U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Geothermal Technologies Office Investments in a Zero-Carbon Future

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U.S. Department of Energy, Geothermal Technologies Office

November 29, 2023

Geothermal Energy: America's Renewable Powerhouse

Electric Power

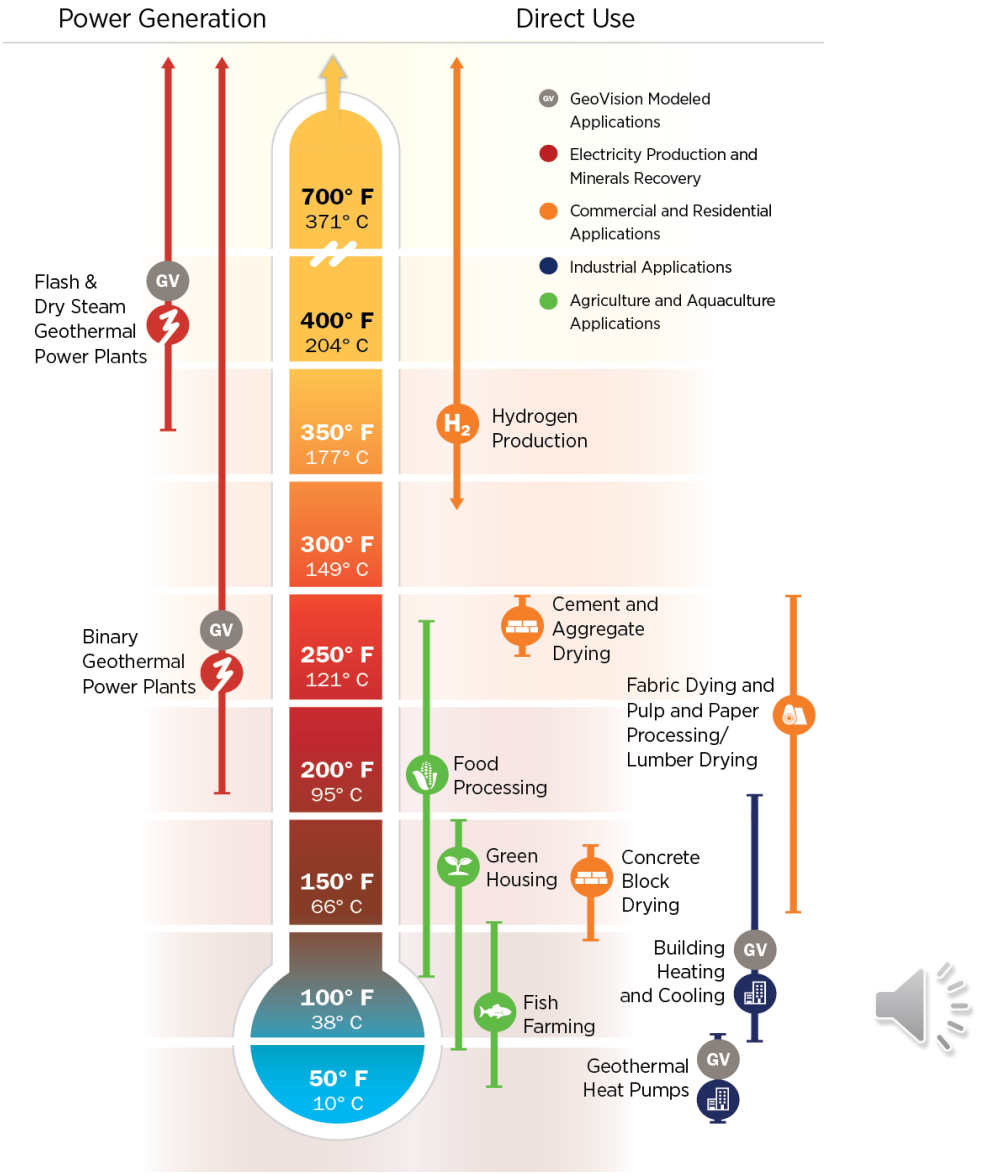
- **High temperatures (>300°F)**
- Wells up to many thousands of feet deep
- Reliable, flexible, baseload grid power

Direct Use

- **Moderate temperatures (80-300°F)**
- Wells hundreds to thousands of feet deep
- Large buildings, agriculture

Heating & Cooling

- **Near-ambient temperatures (40-80°F)**
- Shallow trenches to wells hundreds of feet deep
- Residential, light commercial



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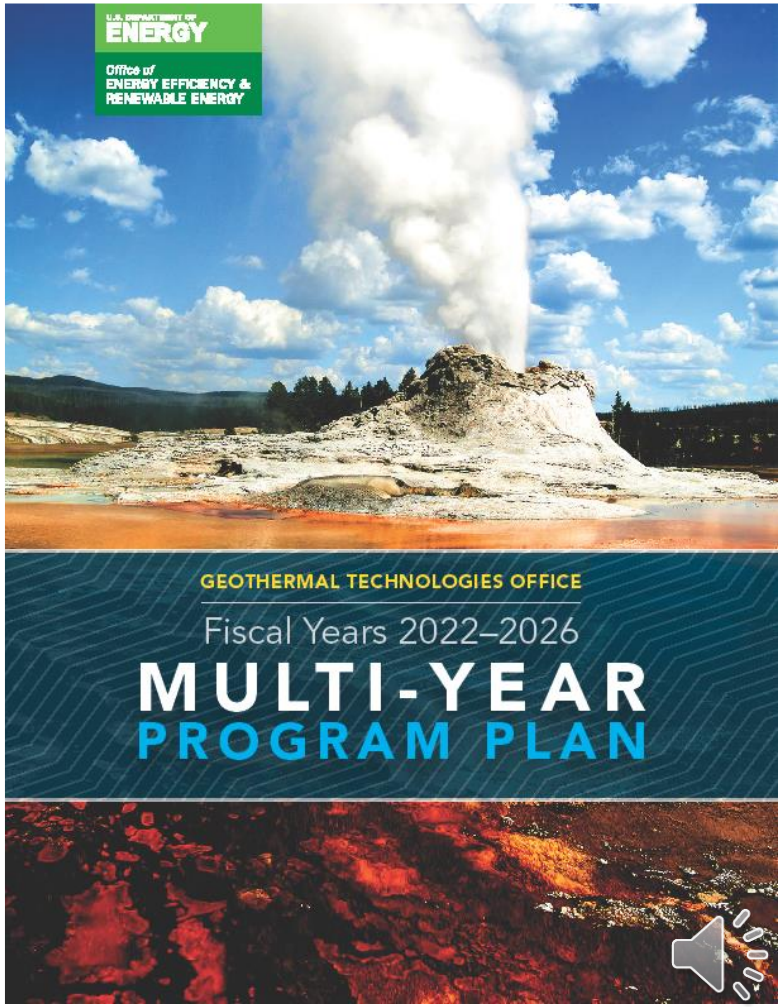
Priorities: 5-Year Strategy for GTO

The Multi-Year Program Plan is a 5-year plan of activities GTO will pursue to support the growth and long-term contribution of geothermal energy to the U.S. electricity grid and American homes and buildings.

Based on GTO's strategic goals for geothermal energy to contribute to the nation's clean energy future by:

- ✓ Providing generation for a carbon-free electricity grid
- ✓ Decarbonizing the U.S. building stock through direct-use applications, district heating and cooling, and geothermal heat pumps
- ✓ Helping to deliver economic, environmental, and social justice advancements.



https://bit.ly/GTOMYPP

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GTO's Multi-Year Program Plan

Exploration and Characterization

- Geophysics and Remote Sensing
- Geochemistry
- Geology

Improve resource targeting for all geothermal resource types

Accessing the Resource

- Drilling Time
- Well Components
- Enabling Technologies

Improve drilling costs toward the "ideal" cost curves used in the GeoVision analysis

Subsurface Enhancement & Sustainability

- Reservoir Response
- Reservoir Development and Management Technologies
- Reservoir Characterization and Monitoring

Enhance and sustain geothermal energy recovery

Resource Maximization

- Heating and Cooling
- Grid Valuation
- Thermal Storage and Utilization
- Value Streams

Accurately capture the value of geothermal energy resources

Data Modeling and Analysis

- Economic Analysis and Validation
- Data Collection, Access, and Analysis Tools
- Policy and Regulatory Analysis

Expand capabilities of using data to identify and address barriers to geothermal deployment

