In FY25, NREL completed the technical analysis for this project. Ground heat exchangers were selected as the most practical means of tempering the thermal microgrids at both sites. NREL analyzed the energy performance of the proposed microgrids using URBANopt-District Energy Systems (DES), an analytics platform for high-performance buildings and energy systems. NREL used the GHEDesigner workflow within URBANopt-DES for preliminary sizing of the ground heat exchangers. Researchers analyzed the expected performance of the thermal microgrids through detailed simulations of Modelica models. At one site, potential for waste heat recovery from commercial refrigeration to the thermal microgrid was explored. NREL also navigated site-specific practical constraints, including a regulatory limitation that significantly limited the borehole depth at one site. Finally, NREL investigated the feasibility of building-level HVAC retrofits for compatibility with water-source heat pumps.

There is significant potential for energy savings through adoption of a thermal microgrid, with opportunities for 30%–35% reductions in source energy use for HVAC.

The final project deliverables will include a preliminary schematic design, along with analysis of expected energy and life cycle cost performance. NREL is developing plans for financing and phased implementation of thermal microgrids at both sites to lay the groundwork for a future demonstration.



Schematic of potential waste heat integration. *Graphic by Marjorie Schott, NREL.*



Graphic illustrating phased implementation of a thermal microgrid from an existing district thermal energy system. *Graphic by Marjorie Schott, NREL.*

[25] https://research-hub.nrel.gov/en/publications/a-simple-data-centric-methodology-for-producible-geothermal-well--2

Oil and Gas Collaboration on Geothermal Energy Storage

Geological thermal energy storage (GeoTES) aims to store excess energy in underground reservoirs, such as depleted oil and gas fields, for seasonal-scale energy dispatching for the grid and other applicable industrial applications. In collaboration with Idaho National Laboratory and Lawrence Berkeley National Laboratory, NREL is partnering with an oil and gas company to explore the use of their mature wells for thermal energy storage.

NREL is launching a scoping study to identify and evaluate the technical and economic feasibility of implementing GeoTES at selected oil/gas sites owned by an oil and gas company. Future work includes identifying a suitable site for a pilot-scale GeoTES demonstration, as well as operating and monitoring this pilot site to validate the performance and reliability of this new technology.

