An Overview of the U.S. Department of Energy's *GeoVision* Report

Preprint

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An Overview of the U.S. Department of Energy's *GeoVision* Report

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Keywords

GeoVision, techno-economic analysis, market analysis, geothermal power, direct use, district heating, geothermal heat pumps, barriers, policy, regulation

ABSTRACT

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, called the *GeoVision* analysis, assessed opportunities to expand geothermal energy deployment by improving technologies, reducing costs, and mitigating barriers. The analysis also evaluated the economic and environmental impacts of such deployment—including industry growth, consumer energy prices, water use, and air emissions—and investigated opportunities for desalination, mineral recovery, and hybridization with other energy technologies for greater efficiencies and lower costs.

The *GeoVision* analysis used a suite of modeling tools and scenarios to evaluate the performance of geothermal technologies relative to other energy technologies. The assessment 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 *GeoVision* analysis considered electricity generation from existing conventional (hydrothermal) geothermal resources as well as unconventional geothermal resources, such as enhanced geothermal systems (EGS). In the heating and cooling sector, the analysis modeled geothermal heat pumps (GHPs, also called ground source heat pumps) and district-heating systems using both conventional and EGS resources.

The analysis culminated in a summary report, *GeoVision: Harnessing the Heat Beneath Our Feet* (DOE 2019), as well as eight supporting task force reports (Lowry et al. 2017, Doughty et al. 2018, Wendt et al. 2018, Augustine et al. 2019, Liu et al. 2019, McCabe et al. 2019, Millstein et al. 2019, and Young et al. 2019). Among other results, key findings of the analysis indicate that optimized permitting could potentially double geothermal capacity by 2050; technology improvements could increase geothermal power generation nearly 26-fold from today; and increased geothermal deployment can provide economic and environmental benefits to the United States. The analysis also concludes that GHPs can provide heating and cooling solutions to the equivalent of 28 million households and geothermal district-heating systems could experience exponential growth—from 21 installations today to 17,500 nationwide.

In addition to summarizing analytical results about geothermal energy opportunities, the report includes a Roadmap of actionable items on which the stakeholder community can engage to 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.

This paper provides an overview and summary of the *GeoVision* report, using results, texts and figures from the report itself. Readers are encouraged to read the full report, which can be found at www.energy.gov/geovision.

1. Overview

The *GeoVision* analysis assessed the domestic geothermal industry across numerous resource types and technology applications, within the context of technical and non-technical barriers and improvements as well as economic and environmental impacts to the nation. The analysis quantified geothermal deployment that could be achievable under a range of potential scenarios and assessed economic and environmental impacts resulting from increased geothermal energy on the U.S. grid and in U.S. homes and businesses. The *GeoVision* analysis examined electricity generation as well as heating and cooling applications and evaluated the impact of additional value streams that could balance the costs of developing a geothermal resource. The results of the *GeoVision* analysis confirm the potential for geothermal to contribute to the portfolio of affordable energy options and be an essential part of the nation's critical energy infrastructure.

Several aspects of geothermal make it unique among energy resources. Geothermal energy resources are available in vast quantities—on a nationwide geographic scale—and can be used in a range of applications, including electric power generation, heating and cooling of homes and businesses, and industrial and agricultural processes. Geothermal energy can provide flexibility to the grid through ancillary services that help respond to changes in electrical load and support reliable grid operation. As an onsite subsurface resource with around-the-clock availability, geothermal energy offers increased energy security compared to other generation technologies.

The geothermal industry has long been aware of the benefits of and challenges to increased geothermal deployment—that is, sourcing more of the nation's energy needs from geothermal resources. However, until the landmark effort of the *GeoVision* analysis, geothermal deployment potential had never been quantified at a national scale or across a broad range of technology applications. The *GeoVision* analysis achieves these objectives, with the results providing a case for the potentially sizable role that geothermal resources could play in meeting the nation's 21st-century energy demands.

The *GeoVision* analysis mirrors much of the methodology and reporting methods used in the Department of Energy's (DOE's) *SunShot Vision Study* (DOE 2012), *Wind Vision* (DOE 2015), and *Hydropower Vision* (DOE 2016). The *GeoVision* analysis included the state of the art in conventional geothermal electricity generation and geothermal heating and cooling applications. The analysis considered resources and technologies under development, including enhanced geothermal systems (EGS), low-temperature and sedimentary geothermal resources, and hybridized geothermal applications, and others.