Geothermal Integration & Awareness

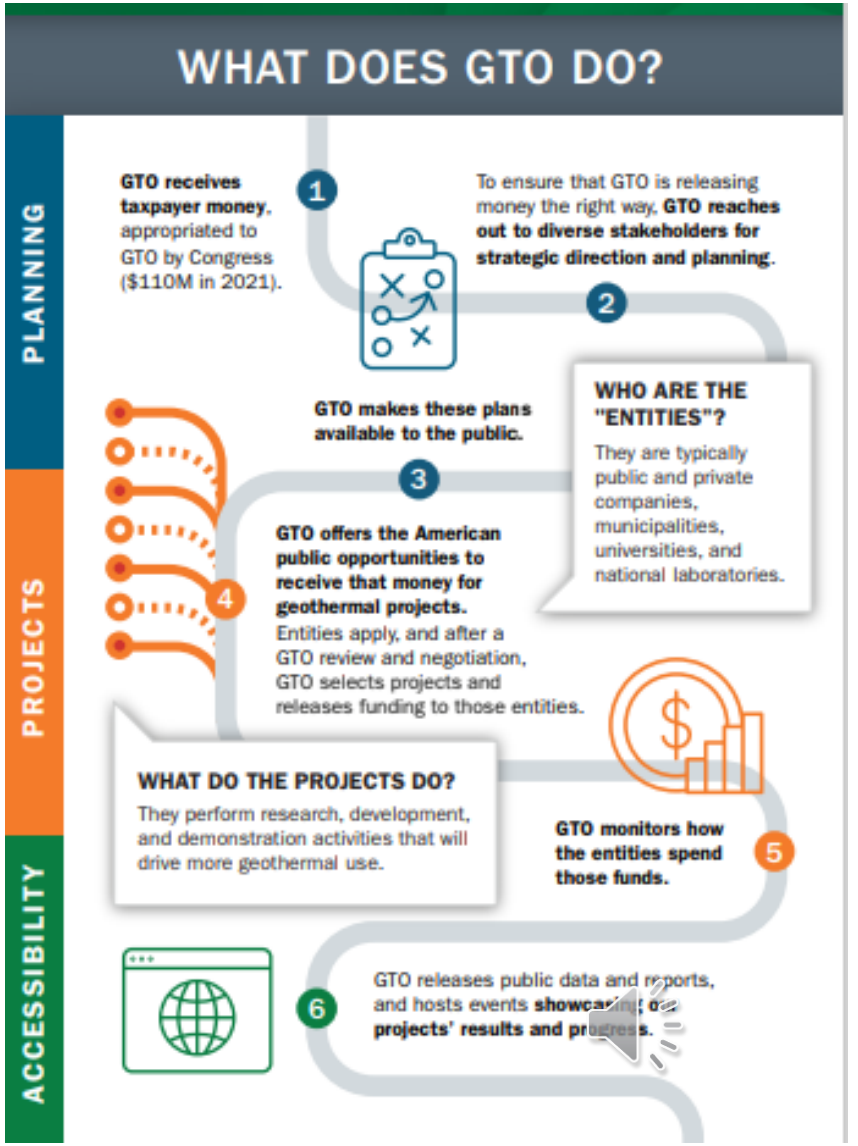
- Machine Learning
- Advanced Manufacturing
- Technology Commercialization
- Energy Transitions
- Stakeholder Engagement

Expand stakeholder education and outreach to improve understanding of geothermal energy

GTO Mission and Program Areas

GTO's mission is to increase geothermal energy deployment through research, development, and demonstration of innovative technologies that enhance exploration and production.

- Data, Modeling, and Analysis
- Hydrothermal Resources
- Low-Temperature and Coproduced Resources
- Enhanced Geothermal Systems



energy.gov/eere/geothermal/geothermal-basics

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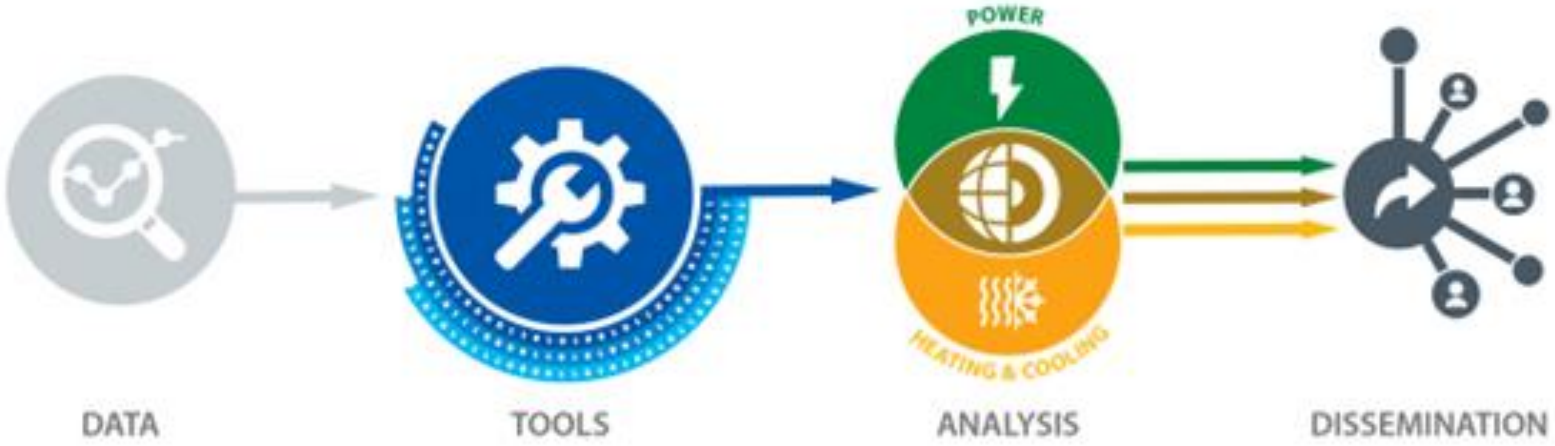
Data, Modeling, and Analysis Program

Analyses of resource assessments; economic, environmental, system-level, and grid integration impacts and value of geothermal technologies; policy and regulatory barriers to geothermal development; and techno-economic modeling and validation of geothermal technology cost and performance. Also supports collection and dissemination of data for stakeholder use, strategic planning, and validation or refinement of GTO's overall RDD&D.



Leathers geothermal power plant in the Salton Sea. Photo courtesy Warren Gretz, NREL (NREL Pix 05559)

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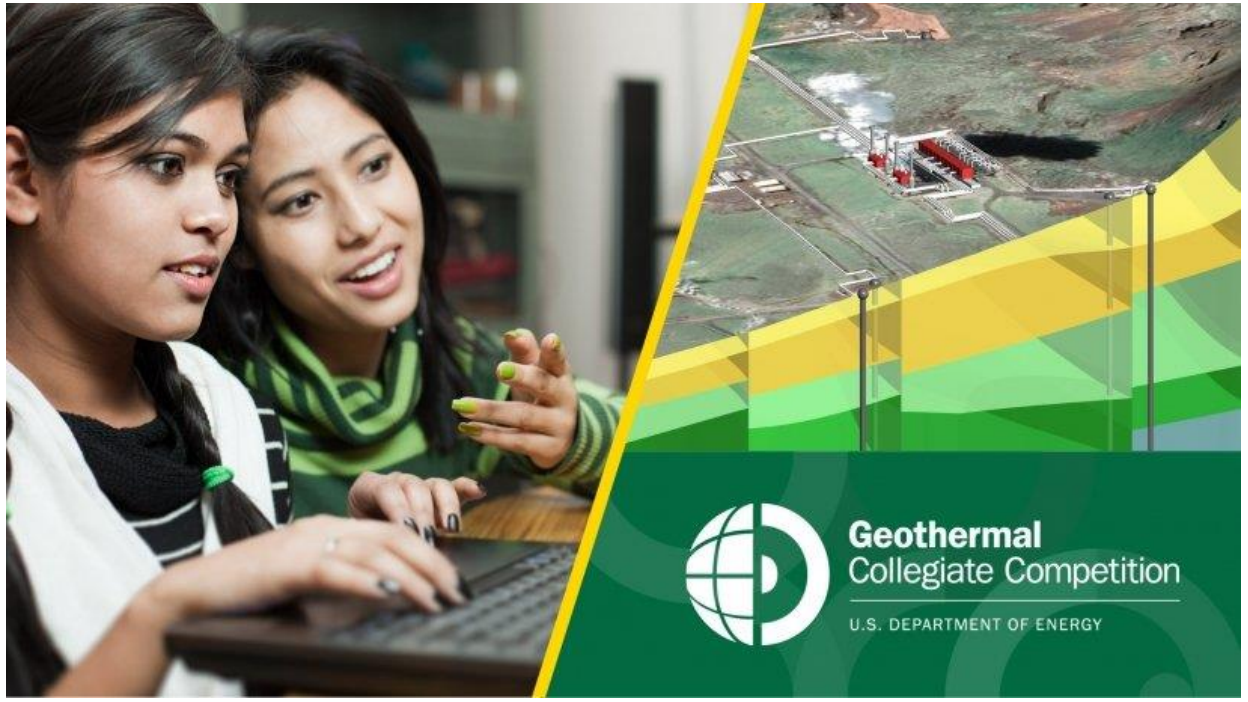
Geothermal Collegiate Competition

- 2023 competition currently underway
  - Two tracks: Technical and Policy
  - Cash prizes of $10,000 for 1st place and $6,000 for 2nd place in each track
  - Submissions due December 20
- Teams of at least three students, who can be from more than one school
- Students at all levels and of all majors, minors, and career paths
- Multidisciplinary teams encouraged



bit.ly/GTOGCC

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Addressing Nontechnical Barriers to Geothermal

GTO-funded projects to assess nontechnical barriers to geothermal projects, including:

- Land access and permitting
- Techno-economic characteristics of the regulatory and nontechnical barriers to development
- Potential value of grid services from geothermal power plants.

