# GEO VISION

## Harnessing the Heat Beneath Our Feet

U.S. DEPARTMENT OF ENERGY

**Sunset over a U.S. Department of Energy geothermal test site (Naval Air Station Fallon in Nevada).**
*Photo credit: Dick Benoit*

# Foreword

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# Letter from the Director

The Earth beneath our feet contains vast energy potential, enough to power the global electric grid many times over. This natural geothermal heat radiating from the Earth's mantle—a byproduct of our solar system's formation billions of years ago—is virtually limitless in supply. Over the past century, geothermal researchers and operators have worked to harness this resource. Geothermal is an increasingly valuable contributor to energy diversity—and for good reason: it's an "always-on," renewable, 50-state solution that can provide flexible electricity and heating and cooling solutions to all Americans.

To grow as a national solution, geothermal must overcome significant technical and non-technical barriers in order to reduce cost and risk. The subsurface exploration required for geothermal energy is foremost among these barriers, given the expense, complexity, and risk of such activities. Early-stage research into technology improvements can help reduce development costs and improve exploration and production, all of which are essential to achieving geothermal's full potential. Realizing this potential will, in turn, drive investment in America's energy diversity. The status of geothermal energy mirrors the oil and gas industry at a time when unconventional oil and gas reserves were known, but the technology did not exist to produce them economically. Through research and collaboration, the oil and gas industry was able to tackle those barriers and attain access to previously untapped resources.

To evaluate similar opportunities for the success of geothermal energy, the U.S. Department of Energy's Geothermal Technologies Office (GTO) initiated the *GeoVision* analysis. This rigorous technical analysis evaluated future geothermal deployment opportunities based on three core objectives:

- Increased access to geothermal resources
- Reduced costs and improved economics for geothermal projects
- Improved education and outreach about geothermal energy through stakeholder collaboration.

The *GeoVision* analysis concludes that meeting all three of these objectives can result in a sizable increase in America's use of geothermal energy. Analysis results show that, with technology improvements, geothermal power generation could increase nearly 26-fold from today—representing 60 gigawatts of installed capacity by 2050. This capacity is paired with tremendous potential for using geothermal energy for heating and cooling: *GeoVision* analysis models indicate the opportunity for more than 17,500 district-heating installations as well as heating and cooling for the equivalent of more than 28 million households using geothermal heat pumps by 2050. Achieving the deployment levels in the *GeoVision* analysis can also deliver substantial value to all Americans by contributing to the long-term portfolio of affordable energy options and providing environmental benefits. Through increased geothermal deployment, America could realize a stronger geothermal energy sector, a more stable power grid, and economic and environmental benefits.

In the pages that follow, you will gain insight into more than just detailed analyses; this report shows us how to move the geothermal dial from what we know exists to what we envision is possible over the next 30 years. The *GeoVision* analysis takes us beyond a declaration of resource potential by illustrating what is real today and painting a picture of what could be real tomorrow.

How the geothermal stakeholder community chooses to impact that reality is fully in our hands. The comprehensive Roadmap presented in this report forms a call for broad stakeholder action across the geothermal community. Through collaboration, we can move toward a common goal of realizing the *GeoVision* deployment levels and the associated benefits to the nation.

The *GeoVision* report reflects a multiyear effort with contributors from industry, academia, national laboratories, and federal agencies. A total of 20 independent experts vetted each step of the analytic process, and a group of more than 40 reviewers representing the domestic and international stakeholder community appraised and commented on the report draft. All participants in this process were instrumental in documenting the state of the industry. On behalf of everyone at GTO, I offer my sincerest thanks to each of you involved in building this view into the future of geothermal energy.

Best regards,

Dr. Susan G. Hamm
Director, Geothermal Technologies Office
U.S. Department of Energy

# Introduction

Energy is the heartbeat of America. It touches nearly everything we do every day—from life at home; to work and communication; to critical infrastructure that saves lives in hospitals, strengthens our national security, and transports us to new places. Some of the most vital questions for the United States in the 21st century focus on energy, including: Where will we get our energy, and how can we build secure, reliable, and resilient systems that accommodate a changing energy mix? How do we protect U.S. energy interests and innovation while participating in a global economy? Which energy solutions ensure economic and environmental vitality today and into the future?

Geothermal energy provides an answer to many of these essential questions. The "heat beneath our feet" is an always-on source of secure, reliable, and flexible domestic energy that can be utilized across industrial, commercial, and residential sectors. The use of geothermal energy also offers important benefits to the nation, including grid stability, greater diversity in the portfolio of affordable energy options, efficient heating and cooling, and reduced air pollution.

