CHAPTER ONE

Developing the *GeoVision*

View inside a condenser at a geothermal combined heat and power plant.
Photo credit: Viktor Hava

1 Developing the *GeoVision*

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 benefits to the geothermal industry and environmental impacts to the nation. The analysis quantified geothermal deployment that could be achievable under a range of potential scenarios and assessed economic benefits to the geothermal industry 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 help balance the costs of developing a geothermal resource. The results of the *GeoVision* analysis confirm the potential for geothermal to 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 and heating and cooling of homes and businesses. 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 addresses gaps in understanding of the potential of geothermal resources and provides a case for geothermal energy to have a sizable role in meeting the nation's 21st-century energy demands. The results of the *GeoVision* analysis confirm the opportunities for geothermal to be an essential part of the U.S. energy infrastructure.

The *GeoVision* analysis mirrors much of the methodology and reporting methods used in the U.S. Department of Energy's (DOE's) *SunShot Vision Study* (DOE 2012), *Wind Vision* (DOE 2015), and *Hydropower Vision* (DOE 2016a).[7] 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, hybridized geothermal applications, and others.

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

7 DOE's *Vision* studies for solar energy, wind energy, and hydropower can be found at the following respective URLs: *SunShot Vision Study* (https://energy.gov/eere/solar/sunshot-vision-study); *Wind Vision* (https://energy.gov/eere/wind/wind-vision); and *Hydropower Vision* (https://energy.gov/eere/water/articles/hydropower-vision-new-chapter-america-s-1st-renewable-electricity-source).

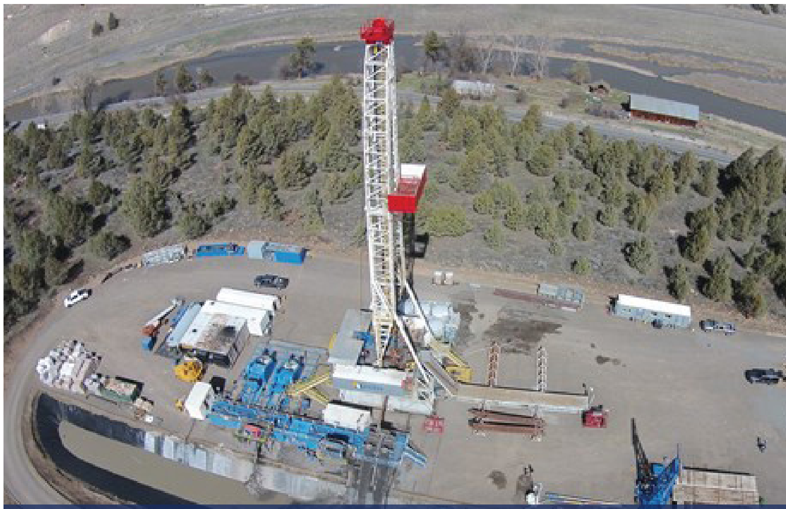
"On the basis of detailed assessments of the geothermal industry, barriers to deployment, and both existing and improved technologies, what level of deployment would be achievable and what would be the corresponding economic benefits to the industry and the environmental impacts of those deployment levels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

To address this question, the 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):

1. Define and evaluate geothermal growth scenarios through 2050, backed by robust data, modeling, and analysis
2. Address all major geothermal resource and market segments, i.e., existing and potential hydrothermal and EGS resources, electric and non-electric technology applications, and other additive value streams
3. Execute an objective and transparent process, supported by peer-reviewed industry data that are made available to decision makers
4. Produce a vision for domestic geothermal industry growth that is aspirational, motivating, and achievable
5. Articulate strategies for growth and identify paths by which the industry and its stakeholders may achieve the results identified in the *GeoVision* analysis.