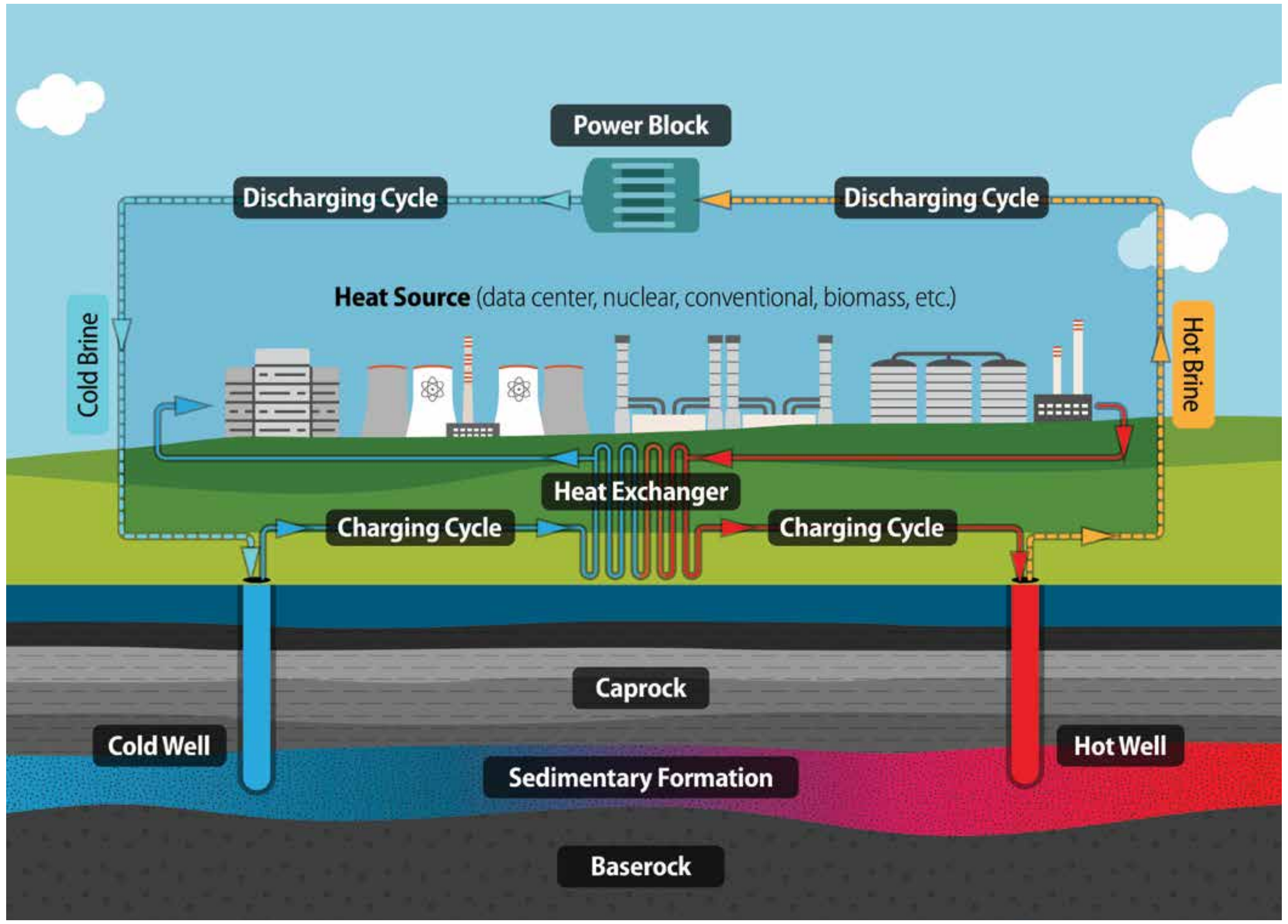


Illustration of GeoTES technologies and processes.
Graphic by Joelynn Schroeder/Dominique Barnes, NREL.

SECTION 4

Industry Leadership

NREL staff and geothermal experts at the Control Center at NREL's Flatirons Campus. *Photo by Joe DelNero, NREL 101025*

Introducing Geothermal Industry Partners and GTO to ARIES: Flatirons Campus Tour

On July 31, the NREL geothermal program hosted a tour of the lab's Flatirons Campus for representatives from GTO, industry, and academia. The tour focused on energy systems integration assets, including the **Advanced Research on Integrated Energy Systems platform**[26] (ARIES)—DOE's most advanced energy systems research platform. Discussion focused on new research and development capabilities of ARIES, with a focus on system response to large dynamic loads and new geothermal-hybrid capabilities. Opportunities for geothermal expansion at the Flatirons Campus were also discussed.

