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Enhanced Geothermal Systems: Introduction and Issues for Congress

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SUMMARY

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Geothermal power is a type of energy generation technology the United States can use to help meet its future energy needs. U.S. energy use is growing, end uses are changing, and the power grid is being modernized and transformed to supply power to address these changing uses and to improve reliability and resilience. Geothermal power can support these changes and can also contribute to national emission reduction goals and other national challenges such as water use.

Of the different types of geothermal technologies available, enhanced geothermal systems (EGS) are the utility-scale generation technology that has the greatest potential to contribute significantly to U.S. energy needs—both in terms of total energy resources and their widespread availability. The U.S. Department of Energy (DOE) estimates total domestic EGS resources are 5,157 gigawatts (GW) of electrical capacity (450% of current U.S. electrical generation capacity) and 15 billion gigawatt-hours (GWh) of thermal power available annually for direct use. Up to 60 GW of this electrical capacity could be commercially available and in production by 2050 (providing up to 8.5% of U.S. electricity generation capacity) based on DOE's projections of technical and non-technical improvements to EGS and related processes. EGS resources are viable in most, if not all, states.

EGS offer a number of potential benefits as a power generation technology. EGS provide consistent, always-on, baseload power. They are also flexible because they can be started and stopped in response to energy demand. They generate few emissions and since they don't require fuel to be shipped to or stored at the plant, there are no fuel safety or security concerns. Without input fuels, EGS is also not sensitive to fuel price fluctuations. EGS are potentially widely available domestically. They also have relatively low water demands compared with other thermal power technologies like natural gas and coal because EGS plants are often binary, air-cooled plants and can use lower-quality water for stimulation and operations activities. EGS also have the potential for coproduction with other power sources, improving the productivity of both sources, and they can be hybridized with other opportunities like hydrogen production or valuable mineral recovery.

EGS face a number of technology development and deployment challenges. EGS technology has relatively high capital costs with a large portion of those costs coming from resource exploration and drilling activities because geothermal resources are subsurface resources and can be hard to confirm and access. The exploration and well drilling activities also require significant regulatory oversight because of the potential for environmental or human impacts. The multiple environmental reviews and the time and costs for them as well as the overall leasing and permitting processes result in development timelines longer than many other power production projects. These longer timelines also contribute to higher costs. Depending on the location of the geothermal resources, the relevant regulations, ownership rights, and permitting processes are defined by federal, state, and/or local laws and will require coordination to develop and implement best practices to enable and support consistent deployment of EGS nationwide.

Additionally, EGS face unique technical challenges due to hard rock conditions, deep drilling distances, and other challenging operational conditions including high temperatures, high pressures, and reactive geochemistry. Additional challenges include concerns about induced seismicity and other environmental issues like emissions, water withdrawals, or impacts on local groundwater. Because EGS technology is relatively new and faces these challenges, commercial implementation is currently limited.

Historically, Congress has considered bills and established laws addressing accessing, leasing, and regulating geothermal resources. A number of areas could be considered for new legislation: for instance, Congress could consider

- revising federal tax incentives to encourage additional development and deployment of EGS;
- improving the coordination of governmental and non-governmental entities on state and federal energy standards, state and federal resource access rights, and research, development, and deployment (RD&D) partnership activities;
- modifying federal leasing and permitting processes to expedite assessment of environmental impacts and to shorten project development timelines;
- supporting technology and workforce transition from and coordinating with the fossil fuel energy subsector;
- enhancing or coordinating support for geothermal projects with other federal environmental or climate research, activities, and goals; and
- changing or expanding federal support of RD&D efforts within federal agencies and through federal programs.

Contents

Figures

Tables

Contacts

Introduction

Geothermal energy—natural heat from deep in the earth—has long been pursued as a source of renewable energy but in the United States has been geographically limited to certain areas in western states.[1] Recent developments in enhanced geothermal systems (EGS) have increased the potential for geothermal power to supply more electricity and in a larger area of the United States.[2] EGS involve drilling multiple injection and production wells and running pipelines to each well. Geothermal fluid[3] is injected into the subsurface to create or widen existing fractures or cracks in the bedrock to allow greater access to geothermal heat at depth—a process called stimulation.[4] The injected geothermal fluid is heated by contact with the bedrock and extracted via the production wells. This hot, extracted fluid can then be used directly for heating or to generate steam to drive turbines to produce electricity. After use, the now-cooled and condensed geothermal fluid is reinjected into the ground—with the goal of maintaining fluid levels and geochemistry in the reservoir—where it can absorb more heat from the reservoir. The extraction/reinjection cycle helps sustain heat extraction from the reservoir and electricity generation in the plant.[5]