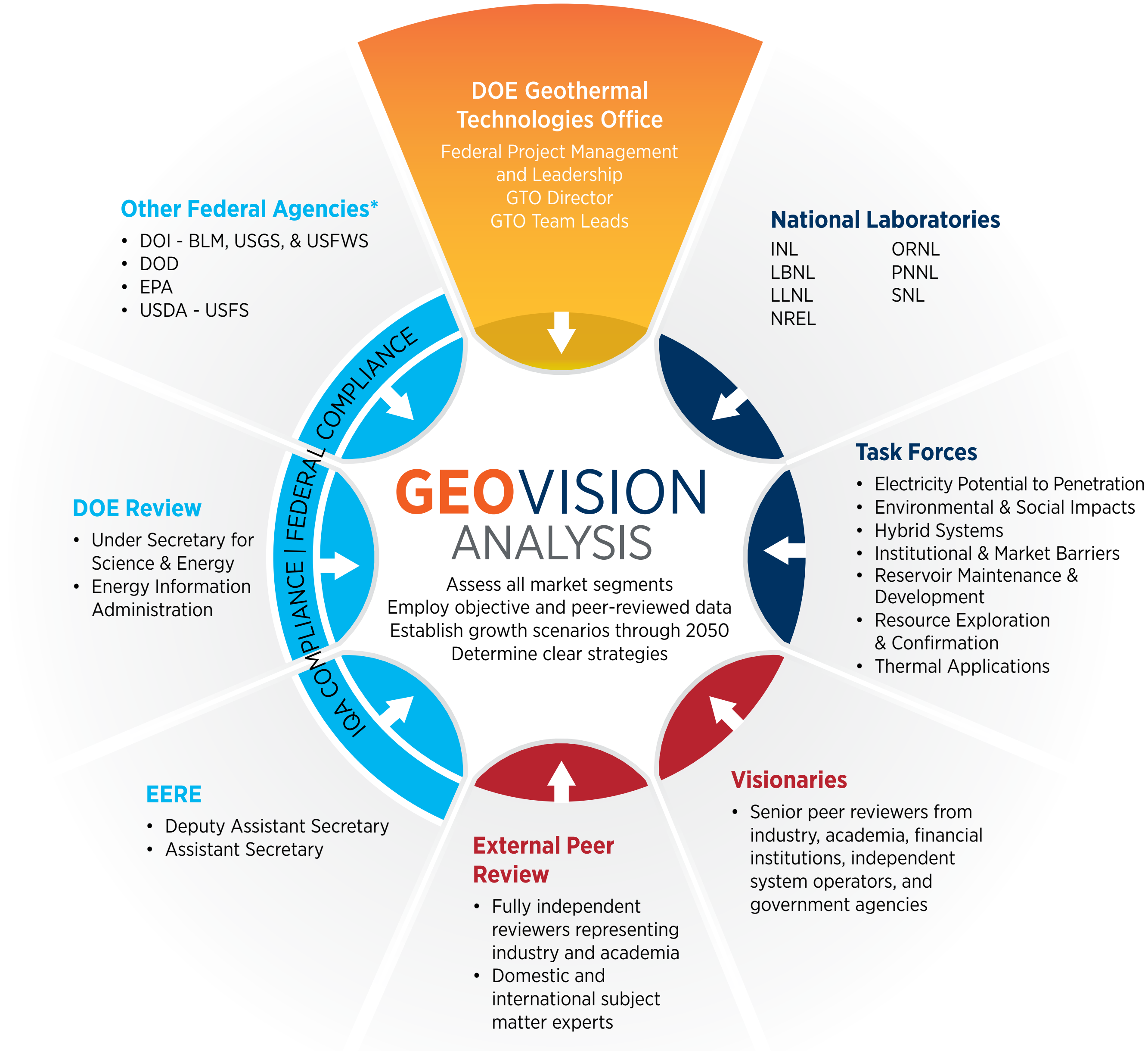
1.1 *GeoVision* Analysis Approach

The *GeoVision* analysis relied on the collection, modeling, and assessment of robust datasets through DOE national laboratory partners. The analysis was executed as a broad collaborative effort, following a process that included 20 industry peers (known as "Visionaries") and a diverse group of more than 40 expert reviewers 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 (Appendix D). Engaging a broad range of stakeholders ensured objectivity and transparency.[8] Collectively, 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. The framework for the *GeoVision* analysis and associated collaborative effort is illustrated in Figure 1-1, including compliance with guidance issued by the Office of Management and Budget as authorized by the Information Quality Act, or IQA.



Aerial drone view of geothermal drilling operations near Klamath Falls, Oregon. *Photo credit: Kevin P. Graham*

8 The Office of Management and Budget's "Final Information Quality Bulletin" provides guidelines for properly managing peer review at federal agencies in compliance with Section 515(a) of the Information Quality Act (Pub. L. No. 106-554). GTO followed these guidelines in conducting the *GeoVision* analysis.



*Other Federal Agencies: Department of Interior, Bureau of Land Management, United States Geological Survey, United States Fish and Wildlife Service, Department of Defense, Environmental Protection Agency, United States Department of Agriculture, and United States Forest Service

Note: National laboratories are defined in Appendix A.