Despite the benefits of geothermal energy and its ability to meet some of the nation's most pressing energy needs, the United States has tapped only a fraction of its abundant geothermal resources. Harnessing the full potential of U.S. geothermal resources will strengthen domestic energy security and allow the United States to continue its leadership in energy innovation.

To examine this potential for geothermal resources to play a key role in the nation's energy future, the U.S. Department of Energy (DOE) initiated the *GeoVision* analysis. The analysis is based on rigorous modeling and simulation that enabled a team of experts to assess the state of geothermal energy, quantify growth opportunities and associated impacts on the nation, and formulate actions to increase geothermal deployment.

This report, *GeoVision*: *Harnessing the Heat Beneath Our Feet,* summarizes the analyses and discusses the many opportunities that geothermal energy offers in both electric and non-electric uses. The report also highlights the outcomes the United States could realize from increased geothermal deployment and outlines a range of activities necessary to reach this deployment. The goal is to provide a glimpse into the abundant possibilities that geothermal energy has to offer the nation and to highlight some of the steps needed to increase geothermal deployment. The full body of analytical work is detailed in the *GeoVision* Analysis Supporting Task Force Reports, as listed in the references section. Not all assumptions, results, and scenarios used in the analysis are contained within this report.

The *GeoVision* report is organized as follows:

| | |
|---|---|
| **Executive Summary** | High-level summary of the *GeoVision* analysis and highlights of key findings |
| **Chapter 1: Developing the *GeoVision*** | Overview of the *GeoVision* analysis, approach, and findings |
| **Chapter 2: What is Geothermal Energy?** | Brief description of geothermal energy, including electric and non-electric applications in the United States, and barriers to growth |
| **Chapter 3: *GeoVision* Analysis: Models and Scenarios** | Summary of the *GeoVision* analysis, models, and scenarios |
| **Chapter 4: *GeoVision* Analysis: Results, Opportunities, and Impacts** | Results of the *GeoVision* analysis, including U.S. deployment potential for electric and non-electric uses of geothermal energy and discussion of the potential for geothermal energy to contribute energy diversity and environmental benefits to the nation |
| **Chapter 5: The *GeoVision* Roadmap: A Pathway Forward** | Roadmap of actions that, if taken, could support growth in the use and application of geothermal energy in the United States |
| **Appendix A** | Acronyms |
| **Appendix B** | Glossary |
| **Appendix C** | Detailed Modeling Assumptions and Results |
| **Appendix D** | Contributors |

**Geothermal drilling rig near a U.S. Department of Energy test site (Naval Air Station Fallon in Nevada).**
*Photo credit: Lauren Boyd/U.S. Department of Energy*

# Executive Summary

## Geothermal is America's untapped energy giant.

Geothermal energy is a renewable and diverse solution for the United States—providing reliable and flexible electricity generation and delivering unique technology solutions to America's heating and cooling demands. Geothermal resources can be found nationwide, are "always on," and represent vast domestic energy potential. Only a fraction of this potential has been realized due to technical and non-technical barriers that constrain industry growth.

The U.S. Department of Energy's (DOE's) Geothermal Technologies Office (GTO) engaged in a multiyear research collaboration among national laboratories, industry experts, and academia to identify a vision for growth of the domestic geothermal industry across a range of geothermal energy types. The effort assessed opportunities to expand geothermal energy deployment by improving technologies, reducing costs, and mitigating barriers. The analysis also assessed the economic benefits to the U.S. geothermal industry and the potential environmental impacts of increased deployment—including jobs, consumer energy prices, water use, and air quality—and investigated opportunities for desalination, mineral recovery, and hybridization with other energy technologies for greater efficiencies and lower costs.

The *GeoVision* analysis culminated in this report, *GeoVision*: *Harnessing the Heat Beneath Our Feet.* In addition to summarizing analytical results about geothermal energy opportunities, the report includes a Roadmap of actionable items that can achieve the outcomes of the analysis. The *GeoVision* Roadmap is a comprehensive call to action to encourage and guide stakeholders toward the shared goal of realizing the deployment levels and resulting benefits identified in the *GeoVision* analysis.

The *GeoVision* analysis demonstrates the unique characteristics of geothermal energy and its unrealized potential, including:

- Constant and secure renewable electric power generation with flexible and load-following capabilities that provide essential services contributing to grid stability and resiliency
- Nationwide energy applications through unique capabilities in electricity generation, as well as residential, commercial, and district heating and cooling
- Commercial technologies that are ready to deploy, augmented by developing technologies with vast potential for increased electricity generation and direct-use applications
- Job impacts in both the manufacturing and geothermal sectors
- Revenue potential for federal, state, and local stakeholders, as well as royalty potential for leaseholders.