While geothermal energy currently produces only 0.4% of U.S. electricity,[6] the United States produces the largest amount of geothermal electricity worldwide[7] and the U.S. Department of

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[1] The United States had 3,722 megawatts (MW) of geothermal power capacity at the end of 2021, out of a worldwide total of 15,854 MW. The majority of traditional geothermal resources are hydrothermal resources located at the boundaries between the Earth's tectonic plates. Alexander Richter, "ThinkGeoEnergy's Top 10 Geothermal Countries 2021—Installed Power Generation Capacity (MWe)," ThinkGeoEnergy.com, January 10, 2021, https://www.thinkgeoenergy.com/thinkgeoenergys-top-10-geothermal-countries-2021-installed-power-generation-capacity-mwe/; Energy Information Agency, "Geothermal Explained: Where Geothermal Energy Is Found," February 15, 2022, https://www.eia.gov/energyexplained/geothermal/where-geothermal-energy-is-found.php.

[2] See U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "How an Enhanced Geothermal System Works," September 9, 2022, https://www.energy.gov/eere/geothermal/how-enhanced-geothermal-system-works.

[3] A geothermal fluid is typically a mixture of water and other constituents either located in a geological reservoir or man-made, which is circulated through a reservoir and heated by the earth. It can be extracted for a variety of power generation, heating, or other applications before being returned to the reservoir. Supercritical CO_2 is also being explored as a potential fluid for use in reservoirs with the appropriate characteristics. Y. Sakai, "Advanced Geothermal Steam Turbines," in *Advances in Steam Turbines for Modern Power Plants* (Kawasaki, Japan: Fuji Electric Co., 2016), https://www.sciencedirect.com/science/article/pii/B9780081003145000191; Yu Wu and Pan Li, "The Potential of Coupled Carbon Storage and Geothermal Extraction in a CO2-Enhanced Geothermal System: A Review," *Geothermal Energy*, vol. 8, no. 19 (2020), https://geothermal-energy-journal.springeropen.com/articles/10.1186/s40517-020-00173-w.

[4] Stimulation for EGS is similar to hydraulic fracturing—fracking—used in extracting fossil fuels, though there are notable differences in implementation and effects. For more details, see "Enhanced Geothermal Systems" and "Induced Seismicity."

[5] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "How an Enhanced Geothermal System Works," September 9, 2022, https://www.energy.gov/eere/geothermal/how-enhanced-geothermal-system-works.

[6] Energy Information Administration, *Monthly Energy Review: May 2022*, 2022, https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf.

[7] Alexander Richter, "ThinkGeoEnergy's Top 10 Geothermal Countries 2021—Installed Power Generation Capacity (MWe)," ThinkGeoEnergy.com, January 10, 22021, https://www.thinkgeoenergy.com/thinkgeoenergys-top-10-geothermal-countries-2021-installed-power-generation-capacity-mwe/; Gerald Huttrer, "Geothermal Power Generation in the World 2015-2020 Update Report," Proceedings World Geothermal Congress 2020+1, April-October 2021, https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01017.pdf.

Energy (DOE) projects that EGS could provide 60 gigawatts (GW) of electricity by 2050 (8.5% of U.S. generation capacity).[8]

EGS leverage the technology developments that have expanded U.S. fossil energy production particularly of shale oil and natural gas. The oil and gas (O&G) industry has a history of boom and bust cycles,[9] and the energy sector and energy markets are transitioning away from some fossil fuels and toward low-carbon energy sources.[10] If these two trends continue, expanded development of EGS could use many of the technologies, equipment, tools, and infrastructure the fossil fuel industry has already developed or is developing (e.g., well drilling equipment, support equipment like down-well sensors, installation and stimulation technology, power plant systems, pipelines, old wells, well right-of-ways, and offshore drilling platforms),[11] while also potentially leveraging the knowledgeable and experienced workforce from the legacy fossil energy subsectors.[12] With some retraining or refocusing, EGS industry could use workers with experience in areas such as underground resource identification, well drilling and completion, infrastructure installation, and power plant operation.