The *GeoVision* analysis followed a "bottom-up" approach, which considered a fundamental question about the levels of deployment possible under varied scenarios:

"On the basis of detailed assessments of the geothermal industry, barriers to deployment, and both existing and improved technologies, what level of deployment would be achievable and what would be the corresponding economic benefits to the industry and the environmental impacts of those deployment levels on the United States?"

To address this question, DOE's Geothermal Technologies Office (GTO) led an analysis of geothermal energy growth scenarios through 2050. The analysis aimed to execute five key activities (Richard et al. 2016), including using robust data and analysis to define and evaluate geothermal growth scenarios through 2050 and producing an inspiring but achievable vision for domestic geothermal industry growth.

2. *GeoVision* Analysis Approach

The *GeoVision* analysis relied on the collection, modeling, and analysis of robust datasets through DOE national laboratory partners. The analysis was executed as a broad collaborative effort. A total of 20 industry peers (known as "Visionaries") vetted the analytical process, and the report was reviewed by more than 40 experts from federal, state, and tribal government agencies, as well as geothermal companies, environmental organizations, academic institutions, electric power system operators, research institutions, and other non-governmental stakeholder groups. Engaging a broad range of stakeholders ensured objectivity and transparency. The more than 115 participants in the *GeoVision* analysis were instrumental in documenting the state of the industry and identifying future opportunities for growth, as well as pinpointing challenges that need to be addressed so that the geothermal industry can continue to evolve and contribute value to the nation.

DOE's GTO provided a governance and leadership role for the *GeoVision* analysis by guiding the formation of the *GeoVision* objectives, integrating the technical task force work products, and leading the external and interagency review process. Technical task forces of national laboratory partners worked with GTO task management to produce the foundational work products that are the basis of the *GeoVision* analysis.

The *GeoVision* analysis aimed to identify potential actionable pathways for expanding the use of geothermal technologies as cost-effective, reliable, and flexible contributors to a diverse, domestic energy portfolio. Achieving this goal can help increase the nation's economic development, energy security, and effective use of infrastructure and resources. The *GeoVision* analysis included development of actions that comprise a technical and institutional Roadmap (DOE 2019; Hamm et al. 2019). The Roadmap forms the basis of a broad call to action to engage stakeholders toward realizing geothermal deployment levels identified in the *GeoVision* analysis and the potential resulting benefits to the nation.

3. Objectives of the *GeoVision* Analysis

As noted, DOE conducted the *GeoVision* analysis to assess the potential for increased geothermal deployment under varying technology and market scenarios. The goal of the *GeoVision* analysis is to enable stakeholders to harness the potential of geothermal energy and, ultimately, increase value for the nation. This value can be realized through domestic energy affordability and security, a more competitive geothermal industry, manufacturing opportunities, energy diversity, enhanced grid stability, and environmental benefits.

The *GeoVision* analysis included acknowledging that future deployment requires identifying and better managing risks and costs associated with geothermal development. The analysis was founded on three overarching objectives essential to reducing risks and cost in order to create opportunities for geothermal energy. Each objective includes multiple facets to be addressed to facilitate the growth potential identified by the *GeoVision* analysis.

The first key objective on which the *GeoVision* analysis is based is **increasing access to geothermal resources**. The *GeoVision* analysis assessed three types of geothermal resources: hydrothermal, EGS, and geothermal heat pumps. The ability to locate, characterize, and access these resources is fundamental to geothermal development. Geothermal resources are situated at varying depths and locations, so different technologies are used to access each type. Some of these technologies are existing and proven, whereas others are new or evolving. Because of differences in technology maturity, geothermal resource classes vary in degrees of risk and types of barriers. The *GeoVision* analysis considered opportunities that might be realized if geothermal stakeholders can overcome risks and barriers, thus enabling easier and more cost-effective resource access.