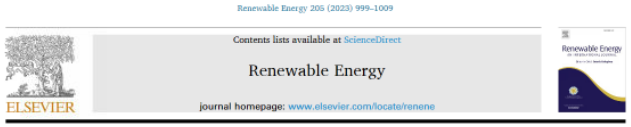
Blue Mountain Geothermal Plant, Nevada Geothermal Power, Humbolt County, Nevada. *Photo by Dennis Schroeder, NREL*

Pathways To Overcome Geothermal Deployment Barriers

Best Practices To Reduce Delays

Implementation of best practices identified in this report may reduce overall geothermal project development timelines, costs, risks, and uncertainties. Examples include:

- Tiering to (i.e., building upon) existing environmental review documents, which may create cost and time efficiencies for agency staff and project developers.
- Development of interagency memorandum of understanding (MOUs), which may decrease project permitting delays through increased interagency coordination and communication.
- Development of comprehensive and agency-integrated permitting and review processes, which may decrease project development delays by reducing duplication of



Renewable Energy 205 (2023) 999–1009

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Mind the gap: Comparing the net value of geothermal, wind, solar, and solar+storage in the Western United States

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Lawrence Berkeley National Laboratory, USA

ARTICLE INFO

Keywords:
Geothermal
Wind
Solar
Storage
Power purchase agreement
Market value

ABSTRACT

Studies show that a diverse portfolio of zero-carbon resources will be needed to decarbonize the U.S. sector, and that high capacity factor resources like geothermal will become particularly important i… of decarbonization as the capacity contribution of variable, weather-dependent resources like wi… declines with increasing market penetration. Yet while wind, solar, and—more recently—storage h… significant U.S. deployment in recent years, deployment of new geothermal plants has barely bud… same period. We explain this disparity in historical deployment by analyzing empirical price data… purchase agreements (PPAs) and wholesale energy and capacity markets, which demonstrate tha… has historically offered a lower "net value" (i.e., wholesale market value minus PPA price) than… resources. Looking ahead through 2026, continued growth in the market share of wind, solar, and st… improve geothermal's relative market value, yet likely not by enough to overcome the persistent… tween geothermal and these other, lower-cost resources. In the face of this challenging market ou… intervention and continued R&D investments may be warranted to sustain a vibrant geothermal … stands ready to contribute to the late stages of decarbonization.

1. Introduction

In recent years, modeling studies have illuminated the growing imperative to decarbonize global economies [1,2], as well as the increasing feasibility of decarbonizing the electricity sector in particular [3–9]. The latter typically reach their conclusions by modeling a port-

Despite its early commercial success—i.e., the first few… (GW) of geothermal capacity in the United States were built… 1980s—and the important role that geothermal is expected… decarbonizing the power sector (and the economy more… through widespread electrification of other sectors, by… powering hydrogen production and direct air capture,…

Non-Technical Barriers to Geothermal Development in California and Nevada

Aaron Levine, Ligia E.P. Smith, Jody Robins, Erik Witter, Caity Smith, and Clare Haffner

National Renewable Energy Laboratory

NREL fact sheet: nrel.gov/docs/fy23osti/85219.pdf
NREL report: nrel.gov/docs/fy23osti/83133.pdf
LBNL report: doi.org/10.1016/j.renene.2023.02.023
Geothermal Interagency Permitting Collaboration Task Force: Summary of Findings: nrel.gov/docs/fy23osti/84684.pdf

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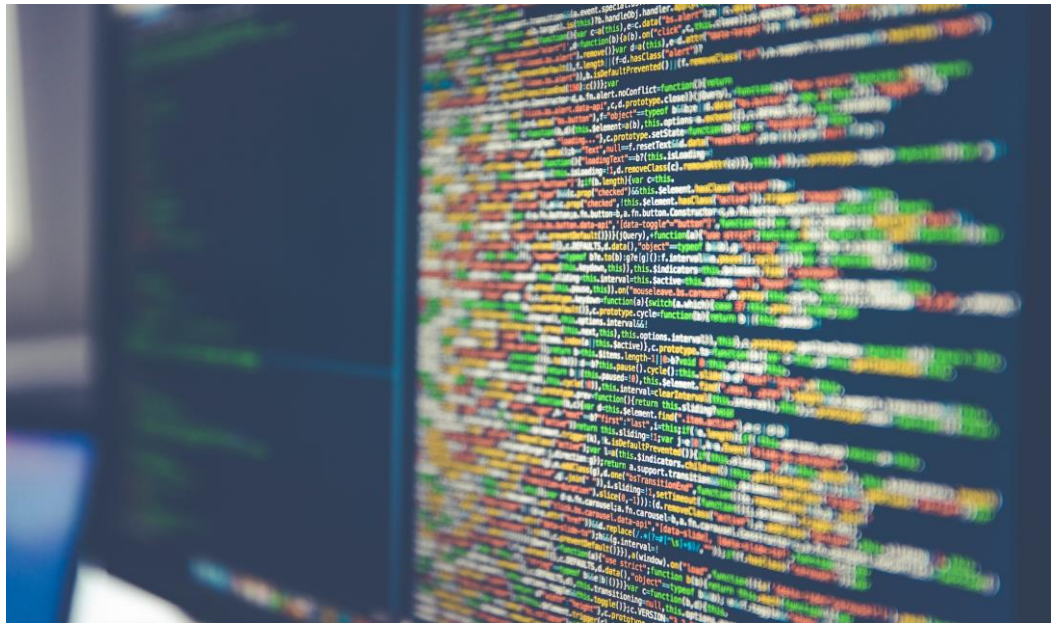
Hybrids Research

- Investigating hybridized geothermal power plants through research, analysis, and modeling that will help build the case for commercial pathways to hybridizing geothermal power plants
  - **Idaho National Laboratory**—*Techno-economic analysis of solar topping cycle hybrid geothermal power plants for retrofit and greenfield applications*
  - **National Renewable Energy Laboratory**—*Techno-economic analysis and market potential of reservoir thermal energy storage charged with solar thermal and heat pumps*
  - **Brookhaven National Laboratory**—*Cements and a modeling tool to calculate viability under various exploitation conditions of high-temperature reservoir thermal energy storage systems*
  - **Lawrence Berkeley National Laboratory**—*Application of using unwanted thermal energy produced by data centers to be used directly in a district heating system or stored in a reservoir thermal energy storage system for later use.*

Aerial view of the Stillwater triple hybrid project (photo courtesy of ENEL Green Power North America, taken from "Better Together: New Synergies and Opportunities From Hybrid Geothermal Projects" by Ann Robertson-Tait and Douglas Hollett via geothermal.org/our-impact/blog/geothermal-hybrid-renewable-systems).

Geothermal Datathon

- **Society of Petroleum Engineers Geothermal Datathon**
  - Challenged participants to use machine learning to create predictive models that can aid future geothermal energy production
  - Used one of the largest geothermal datasets assembled and never-before-analyzed data from FORGE
  - Winners were announced at PIVOT 2023 in September.



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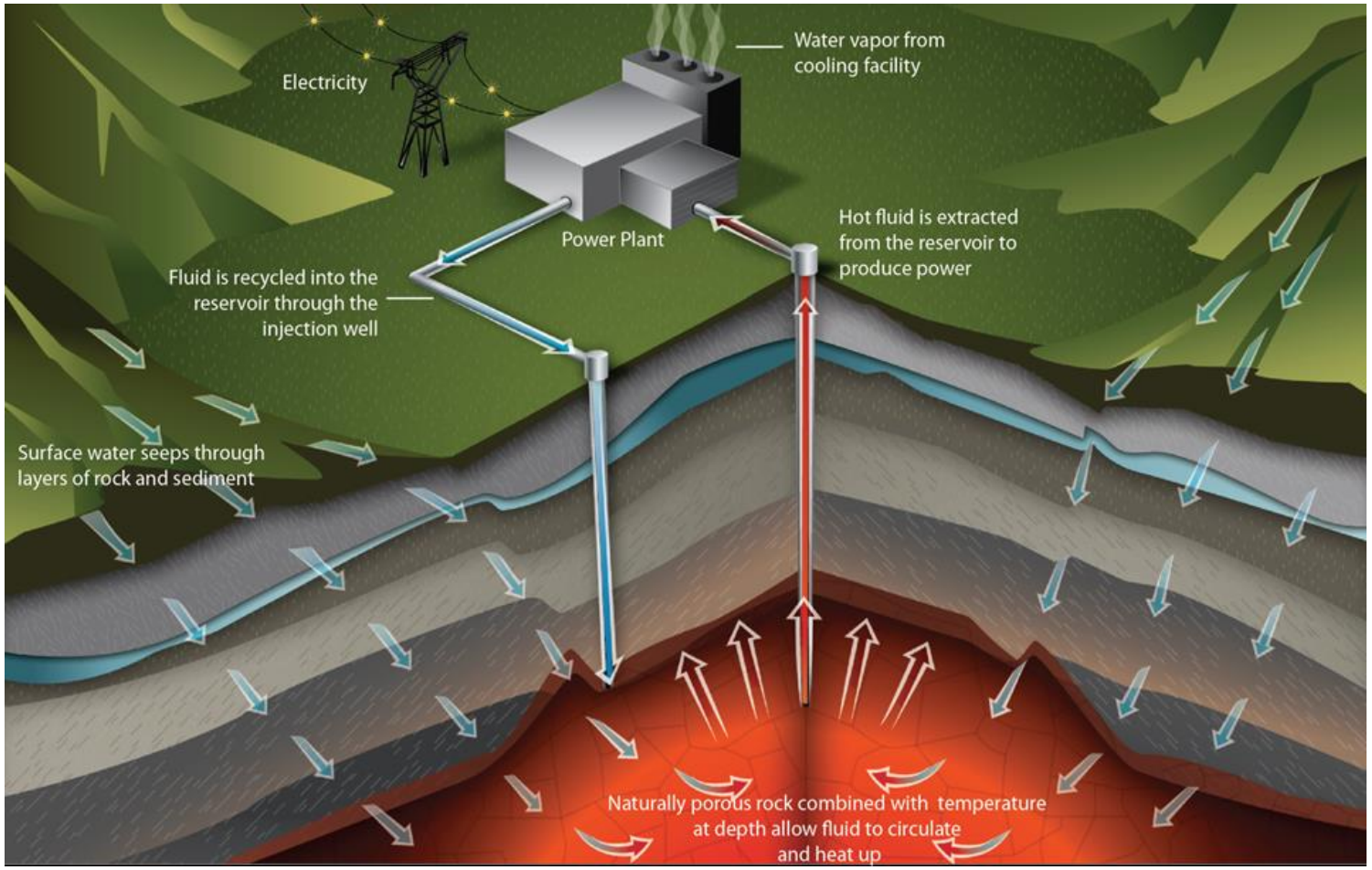
Hydrothermal Resources Program

RD&D to reduce lifecycle cost and risk to bring more hydrothermal power online. Includes exploration and resource confirmation, drilling, field development, reservoir management over multi-decadal timescales, and extraction of critical and strategic minerals from geothermal brines to maximize the ancillary benefits of geothermal resources.