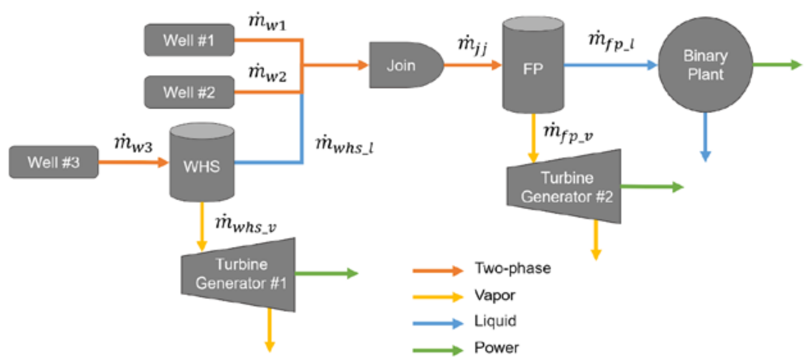
[26] http://www.nrel.gov/aries

Geothermal Researchers Awarded for Operations-Optimizing Software

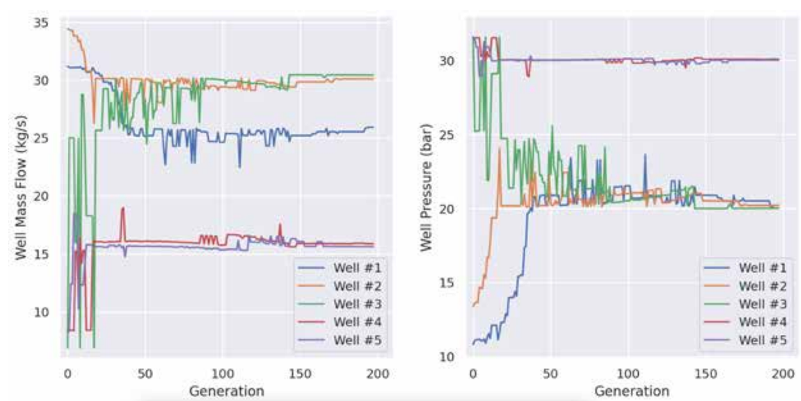
Geothermal program researchers Jon Weers, Nicole Taverna, and Grant Buster won an **NREL Innovation and Technology Transfer award** in 2025 recognizing their work toward earning a commercial, fee-bearing license for the software Geothermal Operational Optimization with Machine Learning (GOOML).

The GOOML project has developed an extensible component-based artificial intelligence/machine learning modeling framework to optimize complex geothermal fields using a data-driven approach. Through building a digital twin of a geothermal steam field, operators can analyze historical and forecasted power production, explore different steam field configurations, and optimize real-world operations, all in a cost-effective digital environment.

GOOML optimizes existing geothermal plants to produce more power without using more resources. It has demonstrated a potential to increase the capacity factors of some geothermal plants by as much as 10% and has the potential to improve the availability of existing geothermal plants by 2%–5%.



Semantic model architecture illustrating GOOML's modular approach to developing configurable digital twins for geothermal plants. *Figure by Upflow, Ltd. and NREL.*



Results from an AI experiment using genetic algorithms to optimize generation by varying mass flow and well pressure. *Figure by NREL.*

Ribbon Cutting for 1,500 Homes Heated and Cooled by Geothermal

In April 2025, Amanda Kolker, geothermal program manager, and Faith Martinez Smith, energy policy and regulatory analyst, attended a ribbon cutting in Littleton, CO, for a large-scale GHP installation that will provide 1,500 homes with affordable geothermal heating and cooling. During the event, Colorado Gov. Jared Polis stressed that this scale of geothermal heating and cooling allows cost-competitiveness with typical HVAC for residential customers.

The project, a partnership between homebuilder Lennar and geothermal supplier Dandelion Energy, with support from Xcel Energy and the state of Colorado, will be the largest of its kind in the United States.

Faith Martinez Smith, Bryce Carter, and Amanda Kolker at the Lennar and Dandelion Energy ribbon cutting. *Photo by Amanda Kolker, NREL*

NREL hosted the Cold UTES for Data Center Cooling Task Force in May 2025. *Photo by Tara Wertz, NREL*

NREL-Hosted Workshops

Cold UTES for Data Center Cooling Task Force Meets at NREL

Over 30 members of the data center industry, including university partners and national laboratories, visited NREL's Flatirons Campus on May 9 for the Cold Underground Thermal Energy Storage (UTES) for Data Center Cooling meeting.

The cross-sector Cold UTES project aims to reduce data center peak cooling demand and associated energy costs. In addition to researcher meetings, the group toured the ARIES large-scale systems integration capabilities, the Composites Manufacturing Education and Technology (CoMET) Facility, the Structural Testing Laboratory, and the 2.5-MW and 5-MW dynamometers.

Cooling data centers with underground thermal energy storage can support grid resilience with time-shifted energy storage and load management, even reducing required grid expansions. Learn more about this project on page 11 of this report.

GEODE Facet 2 Convenes at NREL

NREL hosted the Geothermal Energy from Oil and Gas Demonstrated Engineering (GEODE) Facet 2 Working Group at NREL in October 2024 for their first quarterly brainstorming meeting. The GEODE initiative aims to form a consortium of experts and address technology and knowledge gaps in geothermal energy, leveraging technology and best practices from the oil and gas industry.