The second key objective is **reducing costs and improving economics for geothermal projects**. Geothermal projects are often characterized by high upfront costs and long development timelines that lead to protracted investment payback periods relative to many other utility-scale power generation projects. These factors create risk for developers, tying up capital for long periods of time and making it difficult to obtain cost-effective financing. Risks can be even higher for projects that require unproven technologies to harness the geothermal resource and turn it into useful energy. Lowering development costs and improving overall project economics can reduce developer risk and improve the value of geothermal projects for financiers.

The third key objective is **improving education and outreach about geothermal energy**. Unlike the sun or the wind, geothermal energy resources are located underground and are not commonly visible or tangible. Geothermal energy infrastructure also tends to have a lower profile and smaller footprint than other energy-generation facilities. Given these attributes, geothermal energy is not generally understood or appreciated by the public in the same way as other renewable energy resources such as solar and wind. Stakeholders can collaborate to create effective and accessible educational tools that help increase acceptance and interest—in turn, potentially influencing financing options, land access, and other aspects of geothermal development.

The foundational objectives of the *GeoVision* analysis are closely intertwined. Activities under each objective can occur simultaneously and will influence the other objectives; for example, reducing costs and improving education (second and third objectives) can help improve access to geothermal resources (first objective). Achieving the foundational objectives can reduce risk and costs for geothermal developers, increase growth potential for geothermal energy, and ultimately provide the United States with secure, flexible energy that offers economic and environmental benefits nationwide.

4. Key Findings of the *GeoVision* Analysis

The inputs, assumptions, analysis, and modeling methodologies, results, and impacts are summarized in *GeoVision: Harnessing the Heat Beneath Our Feet* (DOE 2019) and are detailed in the supporting task force reports. Key findings of the *GeoVision* analysis include the following:

- **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 the 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)** 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.

- **Optimized 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.

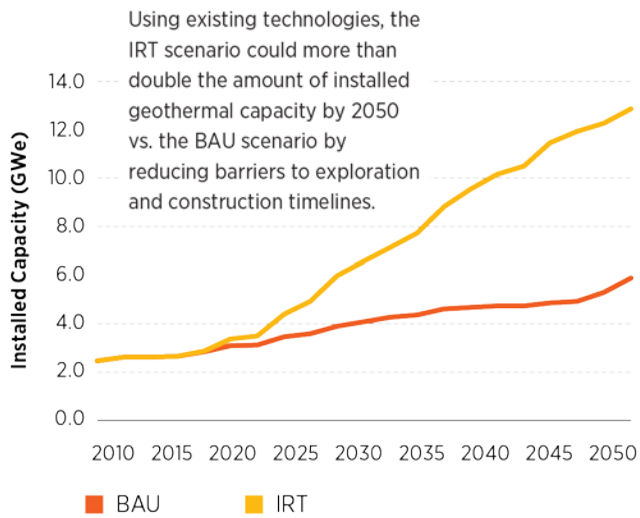

Figure 1: The *GeoVision* analysis Improved Regulatory Timeline (IRT) scenario could more than double installed geothermal capacity beyond the Business-as-Usual (BAU) scenario by 2050

- **Overcoming barriers to geothermal heating and cooling could stimulate market growth.** Geothermal heating and cooling is an underutilized resource for U.S. homes and businesses and an area of key growth potential. The geothermal heat-pump (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 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 installations installed across the country (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 barriers.

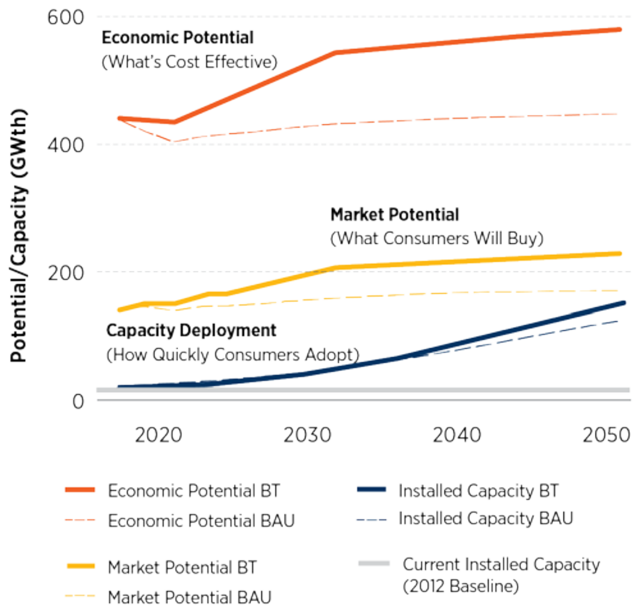

Figure 2: Economic and market potential for geothermal heat pumps under the *GeoVision* analysis Breakthrough (BT) and Business-as-Usual (BAU) scenarios