Desert Peak Geothermal Power Plant (NV). Photo courtesy Sierra Pacific (NREL Pix 07212)

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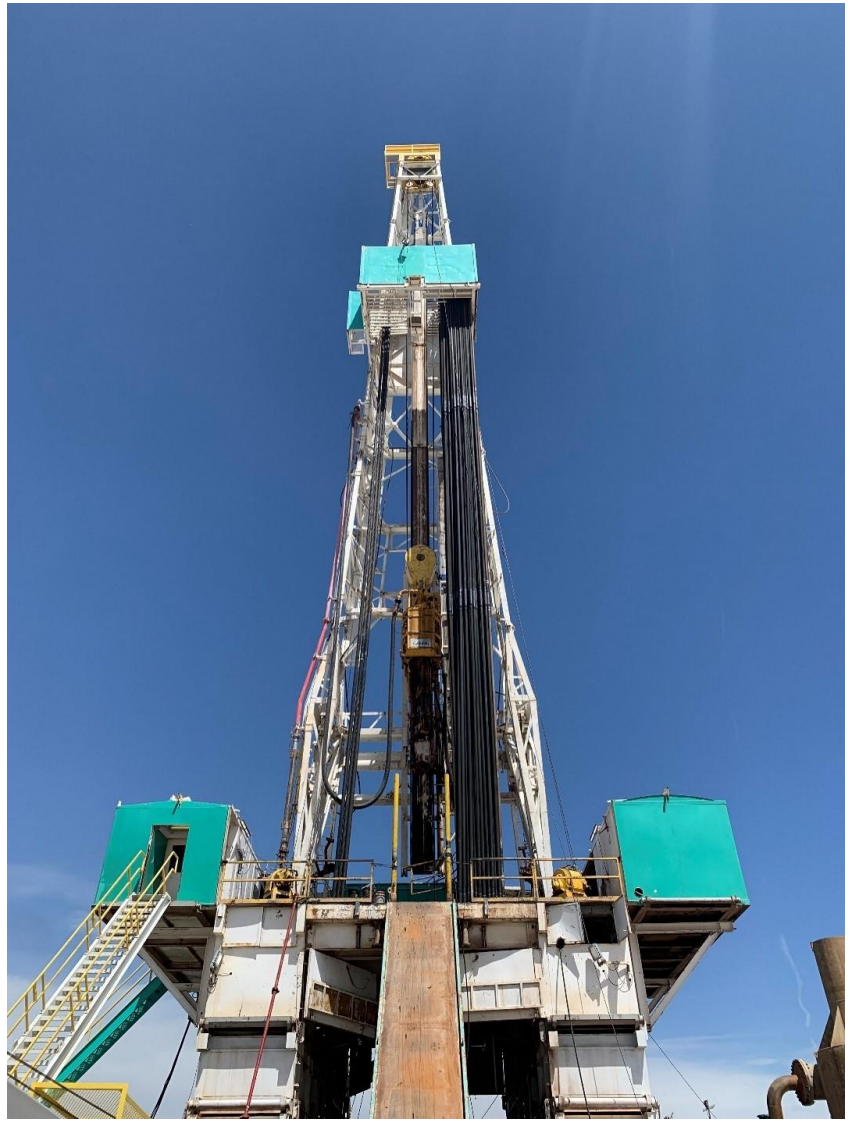
Drilling Demonstrations



Drill rig at Utah FORGE. Photo courtesy Scott Beautz, National Energy Technology Laboratory

Drilling Technology Demonstrations Initiative

- Targets technology developments that will provide significant improvements in drilling performance in commercial geothermal settings
- Critical given that drilling can exceed 50% of the cost of a geothermal project
- Two projects selected:
  - Geothermal Limitless Approach to Drilling Efficiencies (GLADE)
  - Evaluation of Physics-Based Drilling and Alternative Bit Design

energy.gov/eere/geothermal/drilling-demonstrations-initiative

Lithium Resources and Extraction

- **Quantification of Lithium Resources in Salton Sea**
  - National laboratory project to better quantify sources and amounts of lithium present in geothermal brines within the Salton Sea, California

- **Geothermal Lithium Extraction Prize**
  - Prize to find innovations that de-risk and increase market viability for direct lithium extraction from geothermal brines
  - Three winners announced in Sept.:
    - **Winning Team ($1 million):** University of Illinois Urbana-Champaign—Team SelectPureLi, *A Redox Membrane for Lithium Hydroxide Extraction*
    - **Runner-Up ($500,000):** University of Virginia—Team TELEPORT, *Targeted Extraction of Lithium with Electroactive Particles for Recovery Technology (TELEPORT)*
    - **Runner-Up ($500,000):** George Washington University—Team Ellexco, *Chemical-Free Extraction of Lithium from Brines*

U.S. Secretary of Energy Granholm visiting Salton Sea/Imperial Valley (CA)

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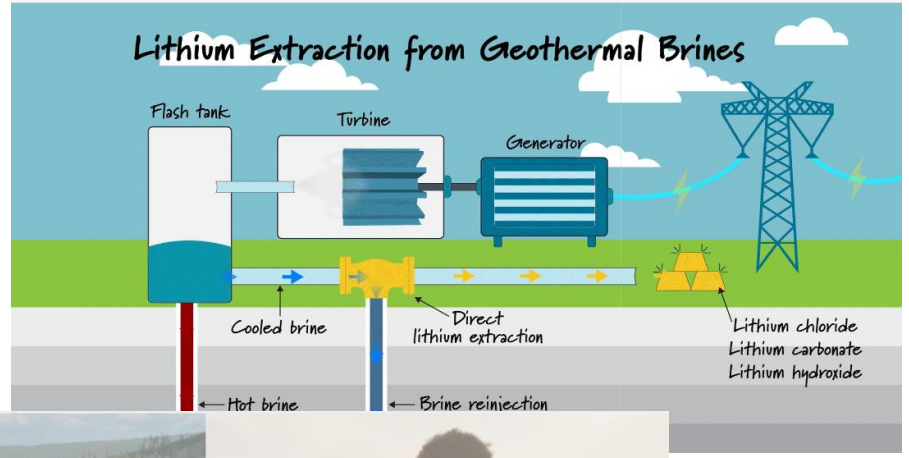
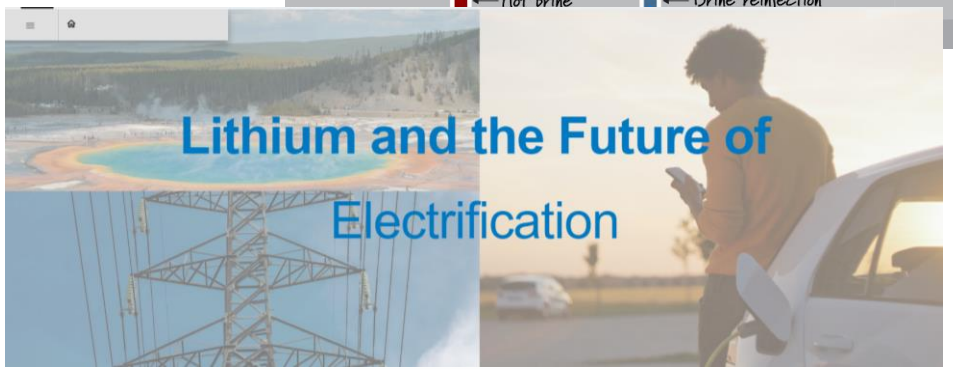
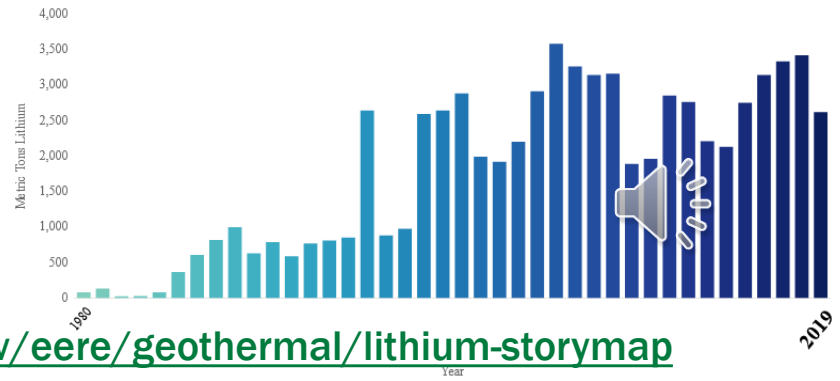
Lithium Resources and Extraction

- Joint Funding Opportunity Announcement between GTO and DOE's Advanced Manufacturing and Materials Technology Office
- Will advance innovative technologies to extract and convert battery-grade lithium from geothermal brine sources in the United States
- $10.9 million for 10 selected projects across nine states, in two topic areas:
  - Field Validation of Lithium Hydroxide Production from Geothermal Brines
  - Applied Research & Development for Direct Lithium Extraction from Geothermal Brines





U.S. Lithium Imports



Visit our Lithium Storymap to learn more about this critical mineral! energy.gov/eere/geothermal/lithium-storymap

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Hidden Systems Data

INnovative Geothermal Exploration through Novel Investigations Of Undiscovered Systems (INGENIOUS): Aims to accelerate discoveries of new, commercially viable hidden systems across the Great Basin region and create predictive geothermal maps at regional and prospect scales. gdr.openei.org/submissions/1391 and ScienceBase.gov (USGS Data).