The *GeoVision* analysis used a suite of modeling tools and scenarios to evaluate the performance of geothermal technologies relative to other energy technologies. The analyses included evaluating the potential role of existing and future geothermal deployment in both the electric sector and the heating and cooling sector. In the electric sector, the analysis considered existing conventional (hydrothermal) geothermal resources as well as unconventional geothermal resources,[1] such as enhanced geothermal systems, or EGS. In the heating and cooling sector, the analysis modeled geothermal heat pumps (GHPs, which are also known as ground-source heat pumps)[2] and district-heating systems (using both conventional and EGS resources).

By evaluating scenarios for increased deployment of geothermal energy, the *GeoVision* analysis provides a foundation to maintain and advance the nation's position as a leader in geothermal energy applications and technology innovation. The models used prevailing and potential future technology assumptions under existing and proposed state and federal policy scenarios. The analysis does not assume or create any previously unintroduced policies; it considers only policies that are in force or have been introduced.

The *GeoVision* analysis provides a comprehensive assessment of the state of geothermal energy and identifies deployment opportunities and pathways for targeted action that could achieve a shared vision for industry growth.

## Key findings of the *GeoVision* analysis:

**Technology improvements could reduce costs and increase geothermal electric power deployment.**
Improving the tools, technologies, and methodologies used to explore, discover, access, and manage geothermal resources would reduce costs and risks associated with geothermal developments. These reductions could increase geothermal power generation nearly 26-fold from today, representing **60 gigawatts-electric ($GW_e$)**[3] of always-on, flexible electricity-generation capacity by 2050. This capacity makes up 3.7% of total U.S. installed capacity in 2050, and it generates 8.5% of all U.S. electricity generation. Technology improvements are on the critical path toward achieving commercial EGS. This is vital because the *GeoVision* analysis demonstrates that, relative to other geothermal resources, EGS resources have the potential to provide the most growth in the electric sector. EGS can also support significant growth within the non-electric sector for district heating and other direct-use applications.

**Optimizing permitting timelines could reduce costs and facilitate geothermal project development, potentially doubling installed geothermal capacity by 2050.**
The *GeoVision* analysis included the examination of key regulatory, permitting, and land-access barriers to geothermal development. Streamlined regulations and permitting requirements can be achieved through a variety of mechanisms to shorten development timelines, which can—in turn—reduce financing costs during construction. For example, the analysis showed that placing geothermal regulatory and permitting requirements on a level similar to that of oil and gas and other energy industries could allow the geothermal industry to discover and develop additional resources and to reduce costs. The *GeoVision* analysis demonstrated that optimizing permitting alone could increase installed geothermal electricity-generation capacity to **13 $GW_e$** by 2050—more than double the 6 $GW_e$ projected in the Business-as-Usual scenario that serves as the baseline for the *GeoVision* analysis.

**Overcoming barriers to geothermal heating and cooling could stimulate market growth.**
Geothermal heating and cooling is an underutilized

1 Conventional geothermal resources refer to naturally occurring hydrothermal resources developed using existing technologies (the term "hydrothermal" refers to the combination of water [hydro] and heat [thermal]). Unconventional geothermal resources refer to a class of resources that will require the development of new and innovative technologies to enable economic resource capture. Enhanced geothermal systems, or EGS, are the most significant of the unconventional geothermal resources and are characterized by the presence of a thermal energy source in the Earth's crust that lacks the permeability and/or groundwater necessary for economic energy recovery. These resource characteristics are elaborated in Chapter 2.

2 Heat-pump technologies, which use the thermal properties of the shallow earth to provide renewable and efficient geothermal heating and cooling, are commonly referred to by two different names: geothermal heat pumps, and ground-source heat pumps. The DOE has traditionally referred to this technology and industry as "geothermal heat pumps," and the Internal Revenue Service federal statutes—as well as state renewable portfolio standards that recognize geothermal technology as eligible—have done so historically on the basis of the specific terminology, "geothermal heat pumps." The *GeoVision* analysis uses the term geothermal heat pumps, while acknowledging that some stakeholders, e.g., the International Ground Source Heat Pump Association and the European Union, have started to adopt the name "ground-source heat pumps" to describe the technology and industry.