Facet 2 is a part of GEODE that focuses on demonstration and deployment, particularly centered around subsurface data and characterization methodologies that could be repurposed from oil and gas to geothermal. The meeting aimed to identify pain points that, if solved, would greatly accelerate geothermal deployment in oil and gas assets as well as potential solutions for the identified pain points.

Closed-Loop Geothermal Working Group Workshop

On June 26, the Closed-Loop Geothermal Working Group held a virtual workshop to connect with stakeholders and report on recent products. In partnership with Pacific Northwest National Laboratory and Sandia National Laboratories, the working group provided updates on GeoCLUSTER, discussed model benchmarking and convective reservoirs, and shared findings from techno-economic assessments with over 60 attendees.

A major highlight of the workshop was the participation of 10 industry organizations: Eavor, XGS Energy, Exceed Geo Energy, GreenFire Energy, NOV, Vallourec, RESPEC, CeraPhi, Geo2Watts, and GoGreen Partners. Seven companies presented to the participants and shared their perspective on closed-loop systems and products. The workshop concluded with a live demonstration of the GeoCLUSTER tool, followed by a discussion session that invited feedback on tool features, parameter selection, and data sharing needs.

Inaugural Geologic Hydrogen Summit

NREL partnered with the Natural Resources Research Institute in Duluth, MN, to host the first Geologic Hydrogen Summit on August 19 and 20. Approximately 150 attendees met to shape the future of geologic hydrogen.

The goal of the summit was to launch a groundbreaking research collaborative aimed at developing a public data platform and advancing a vision for a research demonstration platform that will help assess the true potential of geologic hydrogen.

Attendees discussed the current state of geologic hydrogen, key challenges for industry and research, public-private partnerships, the present regulatory landscape, and actionable steps to de-risk the technology.

The 2025 Geologic Hydrogen Summit, cohosted by NREL and the Natural Resources Research Institute (NRRI) in Duluth, Minnesota. *Photo by NRRI*

Conferences and Events

CONFERENCES NREL ATTENDED IN FY25

- Geothermal Rising Conference
- Stanford Geothermal Workshop
- Taiwan International Geothermal Conference
- Geothermal Congress for Latin America and the Caribbean
- International Meeting for Applied Geoscience & Energy (IMAGE)
- Geological Society of America (GSA) Connects 2025
- Society of Petroleum Engineers Western Regional Meeting
- Fervo Energy's Cape Connect 2025
- International District Energy Association (IDEA)'s CampusEnergy 2025
- Geothermal Rising Thermal Energy Network Symposium
- Geothermal Rising Geothermal Development in the Western US: Challenges, Opportunities and the Path Forward Symposium

NREL researchers and the NREL booth at the 2024 Geothermal Rising Conference in Waikaloa, HI. *Photo by Kelly MacGregor, NREL*

NREL Engages With Industry at the 2024 Geothermal Rising Conference

Twenty NRELians attended the 2024 Geothermal Rising Conference in Waikoloa, HI, in October 2024. NREL research comprised **seven posters and 21 presentations**.

Whitney Trainor-Guitton and Nicole Taverna ran a pre-conference workshop titled "Value of Information for Geothermal Exploration," which covered methods for quantifying uncertainty and risk for geothermal resources related to their project discussed on page 5.

NREL's booth had hundreds of visitors and offered copies of the Fiscal Year 2024 Geothermal Accomplishments report, as well as technical papers, journal articles, postcards, and more.

Faith Martinez Smith, an energy policy and regulatory analyst at NREL, received the Outstanding Research Award at the conference for her stakeholder work, including efforts to identify energy stakeholders, establish relationships, and host listening sessions to better understand community perspectives on geothermal energy technologies in Hawai'i and in partnership with Native Hawaiians.