Technical and non-technical obstacles to greater EGS deployment remain. These include difficulties in confirming geothermal resources (e.g., time and costs for drilling exploration wells), challenges in reservoir[13] management, and considerations for environmental impacts like induced seismicity,[14] water needs, and waste management. There are also non-technical challenges like changing tax incentive structures, permitting barriers, and other regulatory requirements that may result in longer project development timelines and higher costs.

The opportunities for and challenges facing EGS are of interest to Congress. The 117th Congress enacted two pieces of legislation that address some of these issues. The Infrastructure Investment and Jobs Act (IIJA; P.L. 117-58) became law in November 2021 and appropriated funds for additional geothermal energy demonstration projects. The Infrastructure Reduction Act (P.L. 117-

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[8] For more details, see U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf.

[9] Colorado School of Mines, "Boom and Bust: A Cycle Familiar to the Oil and Gas Industry," 2022, https://gradprograms.mines.edu/blog/boom-and-bust-a-cycle-familiar-to-the-oil-and-gas-industry/.

[10] S&P Global, "What Is Energy Transition?" February 24, 2020, https://www.spglobal.com/en/research-insights/articles/what-is-energy-transition.

[11] Emily J. Smejkal et al., "The Feasibility of Repurposing Oil and Gas Wells for Geothermal Applications," GeoConvention, June 20-22, 2022, https://geoconvention.com/wp-content/uploads/abstracts/2022/73300-the-feasibility-of-repurposing-oil-and-gas-wells-f-01.pdf; U.S. Department of Energy, Geothermal Technologies Office, "Wells of Opportunity: ReAmplify," January 12, 2022, https://www.energy.gov/eere/geothermal/wells-opportunity-reamplify; Allie Nelson, "Examining the Technological Overlap Between Oil, Gas and Geothermal," Renewable Energy World, October 5, 2016, https://www.renewableenergyworld.com/baseload/examining-the-technological-overlap-between-oil-gas-and-geothermal-2; George Lockett, "Geothermal Power: an Alternate Role for Redundant North Sea Platforms?" OffShore-Mag.com, March 7, 2018, https://www.offshore-mag.com/pipelines/article/16762144/geothermal-power-an-alternate-role-for-redundant-north-sea-platforms; NSEnergyBusiness.com, "Why the Oil and Gas Industry Should Expand into Geothermal Energy," August 5, 2021, https://www.nsenergybusiness.com/news/why-the-oil-and-gas-industry-should-expand-into-geothermal-energy/.

[12] Daniel Oberhaus and Caleb Watney, "Geothermal Everywhere: A New Path For American Renewable Energy Leadership," Innovation Frontier Project, November 29, 2021, https://innovationfrontier.org/geothermal-everywhere-a-new-path-for-american-renewable-energy-leadership/; Geothermal.org, "Don't Look Up, Look Down: How Oil & Gas Companies Can Survive the Energy Transition by Investing in Geothermal," June 17, 2022, https://geothermal.org/our-impact/blog/dont-look-look-down-how-oil-gas-companies-can-survive-energy-transition-investing.

[13] A reservoir is an underground volume of earth which contains geothermal energy that can be extracted for use.

[14] Induced seismicity is seismic activity created or amplified by stimulation activities for oil and gas (O&G) or geothermal energy development.

169) became law in August 2022 and addresses tax incentives for geothermal projects. Other legislative proposals in the 117th Congress, such as S. 2824 and H.R. 5350, would address some of the challenges that prolong geothermal project development timelines.[15] Still, challenges remain which could be mitigated by federal legislation.

Scope of Report

Geothermal resources can be used for power generation, heating and cooling, and direct-use applications[16] and are being explored for other applications like thermal energy storage and carbon sequestration and storage. This report focuses on geothermal power for utility-scale electricity generation[17] and specifically on EGS because of the potential for significant implementation across the United States. Following convention, geothermal power is considered a renewable power technology.[18] This report introduces geothermal power, reviews areas of potential interest to Congress, and briefly discusses the benefits of EGS and challenges to its commercialization. Cogeneration opportunities and minerals recovery opportunities are also discussed briefly.