Collaboration w/U.S. Geological Survey: gdr.openei.org/submissions/1501

- **Geoscience Data Acquisition in Western Nevada (GeoDAWN):** Focused on new subsurface data in western Nevada and leveraging machine learning for better understanding of geologic conditions and stress regime.
- **GeoFlight: Salton Trough:** Data on hidden geothermal systems in Imperial Valley (CA), using specially equipped, low-flying aircraft to help identify unique surface and near-surface characteristics to create more accurate geologic maps for the area.

Basin & Range Investigations for Developing Geothermal Energy (BRIDGE): Collecting data and conducting surveys in Nevada to locate hidden geothermal systems.

Play Fairway Analysis (PFA) Retrospective Data Sets: Synthesis and analysis of GTO's geothermal PFA program gdr.openei.org/submissions/1498

GeoFlight photos (Glamis Dunes) courtesy Kyle Kendall

Leveraging Oil and Gas to Geothermal

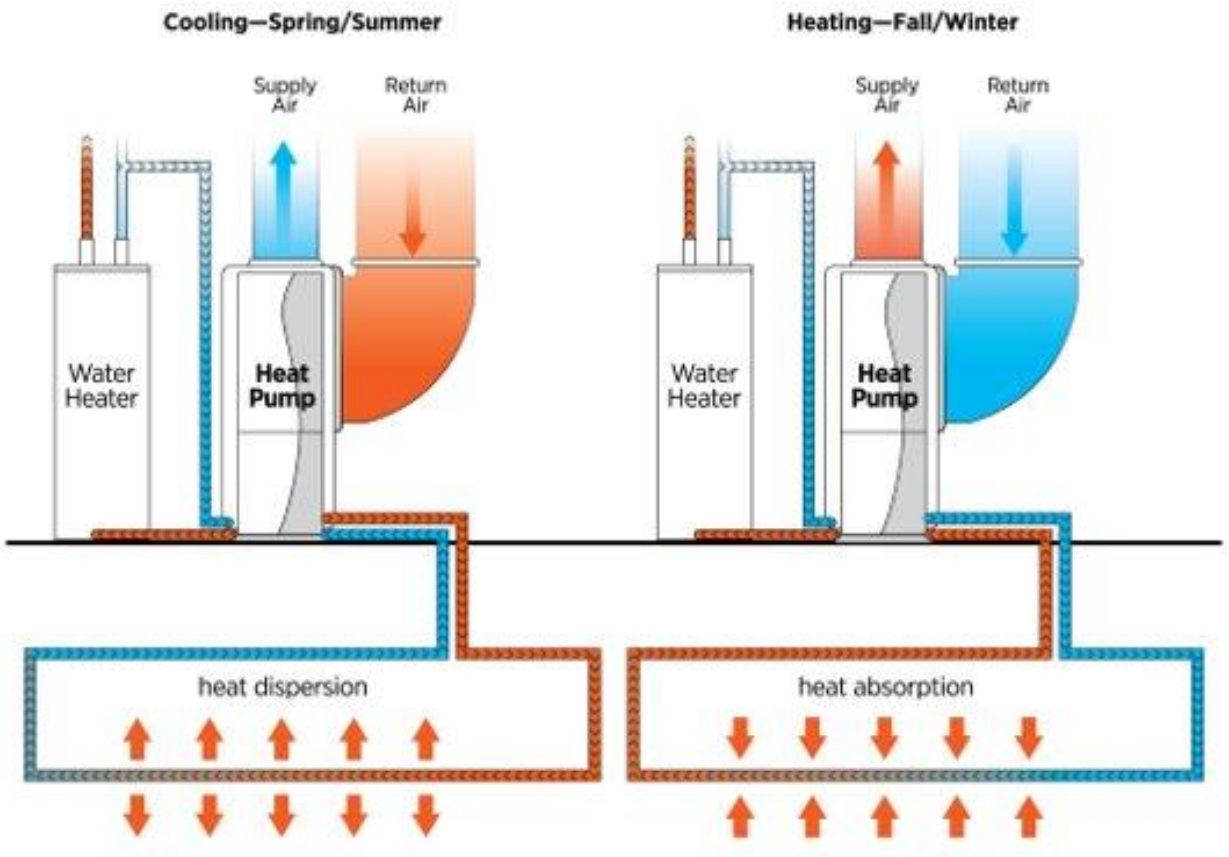
- Geothermal Energy from Oil and gas Demonstrated Engineering (GEODE) initiative
  - Consortium to leverage oil & gas subsurface assets, technologies, and expertise to help solve geothermal energy's toughest challenges, while providing clean energy employment opportunities and environmental benefits for communities.
  - Will issue future competitive solicitations for analysis, RD&D, and workforce efforts
  - Joint initiative between GTO's Hydrothermal and Enhanced Geothermal Systems programs

GTO selected team comprising Project Innerspace, Geothermal Rising, and the Society of Petroleum Engineers as the GEODE consortium administrator.

U.S. DEPARTMENT OF ENERGY
GEODE
Geothermal Energy from Oil and gas Demonstrated Engineering

Low-Temperature and Coproduced Resources Program

RDD&D for technologies applicable to geothermal resources < 300°F (150°C); geothermal resources, including hybrid energy designs, that can be co-developed with other clean energy technologies; direct use of thermal resources for process and space heating applications, geothermal heat pumps, district-scale geothermal heating and cooling systems, and deep direct use; and thermal energy storage.



Heat exchangers and circulation pumps for the geothermal district heating system in Klamath Falls, OR. Photo courtesy Geo-Heat Center (NREL Pix 03694)

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Federal Geothermal Partnerships

- Collaborative initiative between GTO and the Federal Energy Management Program to provide technical assistance and help support deployment of geothermal energy at federal sites
- Federal government is the nation's largest energy user; approximately 450 federal sites make up more than 75% of the federal government's energy use
  - Converting even a few of those to geothermal heating and cooling can significantly decrease carbon emissions while increasing resilience and energy security for key federal sites!
- First two sites selected:
  - U.S. Army Garrison Detroit Arsenal (Michigan)
  - U.S. Military Academy at West Point (New York)

Identify federal sites that are strong candidates for geothermal heating and cooling technologies

Provide technical assistance for site characterization/resource confirmation activities at these sites

Break ground for multiple innovative geothermal system deployments

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Community-Focused Geothermal

Community Geothermal Heating and Cooling Design and Deployment initiative will help communities:

- Reduce energy burden and fossil fuel dependence
- Increase grid resilience and stability
- Improve environmental quality
- Support jobs

Eligible Projects:

- direct use
- heat pumps
- innovative designs & technologies

Part of the Department of Energy's Justice40 initiative

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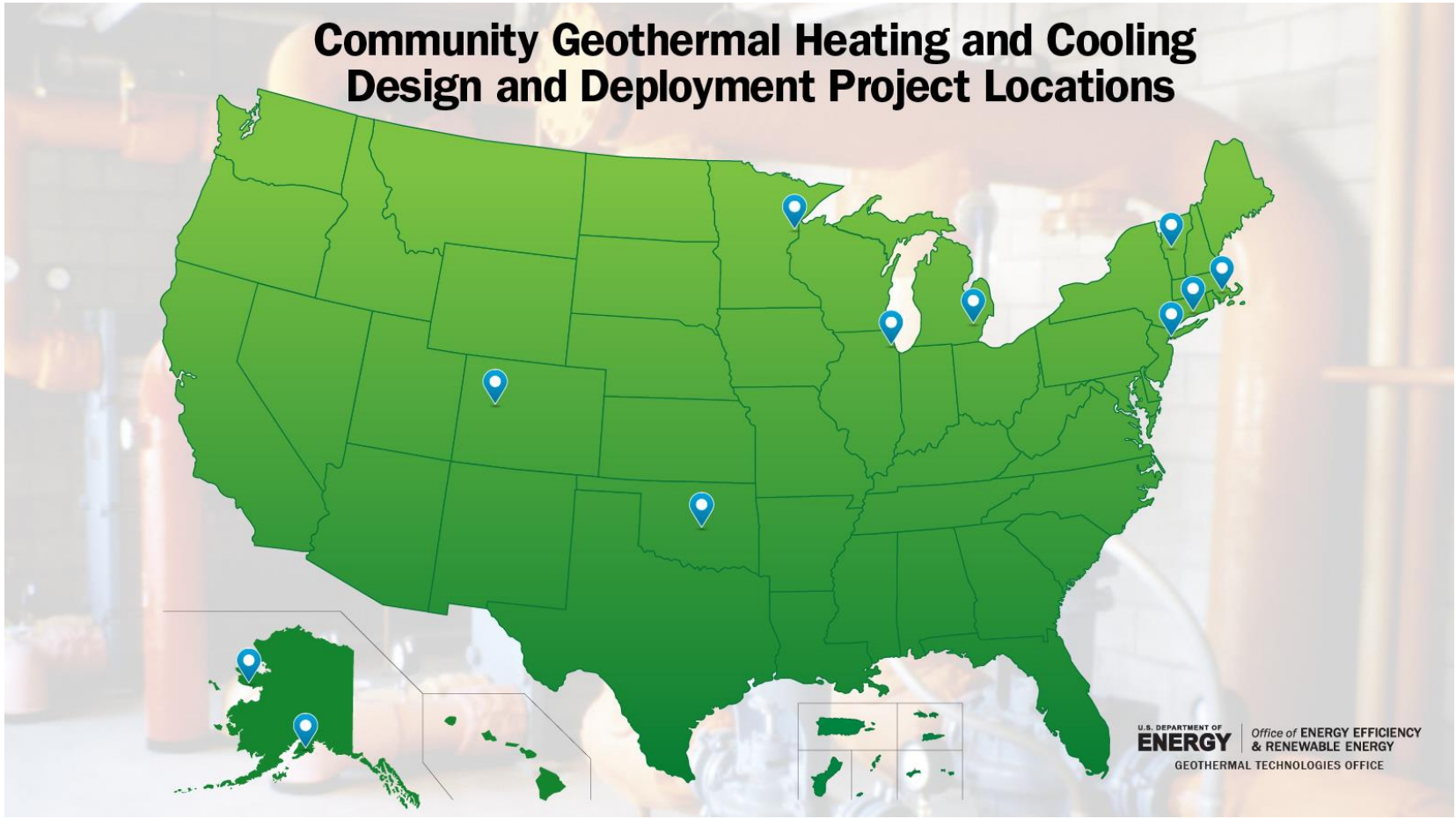
Community-Focused Geothermal