NREL's strong research and workshop presence at the largest industry event of the year demonstrated NREL's position as a leader in geothermal, and the booth allowed the geothermal program to engage with other industry leaders and potential partners. NREL is poised to have over 20 presentations at the 2025 Geothermal Rising Conference as well, to be held in October 2025.

(Left to right): Nicole Taverna, Rebecca Barney, Dayo Akindipe, Jon Weers, Austin Venhuizen, Jonathan Ho, Hannah Pauling, Jabs Aljubran, Abra Gold, Amanda Kolker, Liting Jiang, Whitney Trainor-Guitton, Guangdong Zhu. Not pictured: Karthik Menon. *Photo by Ram Kumar, Idaho National Laboratory*

NREL Shows Strong Presence at Stanford Geothermal Workshop

Fourteen NREL geothermal researchers attended the 50th **Stanford Geothermal Workshop**,[27] Feb. 10–12 in Palo Alto, CA. The team gave **12 technical talks** covering EGS, quantifying the value of geothermal, thermal analysis, thermal energy networks, geothermal data and tools, drilling cost curves, and more.

The workshop is an annual technical event focused on geothermal research and innovation. NREL's team presented the latest analyses and projects, gathering valuable peer feedback.

IDEA's CampusEnergy2025 Conference in Boston

Geothermal program researchers **Matt Mitchell** and **Saqib Javid** represented NREL at the International District Energy Association's **CampusEnergy2025: Accelerating the Energy Transition**[28] conference, Feb. 4–6 in Boston.

They presented "**Pathways to Improve Efficiency and Energy Resilience at the NREL**," a look at four current and upcoming projects at NREL's South Table Mountain campus, including investigating deployment of geothermal heating and cooling systems and thermal energy networks.

Matt also presented "Developing Modeling Capabilities for District Energy Systems," which covered URBANopt analysis, including an example workflow and district scenario as well as a pilot study at Colorado Mesa University in collaboration with Salas O'Brien and Ladybug Tools.

NREL's geothermal program reinforced its leadership role in the district energy space by sharing project updates and URBANopt analysis information with attendees.

NREL staff and visitors listen to a panel of experts during during a Labwide Geothermal Learning Event. *Photo by Agata Bogucka, NREL 101418*

[27] https://geothermal.stanford.edu/events/workshop
[28] https://www.districtenergy.org/campusenergy2025/home

NREL Geothermal Laboratory Program Manager Amanda Kolker presents at the 11th Geothermal Congress for Latin America and the Caribbean in San Salvador, El Salvador. *Photo from GEOLAC*

NREL Joined International Discussion on Geothermal Innovations and Applications to Latin America and Caribbean

Amanda Kolker, geothermal program manager, spoke at GEOLAC 2024, the 11th Geothermal Congress for Latin America and the Caribbean, in San Salvador on Dec. 4-5. She also joined energy industry experts on a panel titled **"Technologies and Innovative Approaches: Driving Down Costs and Driving Up Feasibility."** The panel addressed geothermal technologies applicable to regional projects and energy goals, and explored avenues for international collaboration on geothermal research and development.

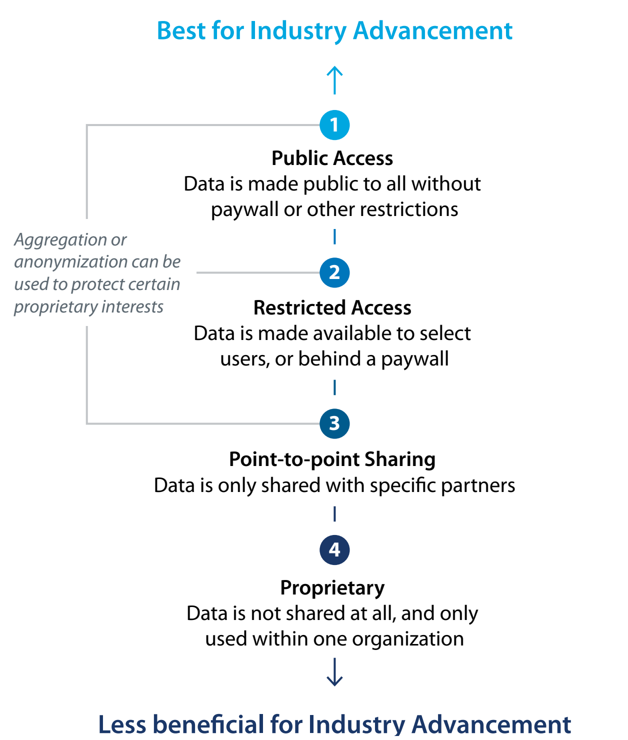
Kolker discussed the role of DOE, NREL, and other U.S. organizations in leading technology innovations to advance geothermal energy, such as next-generation geothermal power technologies and geothermal energy from oil and gas infrastructure.