Ground-source heat pumps are not a power generation technology but an energy efficiency technology and are not covered in this report outside of the occasional comparison with other geothermal technologies.[19] This report also does not cover leasing on federal lands,[20] district heating, carbon sequestration and storage,[21] or advanced energy storage opportunities.[22]

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[15] S. 2824 is the Senate version of the Enhancing Geothermal Production on Federal Lands Act and H.R. 5350 is the House equivalent; these seek to amend the Geothermal Steam Act of 1970 to add a categorical exclusion for geothermal test projects and define geothermal leasing priority areas—with the goal to shorten project development times by promoting timely identification of geothermal resources.

[16] Geothermal reservoirs of low- to moderate-temperature water—20°C to 150°C (68°F to 302°F)—provide direct heat for residential, industrial, and commercial uses. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Geothermal Basics," September 9, 2022, https://www.energy.gov/eere/forge/geothermal-basics.

[17] Utility-scale electricity generation is electricity generation from a power plant of at least one megawatt of total electricity generating capacity. Energy Information Administration, "Frequently Asked Questions (FAQ): Electricity," https://www.eia.gov/tools/faqs/index.php#electricity.

[18] Any given geothermal reservoir has a maximum sustainable energy extraction rate dependent on the heat of the surrounding earth, water content, and water and heat flow characteristics of the reservoir's geology. See **Figure 3** for an illustration of this balance.

[19] This heat-pump technology—also referred to as GeoExchange, earth-coupled, ground-source, or water-source heat pump—leverages the heat storage capacity of the earth and the temperature differences between the surface environment and the sub-surface to more efficiently provide heating and cooling (similar to air-source heat pumps). This technology does not utilize geothermal heat generated deep in the earth and is not a power generation technology but an energy efficiency technology.

[20] For additional information on federal leasing for geothermal, see CRS Report R46723, *U.S. Energy in the 21st Century: A Primer*, coordinated by Melissa N. Diaz or CRS Report R46537, *Revenues and Disbursements from Oil and Natural Gas Production on Federal Lands*, by Brandon S. Tracy.

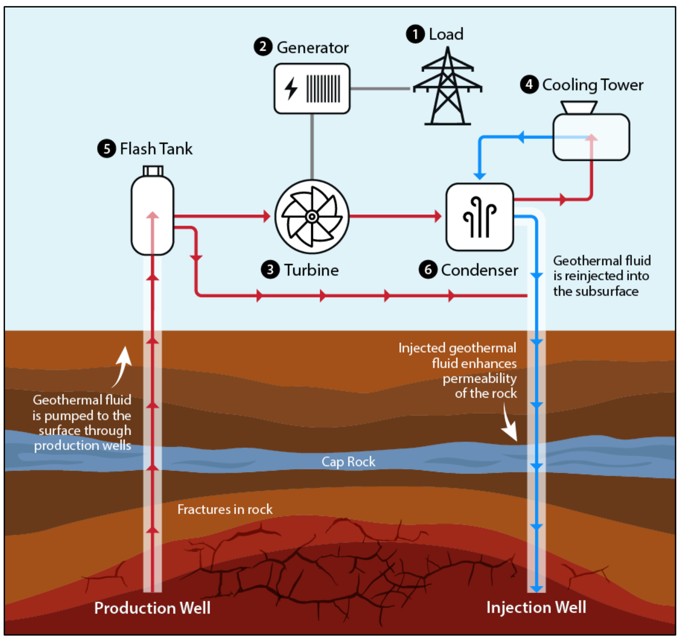
[21] See CRS In Focus IF11861, *DOE's Carbon Capture and Storage (CCS) and Carbon Removal Programs*, by Ashley J. Lawson.

[22] A variety of belowground storage technologies are being developed: aquifer thermal heat storage (ATES), underground thermal energy storage (UTES), borehole thermal energy storage (BTES), and pit thermal energy storage (PTES). B. Akhmetov et al., "Thermal Energy Storage Systems—Review," Bulgarian Chemical Communications, vol. 48, 2016, https://www.researchgate.net/publication/315794616_Thermal_energy_storage_systems_-_review.