3 $GW_e$ = gigawatts-electric, which is power available in the form of electricity—in the case of geothermal, converted from heat energy in the Earth. The *GeoVision* analysis also considers gigawatts-thermal ($GW_{th}$) for direct-use and GHP applications. $GW_{th}$ is the power available directly from heat or thermal energy. In GHP applications, $GW_{th}$ is the heating/cooling capacity of the system itself; for direct-use applications, $GW_{th}$ refers to the heating capacity that is extracted directly from the geothermal heat in the ground and delivered to the direct-use application.

resource for U.S. homes and businesses and an area of key growth potential. The GHP industry is expected to reduce energy costs to residential and commercial consumers and provide greater reliability and consistency in heating and cooling options. The existing installed capacity is about 16.8 gigawatts-thermal ($GW_{th}$) (Lund and Boyd 2016) and is equivalent to GHP installations in about 2 million households. The *GeoVision* analysis determined that the market potential[4] for GHP technologies in the residential sector is equivalent to supplying heating and cooling solutions to 28 million households, or **14 times greater** than the existing installed capacity. This potential represents about 23% of the total residential heating and cooling market share by 2050. Similarly, the economic potential for district-heating systems using existing direct-use geothermal resources combined with EGS technology advances is **more than 17,500 installations nationwide**, compared to the 21 total district-heating systems installed in the United States as of 2017 (Snyder et al. 2017). These district-heating installations could satisfy the demand of about 45 million households (EIA 2015; McCabe et al. 2019; Liu et al. 2019). Realizing direct-use, district-heating potential will require advancing EGS technology and reducing soft-cost[5] barriers.

**Geothermal energy offers economic development opportunities in both rural communities and urban centers across the United States.**
The results of the *GeoVision* analysis indicate that taking action consistent with the associated *GeoVision* Roadmap could expand the domestic geothermal industry and potentially add job opportunities in both urban and rural communities. Development of a robust residential and commercial GHP industry could also expand the U.S. geothermal workforce.[6]

**Increased geothermal deployment could improve U.S. air quality and reduce $CO_2$ emissions.**
The *GeoVision* analysis indicates opportunities for improved air quality resulting from reductions in sulfur dioxide ($SO_2$), nitrogen oxides ($NO_x$), and fine particulate matter ($PM_{2.5}$) emissions. The analysis further identifies opportunities for reduced carbon-dioxide emissions. For the electric sector, this could cumulatively result in up to 516 million metric tons (MMT) of avoided carbon-dioxide equivalent ($CO_2e$) emissions through 2050. For the heating and cooling sector, impacts through 2050 could cumulatively include up to 1,281 MMT of $CO_2e$ emissions avoided. By 2050, the combined $CO_2e$ reductions for the two sectors is equivalent to removing about 26 million cars from the road annually.

**The geothermal deployment levels calculated in the *GeoVision* analysis could be achieved without significant impacts on the nation's water resources.**
Compared to the Business-as-Usual scenario, the high levels of deployment evaluated in the *GeoVision* analysis result in a slight increase (~4%) in the amount of water consumed by the power sector in 2050. This increase in consumption can be mitigated through the use of non-freshwater resources such as municipal wastewater and brackish groundwater.

Geothermal energy is secure, reliable, flexible, and constant. It offers the United States a renewable source for power generation as well as heating and cooling of homes and businesses. Geothermal resources and technologies are primed for strong deployment growth and stand ready to provide solutions to meet America's 21st-century demands for energy security, grid stability and reliability, and domestic and commercial heating and cooling needs.

**Workers on a drilling rig at The Geysers geothermal field in California.**
*Photo credit: Robert Hopkins*

4 The market potential of a renewable resource is defined broadly as the portion of technical potential that is likely to be deployed considering the technical viability of the project and the reaction of consumers in the market to economic factors (Sigrin et al. 2016, McCabe et al. 2019). See Figure 3-1.

5 Soft costs are non-construction costs incurred before project commissioning, including (among other things): public perception/educating the public, utilities, regulators, and policymakers; risk; financing; permitting; legal fees; insurance; workforce availability and training (including installers and small drillers); political support, e.g., policies, political terms, and regional resources; power purchase agreements; and attracting large players (oil and gas companies).

6 A task force report supporting the *GeoVision* analysis assessed gross job impacts from geothermal deployment compared with business-as-usual scenarios (Millstein et al. 2019). These gross job impacts represent total jobs needed to fulfill increased geothermal deployment. Because those jobs may displace other energy-generation technologies and do not represent the net impact of geothermal jobs on employment within those other sectors, they are not discussed or quantified here. Assessing net job impacts was beyond the scope of the *GeoVision* analysis. Refer to Millstein et al. 2019 for more details about gross jobs impacts.