Geothermal energy utilization is expanding in Latin American and the Caribbean. NREL demonstrated its role as an innovator and leader in the global geothermal industry and initiated partnerships with Latin American and Caribbean countries.

NREL Highlights Oil and Gas/Geothermal Data Sharing at Society of Petroleum Engineers Event

Nicole Taverna represented the NREL Geothermal Program at the Society of Petroleum Engineers (SPE) Western Regional Meeting in May, themed "Technology for Transition into the New Energy Frontier".

Taverna presented on **"Data Sharing as a Catalyst for Expanding the Energy Frontier"** to a primarily oil and gas audience to highlight mutually beneficial models for data sharing while also protecting proprietary interests. Enhanced data sharing between the industries would greatly accelerate geothermal deployment in oil and gas assets (spent or active).



Tiered models for data sharing ordered by benefits to industry.
Graphic by Dominique Barnes, NREL

NREL researcher Guangdong Zhu presents at the Thermal Energy Networks Symposium in February 2025. *Photo by Faith Smith, NREL*

Geothermal Rising's Thermal Energy Networks Symposium

Faith Smith, Guangdong Zhu, Diana Acero-Allard, Matt Mitchell, and Nicholas Long attended the Geothermal Rising Thermal Energy Networks Symposium, Feb. 6–8 in Cambridge, Massachusetts. During the morning plenary panel, Faith presented a preview of new data and analysis that will be included in NREL's forthcoming "2025 Geothermal Energy Market Report."

Guangdong presented "A Techno-Economic Model for Thermal Energy Network (TEN) Systems." He discussed a collaborative effort with the nonprofit HEET for a Python-based, open-source, reduced-order model. NREL contributors to this project include researchers Juliet Simpson, Rebecca Barney, and Abra Gold and intern Liting Jiang.

VIP Visitors

On April 3, 2025, U.S. Secretary of Energy Chris Wright visited the NREL campus for his first tour in his new role. The tour focused on the unique role NREL plays in bridging foundational research with real-world applications—highlighting not only the broad array of energy technologies and resilient systems studied at NREL, but also the experts whose passion and innovation drive this work forward. Secretary Wright's visit was part of his National Laboratories tour. During his time at NREL, Amanda Kolker presented on the NREL geothermal program with Colorado Governor Jared Polis also in attendance.

Colorado Governor Jared Polis (left) greets DOE Secretary of Energy Chris Wright. *Photo by Agata Bogucka, NREL 98047*

NREL Geothermal Program Hosts Lab-Wide Educational Event on Geothermal Resources and Technologies

NREL geothermal experts including Amanda Kolker, Dayo Akindipe, Whitney Trainor-Guitton, Aaron Levine, Jon Weers, Saqib Javed, and Josh McTigue provided a lab-wide "lunch and learn" on geothermal energy on July 29, 2025, to broaden NREL familiarity with geothermal technologies across the lab. Experts served on a 'Ask a Geothermal Expert' panel, responding to questions about geothermal from attendees across centers and directorates. Also in FY25, NREL researchers hosted internal workshops on geothermal capabilities and software to strengthen geothermal researcher capacity at the lab.

Photo by Agata Bogucka, NREL 101414

Publications Highlights

New Modeling Shows Borehole Thermal Energy Storage Can Provide Reliable Heating In Extreme Cold Climates

LEARN MORE

bit.ly/47vxWOt

Research from NREL's Center for Energy Conversion and Storage Systems has demonstrated a way to store and reuse heat underground to meet the heating demands of cold regions like Alaska.