- **Geothermal energy offers economic development opportunities in both rural 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 rural and urban communities. Development of a robust residential and commercial GHP industry could also expand the U.S. geothermal workforce.

- **Realizing levels of geothermal deployment calculated in the *GeoVision* analysis could improve U.S. air quality and reduce carbon-dioxide (CO_2) emissions.** The *GeoVision* analysis indicates opportunities for improved air quality resulting from reductions in sulfur dioxide, nitrogen oxides, and fine particulate matter emissions. The analysis further identifies opportunities for reduced CO_2 emissions. For the electric sector, this could cumulatively result in up to 516 million metric tons 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 million metric tons 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.

- **Realizing the levels of geothermal deployment 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.

5. Risks, Costs, and the *GeoVision* Analysis

As discussed in Section 3, each of the three key objectives underlying the *GeoVision* analysis includes multiple concepts and activities that must be addressed to realize levels of deployment identified by the *GeoVision* analysis. At the center of all three objectives are varying types and levels of risk management and cost reduction, both of which are pivotal to increasing opportunities for geothermal energy. This section hones in on a few key barriers to geothermal growth, particularly as they relate to risk and cost in geothermal development.

5.1 Financing and Costs

In the electric sector, geothermal power projects have higher capital and financing costs than most other energy projects (Cole et al. 2016, Mendelsohn and Hubbell 2012, Wall et al. 2017).

Challenges arise from the risk and cost of characterizing and quantifying subsurface resources, coupled with long construction timelines and financing terms that delay investment payback. Financing becomes available at lower interest rates in the later drilling and construction phases of a project, after test drilling and resource confirmation are completed (Glacier Partners 2009; Wall et al. 2017; Doughty et al. 2018). Project risk decreases as production drilling ensues and the resource is proven to have commercial potential.

5.2 Industry Size and Technology Maturity

The risks and challenges encountered while drilling deep, high-temperature geothermal wells are broadly similar to those in the oil and gas industry, although the industries are vastly different in scale. Approaches similar to those used in oil and gas can be employed in geothermal to manage drilling risks and costs, but the comparatively small size of the geothermal industry presents challenges in gaining sufficient momentum to achieve comparable results. Developing new technologies and business practices will also be necessary for the geothermal industry to manage risks unique to geothermal resources (Doughty et al. 2018, Lowry et al. 2017).

5.3 Development Timelines

The geothermal industry faces risks related to long development timelines (typically 7–10 years) that delay payback on initial investments and increase project financing costs. The *GeoVision* analysis evaluated scenarios to reduce geothermal development timelines and financing costs, such as streamlining regulatory processes (Young et al. 2019).

5.4 Induced Seismicity

One notable challenge for the geothermal industry is the perceived risk of induced seismicity. Movement of fluids into or out of any well (e.g., water, oil and gas, geothermal) can induce or trigger some level of seismic or microseismic activity. The extent and magnitude of that activity and its proximity to property and people determines the level of potential risk. Injection of fluids under high pressures and into critically stressed rock generally results in the greatest amount of seismic or microseismic activity. High-pressure injection is uncommon in conventional geothermal energy extraction and the risks to people and property are correspondingly small. However, higher-pressure stimulation technologies may ultimately be required to achieve economic deployment of EGS, potentially elevating the risks of induced seismicity. DOE developed a mitigation protocol (Majer et al. 2012) to address induced seismicity from EGS.

6. Conclusions

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. By evaluating scenarios for increased deployment of geothermal energy, the *GeoVision* analysis provides a foundation to maintain and advance the nation as a leader in geothermal energy applications and technology innovation.

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