Selected 11 communities in 10 states to assess and design community-scale geothermal heating and cooling systems

Urban

- Ann Arbor, MI
- Chicago, IL
- Duluth, MN
- Framingham, MA
- New York City, NY
- Wallingford, CT

Rural

- Carbondale, CO
- Middlebury, VT
- Seward, AK
- Shawnee, OK

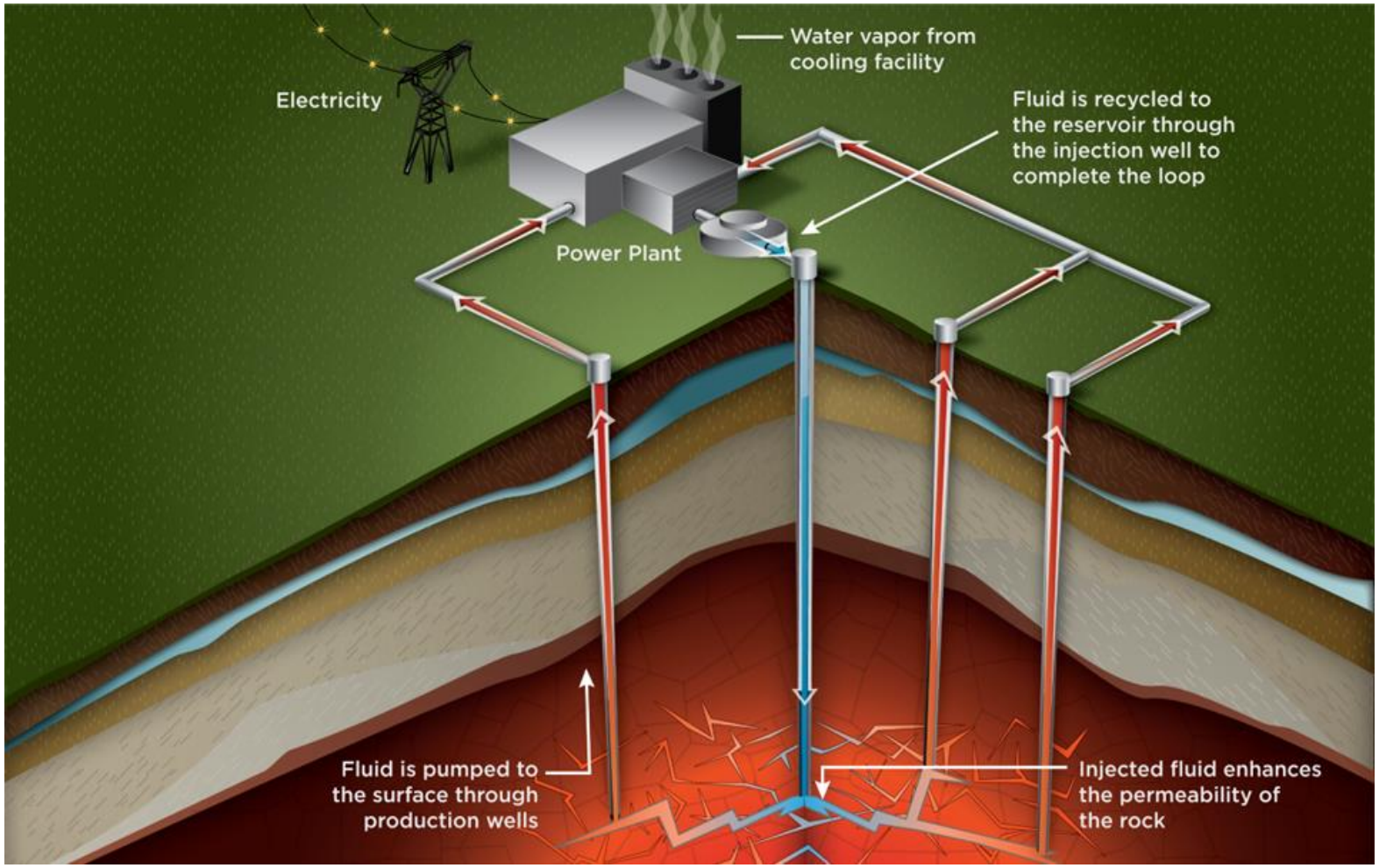
Remote

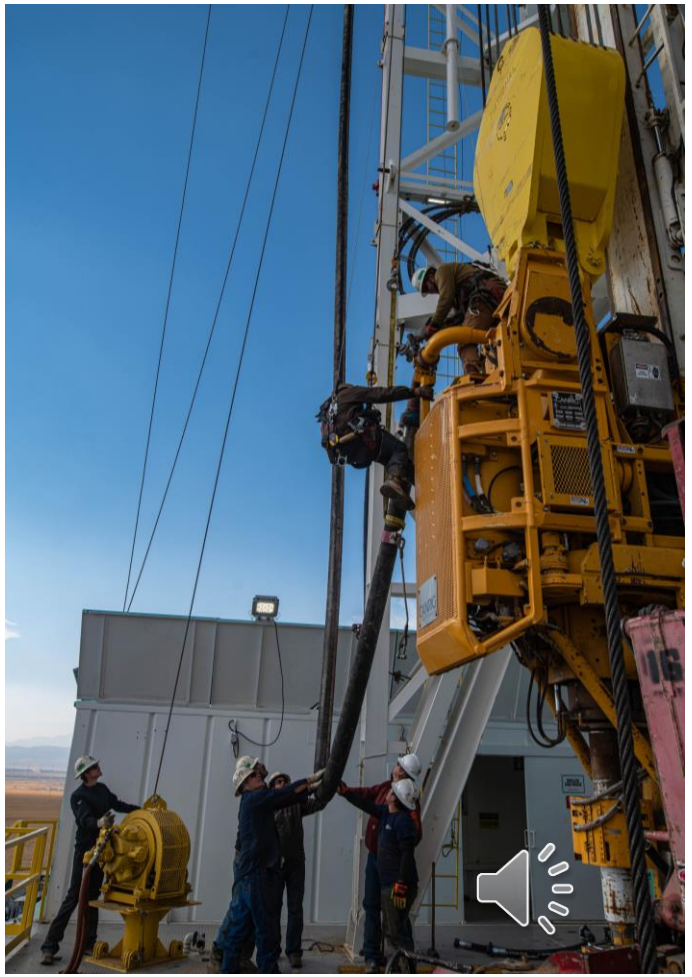
- Nome, AK

energy.gov/eere/geothermal/community-geothermal-heating-and-cooling-design-and-deployment

Enhanced Geothermal Systems Program

Gain an evidence-based understanding of basic and applied science and engineering challenges surrounding long-term subsurface heat flow, permeability enhancement, and stress evolution to enable development of sustainable, humanmade geothermal reservoirs.





Workers moving the drill string on a rig at GTO's Utah FORGE EGS site. Photo courtesy Eric Larson, Flash Point SLC.