Figure 1-1. Framework of the interaction of parties involved in the formation and execution of the *GeoVision* analysis

Figure Note: DOE's GTO provided a governance and leadership role for the GeoVision *analysis by integrating the technical task force work products, guiding the formation of the* GeoVision *objectives, 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. This work was iteratively and transparently reviewed by a group of industry peers ("Visionaries"), as well as by a diverse group of expert external reviewers from federal, state, and tribal government agencies, and by geothermal companies, environmental organizations, academic institutions, electric power system operators, research institutions, and other non-governmental stakeholder groups.*

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 expand the domestic geothermal industry and increase the nation's energy security through greater energy resource diversification. The *GeoVision* analysis was built on a structural framework of overarching objectives (Section 1.2). This framework facilitates the definition of action and sub-action areas that comprise a technical and institutional Roadmap (Chapter 5) designed to achieve the outcomes of the *GeoVision* analysis. 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.

1.2 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 reduced water withdrawals and air emissions.

The *GeoVision* analysis was founded on the knowledge that increased geothermal deployment requires identifying and better managing risks and costs associated with development. As such, the analysis was based on three overarching objectives essential to reducing risks and costs. Addressing the aspects within each objective can 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 (Section 2.1): hydrothermal, EGS (unconventional), 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 *GeoVision* analysis identifies opportunities to expand the use of geothermal technologies as cost-effective, reliable, and flexible contributors to a diverse U.S. energy portfolio, thus helping to expand the domestic geothermal industry and increase energy security through greater energy resource diversification.

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.

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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 benefits to the geothermal industry and environmental benefits nationwide.

A stationary blade casing for a geothermal steam turbine.
Photo credit: Sarah Pistone

1.3 Risk, Costs, and the *GeoVision* Analysis

As noted in Section 1.2, risk management and cost reduction are pivotal to increasing opportunities for geothermal energy. As discussed, each of the key objectives underlying the *GeoVision* analysis includes multiple concepts and activities that must be addressed to realize levels of deployment identified by the analysis. This section hones in on a few key barriers to geothermal growth, particularly as they relate to risk and cost in geothermal development.

Financing and Costs

In the electric sector, geothermal power projects have higher capital and financing costs than many other energy projects. Conventional geothermal developments have capital costs of about \$3,000 to \$6,000 per kilowatt-electric (kW_e), as compared to land-based wind or utility-scale solar photovoltaic capital costs, which are \$1,700 to \$2,100/kW_e (Cole et al. 2016).[9] Additionally, finance data show that investors require a higher expected investment return for geothermal projects compared to other renewable power projects (Mendelsohn and Hubbell 2012), translating to higher financing costs (Wall et al. 2017). Reducing both capital and financing costs can help make geothermal power generation more competitive.

Financing disparities overlap the three key objectives of the *GeoVision* analysis. 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. In the test-drilling stage of a geothermal project, resource-confirmation activities and financing tend to carry high risk and high cost; at this stage, developers (and, hence, financiers) cannot be certain that a geothermal resource will provide a return on investment. Risks and costs vary for different types of geothermal resources, generally increasing with depth and temperature. Resource-confirmation activities also carry non-technical risks, such as uncertainties associated with project permitting

9 Capital costs vary by resource grade and power-plant configuration. Conventional geothermal power-plant developments consider hydrothermal flash and binary power plants, which have capital expenditures, or CAPEX, of \$5,049 and \$6,042/kW_e, respectively. Land-based wind developments have CAPEX ranging from \$1,737 to \$2,109/kW_e for resource grades from techno-resource group (TRG) 1 to TRG 10, respectively. Utility-scale solar photovoltaic CAPEX is \$2,024/kW_e. All data are from the 2016 Annual Technology Baseline (National Renewable Energy Laboratory 2016).

or land access. Financing becomes available at lower interest rates in the later drilling and construction phases of the project (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.

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.[10] Oil and gas companies are accustomed to subsurface and drilling risks, and, as such, know how to manage and reduce them. Oil and gas companies also tend to be well-capitalized and have successfully leveraged new technologies and improved business standards to minimize resource risks and costs (Text Box 1-1). In the geothermal industry, drilling risks and costs can be managed through similar approaches, but the comparatively small size of the industry presents challenges in gaining sufficient momentum to achieve similar results. Developing new technologies and business practices will also be necessary for the geothermal industry to manage risks unique to geothermal resources. Analysis related to drilling risks, technologies, and improvements for geothermal exploration and project development is available in Doughty et al. 2018 and Lowry et al. 2017. Addressing challenges related to drilling and other technologies is an important facet of the first two objectives of the *GeoVision* analysis.

Development Timelines

As noted in the second objective for the *GeoVision* analysis, 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 potential scenarios for shortened development timeframes for geothermal electric projects. These scenarios include the effects of streamlined regulatory processes that would allow for faster and less costly drilling and testing of resource-confirmation wells (Young et al. 2019).[11] Such improvements could help reduce financing costs and improve project economics (second objective). In the geothermal district heating and GHP markets, risks are more closely related to lengthy payback periods; a lack of viable project financing models; and a lack of consumer education, awareness, and outreach (third objective).