Geothermal Power

Geothermal technologies harness heat from the earth for direct use[23] or to convert it to electricity. Geothermal power is considered a renewable energy resource and is derived by capturing heat from an underground reservoir using liquid (largely water but with other constituents) or naturally generated steam under high-pressure. There are three primary types of geothermal power systems in use: dry steam, flash, and binary. In a dry steam configuration, there is sufficient steam present in the reservoir to power the system. In a flash configuration, the high-temperature liquid in the reservoir is converted into steam via a flash tank. In a binary configuration, the heat from the steam and liquid from the reservoir is used to convert a secondary liquid—generally one with a lower boiling point than water—to vapor. In all configurations, the vapor is either passed through a turbine to generate electrical power or used directly for heating. The vapor is condensed back into liquid and reinjected into the ground; for a binary plant the binary fluid is condensed for reuse in the plant, and the geothermal fluid is reinjected into the ground. **Figure 1** has diagrams of the basic elements of a geothermal power system, in this case using a flash steam system and an open cooling loop.[24] **Figure 2** shows the three primary types of geothermal power plants.

Figure 1. Diagram of the Basic Elements of a Geothermal Power System



Source: CRS publications.

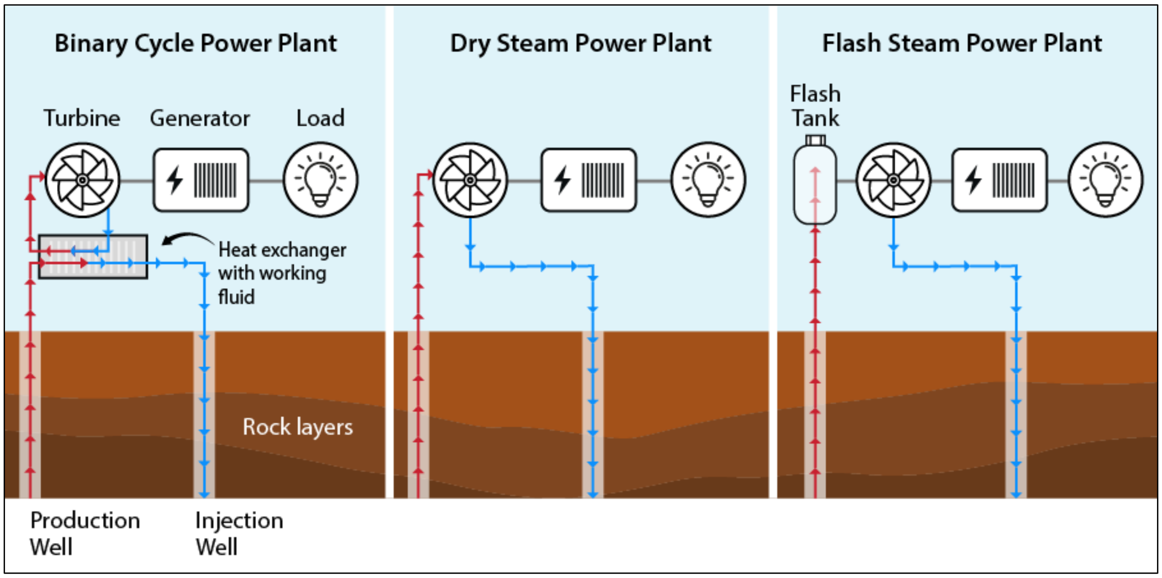
Notes: Hot, high-pressure geothermal fluid is extracted through production wells. Depending on the reservoir conditions, the power plant can have a variety of equipment and configurations. In this example, the fluid is passed through a flash tank [5] which allows for conversion of some of the water into steam. The steam expands to drive a turbine [3] to run a generator [2] and the resulting electricity is transmitted to the grid to supply the

[23] Direct use is using heat extracted from underground to directly heat (via piping and or heat exchangers) air, spaces, equipment, or products.

[24] Open cooling loops cool the hot working fluid by exposing them to either cooler air or water, and in the process the fluid is exposed to the atmosphere and some can evaporate. Open loop cooling has the risk of contamination from the contact with the atmosphere and generally requires additional water treatment. Closed loop cooling does not expose the working fluid to the atmosphere, does not have the associated risks of evaporation and contamination, and has reduced emissions and reduced overall cooling water consumption, but at the cost of generally being less efficient at cooling.

load [1]. After the steam expands through the turbine, it is passed through a condenser [6] where it is cooled and condensed back to liquid through the use of heat exchange via a cooling tower [4]. The cooler and denser fluid is then typically pumped underground via an injection well; ideally the fluid is returned to the reservoir to a location where it can capture heat as it flows toward the production well to repeat the cycle.

Figure 2. Three Primary Types of Geothermal Power Plants



Source: CRS publications.