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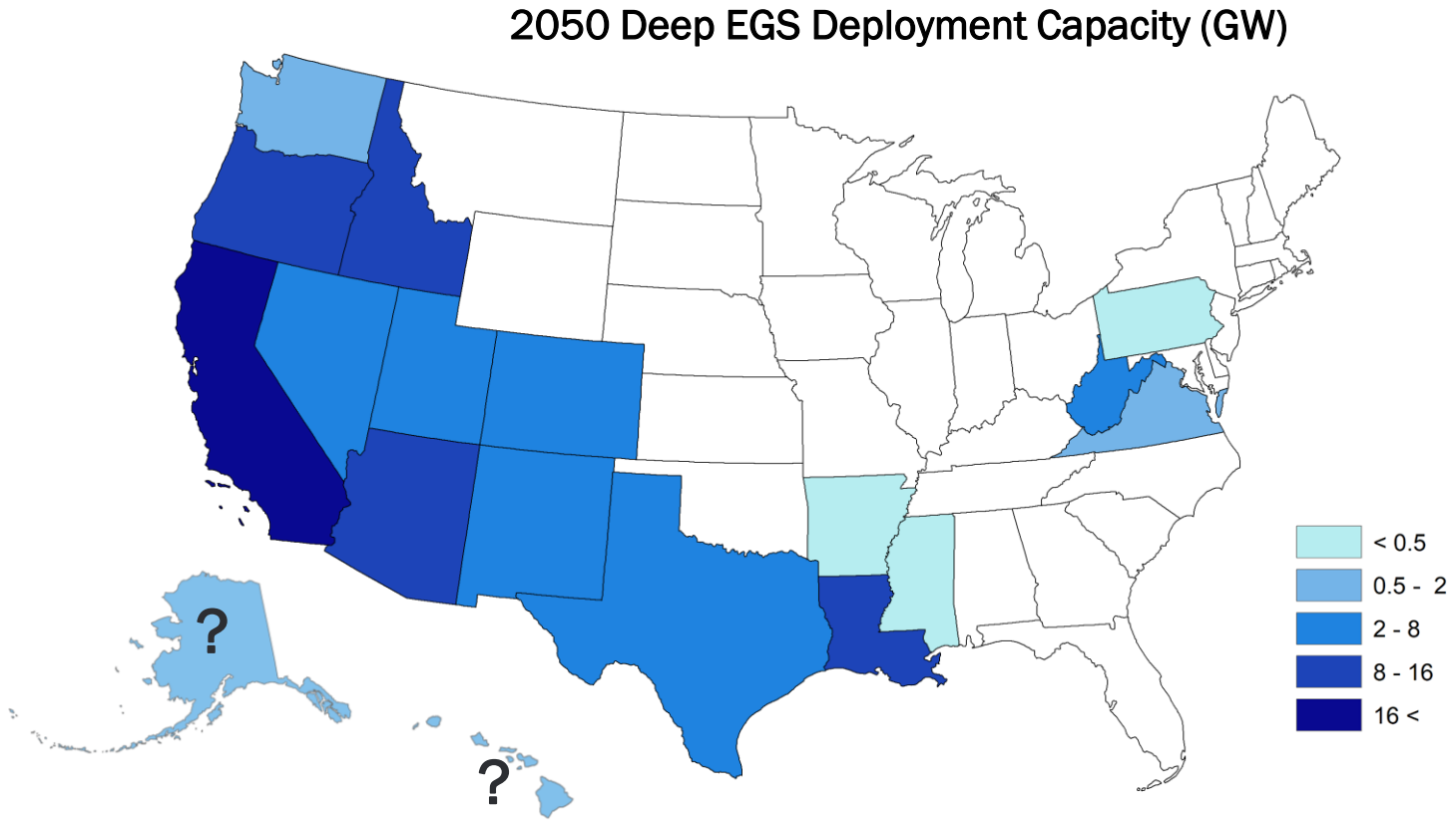
Enhanced Geothermal Shot™

Achieving the Enhanced Geothermal Shot™ target ($45/MWh by 2035) will enable access to the nation's vast heat resource, driving U.S. leadership in EGS and enabling a carbon-free energy future.



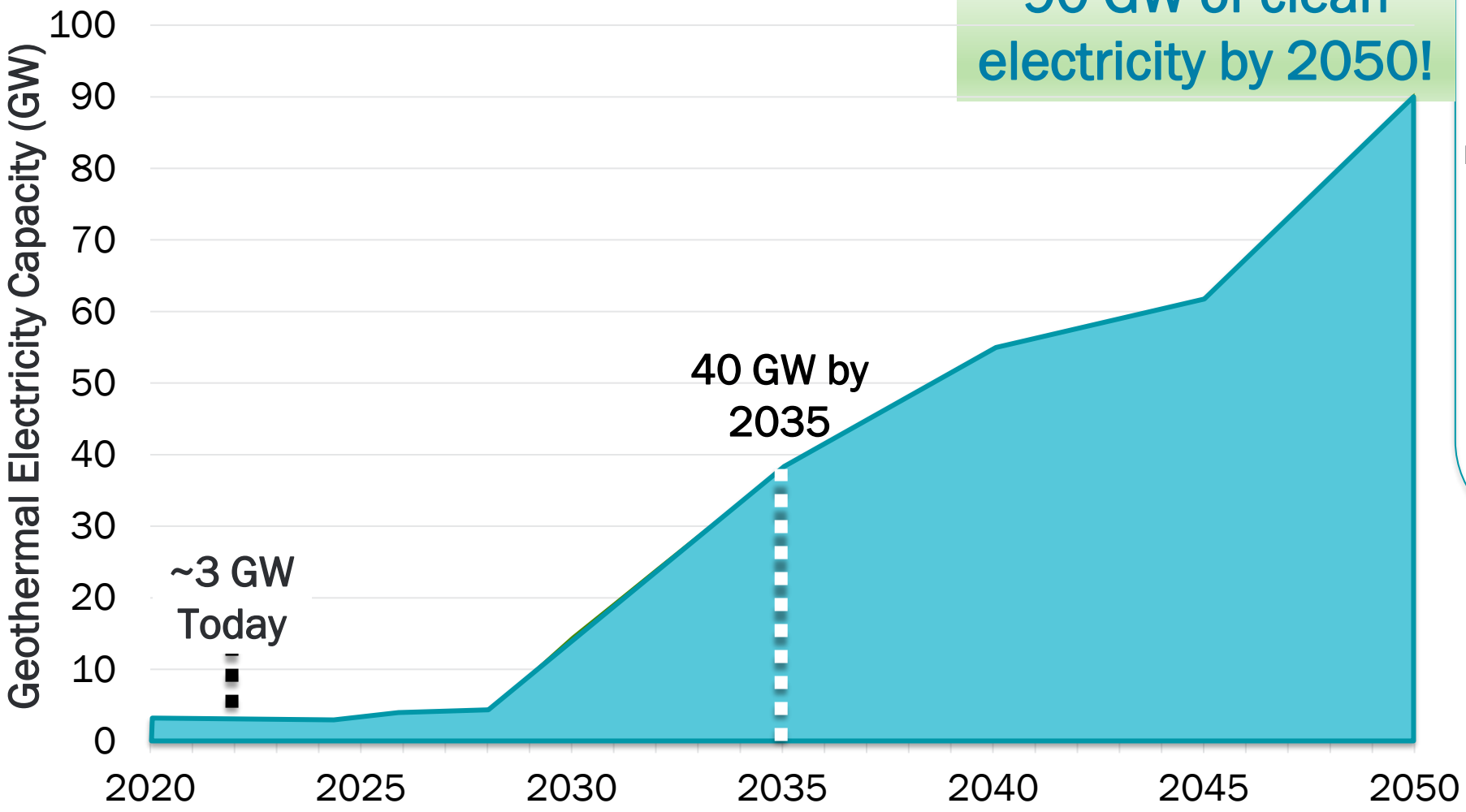
90 GWe by 2050

- Nationwide expansion of EGS for firm, flexible, secure power; grid stability
- Clean, efficient heating and cooling for U.S. households nationwide
- Just transition and leveraging of skilled fossil fuel workers
- Economic growth for negatively impacted communities
- Opportunity for other important industries and domestic supply of critical materials

Enhanced Geothermal Shot™

ELECTRICITY

90 GW of clean electricity by 2050!



HEATING & COOLING

Up to **1,281 MMT** of avoided CO_2e

Total Emissions Reductions = removal of **20 million** cars per year

GEOTHERMAL HEAT PUMPS	**28 million** residential installations by 2050
DISTRICT HEATING	**17,500** installations by 2050

Source: *GeoVision* Analysis (DOE 2019)
energy.gov/eere/geothermal/geovision

Enhanced Geothermal Shot™ Technical Pathways

Pathways to unlock Earth's nearly inexhaustible heat resources for dispatchable, high-value, baseload power

Today

3.7 GWe of geothermal from power plants in the western U.S.

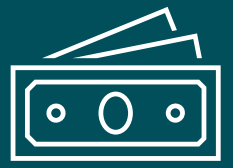
EGS in pilot stage but poised for explosive growth

Deep EGS binary costs $400/MWh

Technology Pathway

- Seeing with Greater Precision
- Predicting with Greater Precision
- Accessing the Subsurface
- Designing and Building Wells
- Manipulating and Creating Durable Reservoirs

Target



… reduce EGS energy costs to **$45/MWh with 40 GWe deployed by 2035**

Impact

90 GWe by 2050

Send questions and comments about the Technical Pathways: EGShotRoadmap@ee.doe.gov

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Frontier Observatory for Research in Geothermal Energy (FORGE)

Located near Milford, Utah, FORGE is a dedicated site where scientists and engineers can develop, test, and accelerate breakthroughs in EGS technologies and techniques.

- One of the best-characterized geothermal sites in the world
- Wells include 1st-of-its-kind highly deviated well in hard/hot granite; fastest drilling of hard hot granitic rock to date
- Conducting three-stage reservoir stimulation with *in situ* seismic monitoring
- Completed drilling of 16B production well
  - Intersects existing injection well (16A) through reservoir of hydraulically created fractures
  - Confirmed connectivity of the doublet pair
  - Continued stimulations and circulation testing planned

- **2023 R&D Annual Workshop** in September highlighted progress in FORGE 2020 solicitation projects. Presentations: https://openei.org/wiki/R%26D_Projects

Utah FORGE project confirms connectivity of EGS reservoir

Utah Forge site at sunset (source/ photo: Eric Larson, FlashPoint SLC via UtahForge)

The Salt Lake Tribune

Utah geothermal project hits a milestone, pumping water through deep granite

Utah FORGE scientists connect two deep wells that could one day generate a continuous flow of hot water to produce power.