Travertine deposits from an active geothermal hot spring forming a natural dam across the Jemez River in New Mexico.
Photo credit: James Lovekin

10 In 2016, oil and gas operators in the United States—supported by a $48 billion oil field service industry—were estimated to have collectively drilled 151,481,900 feet in as many as 14,632 wells (WorldOil 2017, Grand View Research 2018). Accurate data on total annual domestic geothermal wells drilled are unavailable. However, by comparison to oil and gas, the relatively small size of the geothermal industry is illustrated by comparing the 860 total geothermal wells in the state of California (which has the world's largest installed capacity of geothermal power generation) to the 892 oil and gas wells drilled in California in 2017 alone (WorldOil 2017, State of California 2018).

11 The *GeoVision* analysis considered multiple pathways for streamlined permitting and regulations. These pathways, which are summarized in Section 2.4 and elaborated in Young et al. 2019, include timeline reductions resulting from potential geothermal categorical exclusions. A categorical exclusion is "a category of actions which do not individually or cumulatively have a significant effect on the human environment and which have been found to have no such effect in procedure adopted by a Federal agency in implementation of these regulations (§ 1507.3) and for which, therefore, neither an environmental assessment nor an environmental impact statement is required" (40 CFR 1508.4). In the *GeoVision* analysis, the Improved Regulatory Timeline scenario assumed shortened development timelines. Potential regulatory-related scenarios for such timeframes include centralized permitting offices and a categorical exclusion that would allow drilling and testing of confirmation wells— consistent with the general parameters established for oil and gas in section 390 of the Energy Policy Act of 2005 (EPAct 2005) and as proposed for the geothermal industry in section 3012 of S. 1460, the Energy and Natural Resources Act of 2017 (115th Congress)—to prove out a reservoir and allow for project financing for the remainder of the project. Exploring the details of such a categorical exclusion was outside of the scope of the *GeoVision* analysis. The Bureau of Land Management completed in a study in 2018 exploring this concept in more detail.

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[12] 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. The United States has demonstrated leadership in this area with a DOE-developed mitigation protocol to address induced seismicity from EGS.[13] The geothermal industry will need to continue to proactively manage and reduce induced seismicity risks effectively and help the public discern between real and perceived risks. These goals can be achieved through ongoing communication with stakeholders (third objective) as well as through new and improved technologies that provide developers with greater understanding and control of potential induced seismicity. This topic is discussed in more detail in Doughty et al. 2018, and the *GeoVision* Roadmap includes potential actions to enhance understanding and management of induced seismicity in geothermal development.

Text Box 1-1. Technology Transfer between the Geothermal and Oil and Gas Industries Can Reduce Cost and Risk

The geothermal industry and the oil and gas industry use similar steps and technologies to locate and drill resources that are then used to produce energy. The resource characteristics, however, can differ substantially; for instance, oil and gas reservoirs tend to be under higher pressures than geothermal reservoirs, but at significantly cooler temperatures. Augustine 2016 provides an illustrative comparison of the differences in some key technical parameters between geothermal and oil and gas resources.

The geothermal industry is also smaller than the oil and gas industry in terms of both existing market value and number of industry participants. Despite these differences in resource environment and market size, the technology and intellectual capital transfer between the two can be bidirectional. Numerous advancements in geothermal technologies have been supported by adapting oil and gas technologies to conditions beyond their original technical limits. Likewise, the oil and gas industry has benefited from adapting technologies originally intended for use in geothermal energy.

The most notable example of geothermal technology transfer to the oil and gas industry is the research, development, and commercialization of polycrystalline diamond compact drill bits, led and supported by DOE for the geothermal industry. This innovation ultimately catalyzed the growth of a $1.9 billion industry and resulted in cost savings for the oil and gas industry. As of 2006, polycrystalline diamond compact drill bits were used to drill roughly 60% of global footage (DOE GTO Multi-Year Research, Development, and Demonstration Plan 2008, Gallaher et al. 2010). By 2015, that number had increased to 90% of global footage (Scott and Hughes 2015). The use of these drill bits in offshore applications in the oil and gas industry has been estimated to reduce costs by $58.54 per foot drilled, yielding cost savings of $15.6 billion from 1982 to 2008 (DOE GTO Multi-Year Research, Development, and Demonstration Plan 2008, Gallaher et al. 2010).

12 "High pressures" is defined as those approaching lithostatic pressures, which are confining pressures or the pressures exerted on a layer of rock by the weight of the overlying material.

13 DOE's Geothermal Technologies Office developed the "Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems" as a 7-step process for addressing induced seismicity concerns (Majer et al. 2012).