Published in the journal Energy and Buildings, the feasibility study examined a 20-year period in which borehole thermal energy storage (BTES)—a system that stores heat underground—could reliably supply heating to two Department of Defense buildings in Fairbanks, Alaska.

Through building energy usage and system performance modeling, researchers showed how waste heat from a nearby coal plant could be captured during summer months, stored underground, and then drawn on in the winter to warm the buildings via GHPs.

The analysis was funded by GTO and led by Hyunjun Oh, a geothermal research engineer in NREL's thermal energy science and technologies research group, in collaboration with Conor Dennehy, Saqib Javed, and Robbin Garber-Slaght at NREL's Alaska Campus and the U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory.

To meet the needed winter heating load, the team pre-designed a system of 40 boreholes at a depth of 91 meters located about 100 meters away from the buildings, in alignment with regulatory guidelines and nearby land availability. They then modeled the 20-year performance of the BTES system, running simulations for two scenarios: one in which the ground subsurface was preheated for 5 years using a hot water injection before supplying heat to the buildings, and one without preheating.

In both scenarios, wells at the center of the borehole field produced about one-third more thermal energy than those on the outer edges, likely because the outer wells lost heat to the surrounding ground. This finding offers insight into how borehole fields can be better designed and insulated for more balanced energy distribution.

Additionally, systems that underwent preheating before regular use showed even better performance, with higher underground temperatures and greater thermal energy production during the first 8 years of operation compared to systems without preheating.

Fact Sheet Highlights Novel High-Temperature Generator/Motor Design

LEARN MORE

bit.ly/4gdqv0N

NREL designed, built, and tested a novel high-temperature generator for efficient power generation in a 250°C environment and published a fact sheet to promote the design to a broad array of industries. This work was completed under an Advanced Research Projects Agency - Energy (ARPA-E) project partnered with Tetra Corporation and TPL Inc, focused on upgrading power electronics in Tetra's advanced drilling system for harsh, high-temperature geothermal drilling environments. NREL is investigating additional applications for this design, which exceeded initial performance targets, as either a generator or motor capable of efficient performance at high temperature.

Full List of FY25 NREL Publications

Journal Articles

Kneafsey, T., Dobson, P., Blankenship, D., Schwering, P., White, M., Morris, J. P., Huang, L.,. . .Weers, J., et al. 2025. "The EGS Collab project: Outcomes and lessons learned from hydraulic fracture stimulations in crystalline rock at 1.25 and 1.5 km depth." *Geothermics*, Volume 126 (103178). **https://doi.org/10.1016/j.geothermics.2024.103178**

Labuschagne, C., McGilton, B., Fingersh, L. J., Kesseli, D., Skinner, M., Lambert, S., and Sindler, P. 2025. "Design and Performance Validation of a High-Temperature Downhole Permanent Magnet Generator Used for an Electro-Pulse Boring System in Geothermal Energy Applications." Article No. 123376. *Renewable Energy, 252*. **https://doi.org/10.1016/j.renene.2025.123376**

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Zwickl-Bernhard, S., Long, N., Jordan, S., Bauer, F., Simpson, J., and Trainor-Guitton, W. 2025. "Optimizing District Energy Systems Under Uncertainty: Insights from a Case Study from Washington D.C., USA." Article No. 119979. *Energy Conversion and Management, 341*. **https://doi.org/10.1016/j.enconman.2025.119979**; **https://docs.nrel.gov/docs/fy25osti/93372.pdf**

Technical Reports

Akindipe, D., McTigue, J., Dobson, P., Atkinson, T., Witter, E., Kumar, R., Sonnenthal, E., Umbro, M., Lederhos, J., Adams, D., and Zhu, G. 2024. *Techno-Economic Analysis and Market Potential of Geological Thermal Energy Storage (GeoTES) Charged With Solar Thermal and Heat Pumps*. **https://doi.org/10.2172/2474842**

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