Bipartisan Infrastructure Law EGS Pilot Demos

SEC. 41007. Enhanced Geothermal Systems Demonstrations

Topic 1: **EGS Proximal:** Using existing infrastructure proximal to existing geothermal/hydrothermal development w/immediate potential for electrical power production.

Topic 2: **EGS Green Field**: Sites with no existing geothermal development and potential for shallow sedimentary, igneous and/or mixed metamorphic rock EGS w/near-term electrical power production potential.

Topic 3: **Super-hot / Supercritical EGS**: Super-hot/supercritical EGS demos at well-characterized sites w/near-term electric power production potential.

Topic 4: **Eastern U.S. EGS**: EGS stimulation demonstration located at a well-characterized eastern U.S. site, w/existing wells in place and near-term electrical power/heat production potential.

Round One selections expected soon!

EGS Enhanced Geothermal Systems PILOT DEMONSTRATIONS

Other EGS Highlights

ReAmplify is providing $8.4 million to establish the commercial viability of geothermal energy production in existing oil and gas wells.

energy.gov/eere/geothermal/wells-opportunity-reamplify

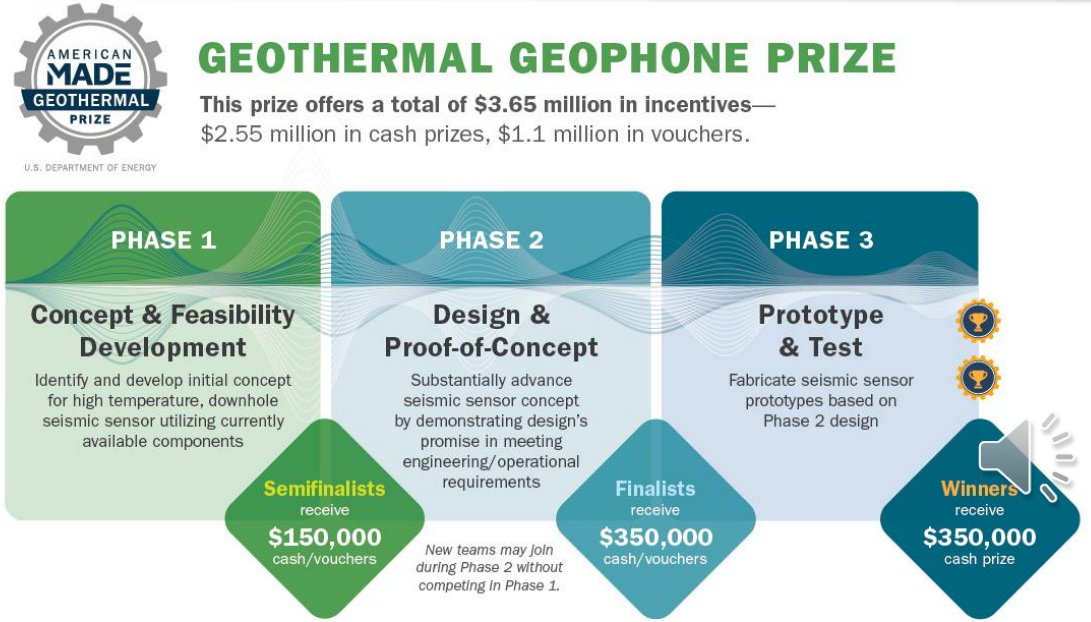
Four ReAmplify projects selected in 2022:

- Geothermix, LLC
- ICE Thermal Harvesting
- Transitional Energy
- University of Oklahoma

Geothermal Geophone Prize

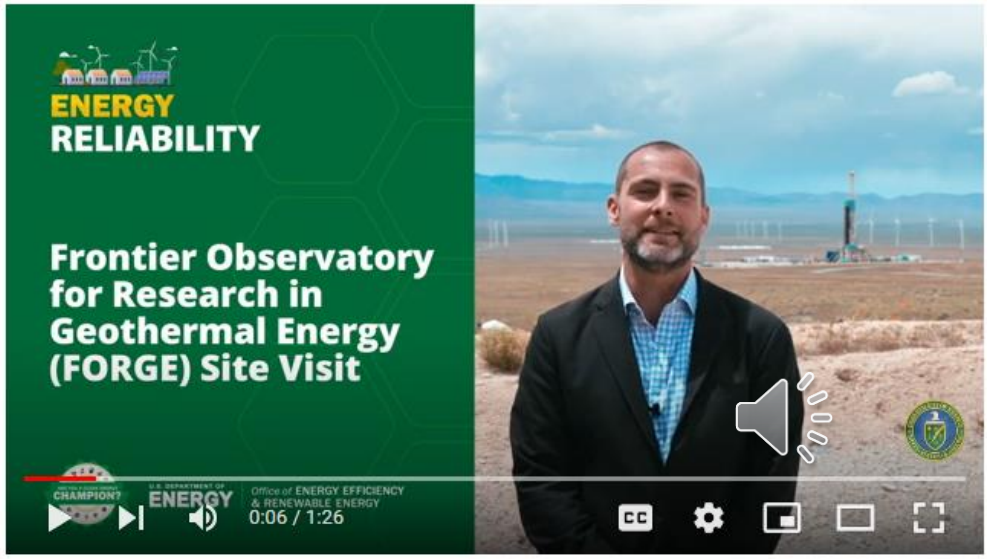
- $3.65-million competition to address the challenges of operating seismic sensors in harsh geothermal environments
- 10 semifinalists in Phase 1
- Phase 2 currently open; not necessary to have participated in Phase 1 to enter Phase 2

americanmadechallenges.org/challenges/geophone/



Geothermal is a HOT Topic at DOE!

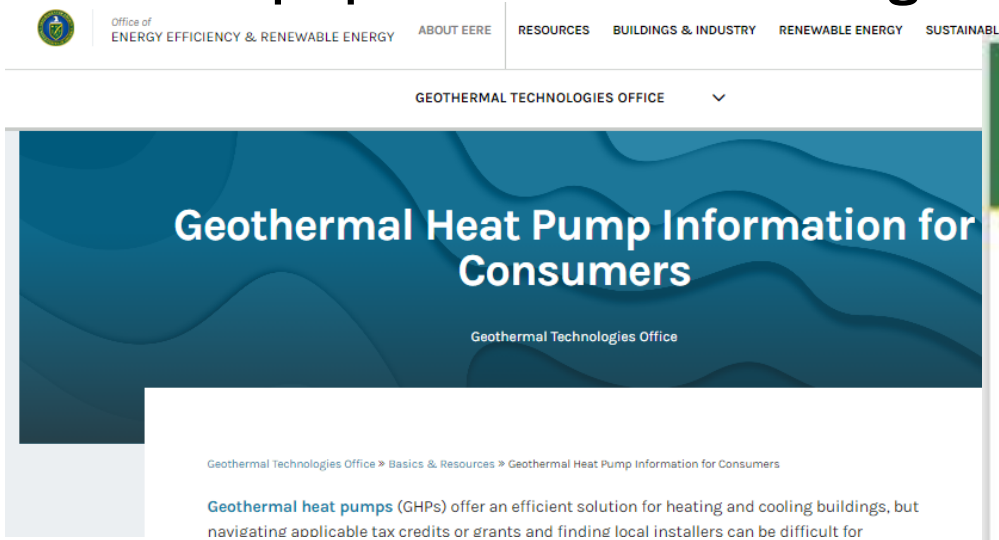
- Enhanced Geothermal Shot™ Summit
- Acting Assistant Secretary Alejandro Moreno toured FORGE site
- Deputy Secretary Turk attended Western Governors Association (WGA) Annual Meeting
- Lauren Boyd and DOE's Jeff Marootian spoke at Fervo Energy Tech Day
- Arlene Anderson presented at the International Ground Source Heat Pump Association Town Hall, the Midwestern Governors Association meeting, and the International District Energy Association Conference
- Lauren Boyd presented to ARPA-e Summer Scholars and the Geothermal Rising webcast
- Alexis McKittrick spoke at the Southwest Research Institute's Thermal Mechanical Chemical Energy Storage Workshop.
- GTO's Alexandra Prisjatschew presented at the Clean Energy States Alliance Domestic Lithium webinar
- GTO's Jeff Bowman moderated a thermal energy panel at the Industrial Heat Shot™ Summit



Resources and Outreach

GTO uses multiple tools and resources to help spread the word about geothermal energy and engage with stakeholders.

- Storymaps
- Updated Website
- Stakeholder Toolkits
- The Drill Down
- Infographics
- Project Postcards
- Funding Opportunity Quick Guides
- Fact Sheets
- Presentations



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Thank You!

the drill down

Get the hottest geothermal news from *The Drill Down*, GTO's monthly newsletter!

Sign up today:
geothermal.energy.gov

Interested in serving as a merit reviewer for GTO RD&D projects?

Send us your resume or CV:
doe.geothermal@ee.doe.gov

Back-Up/Additional Info

Industrial Heat Shot

DOE has identified three key methods to decarbonize industrial heat and achieve the target:

ELECTRIFICATION
of heating operations

INTEGRATION OF LOW-EMISSIONS HEAT SOURCES (such as geothermal energy, concentrated solar power, or nuclear energy)

INNOVATIVE
low- or no-heat process technologies