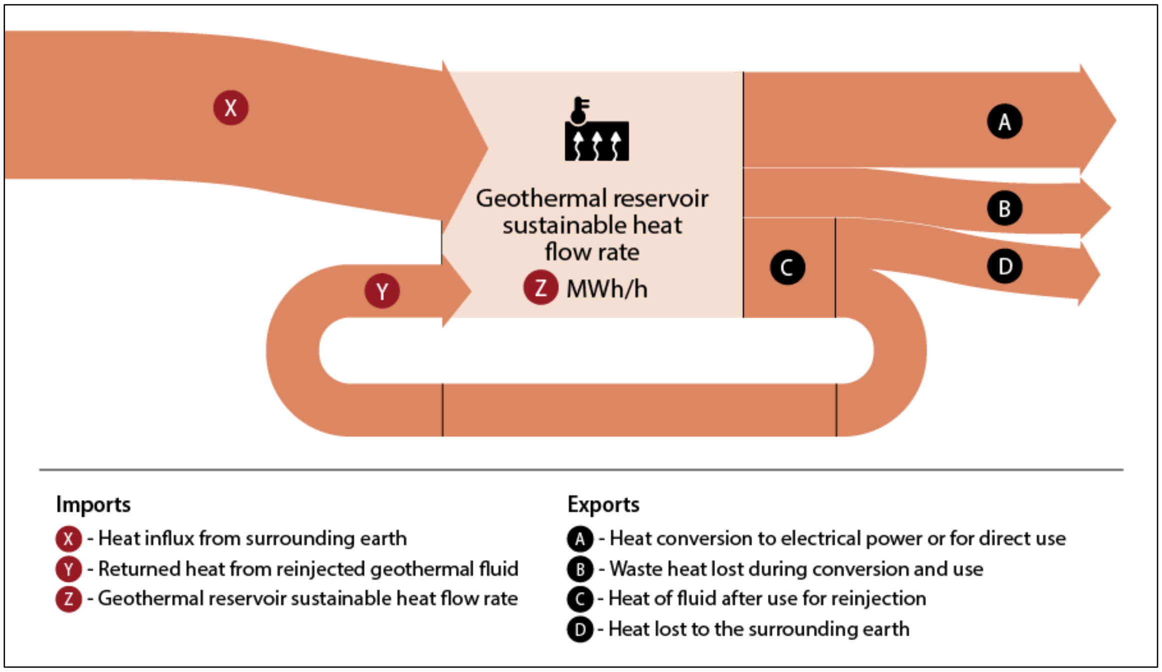
Notes: Binary power plants use a secondary fluid in the power production cycle to access lower-temperature geothermal resources and isolate the power production equipment from the reactive geothermal fluid. Dry steam plants use sufficient levels of steam available in the reservoir to directly drive power production. Flash steam plants convert the geothermal fluid to steam to drive the power production.

Geothermal power is renewable as long as fluid flow through the reservoir is maintained and energy is extracted at a sustainable rate, which is dependent on the conditions of the reservoir.[25] **Figure 3** is a diagram of the sustainable energy flows of a geothermal reservoir. The energy inputs to the reservoir include heat from the earth[26] (labeled 'X' in the diagram) and heat from geothermal fluids reinjected via the injection wells ("Y"). Energy exports from the reservoir include the energy converted to electricity in the power plant or used for direct heating ("A"), waste heat lost during those uses ("B"), and the now-lower energy content of the geothermal fluid after it has passed through the power plant ("C"), some of which is lost to the surrounding earth once it is reinjected ("D"). The reservoir conditions and power generation levels can be sustainably maintained as long as the exports (A+B+C) do not exceed the imports (X+Y).

[25] For more details, see "Resource Access and Management Challenges.**Error! Reference source not found.**"

[26] Geothermal heat is continuously generated by the cooling of the Earth since its formation and the decay of radioactive materials deep in the earth.

Figure 3. Diagram of Sustainable Heat Flows for a Geothermal Reservoir



Source: CRS Publications

Notes: A geothermal reservoir has a sustainable heat flow rate that is dependent on the combined heat inputs and heat outputs of the reservoir. The energy outputs (A+B+C) must be less than or equal to the inputs to the reservoir (X+Y) to maintain sustainable energy production. Some of the flow rates are dependent on physical characteristics of the system and are largely not variable: rates 'X' and 'D' are dependent on the thermodynamic properties of the reservoir and those can be affected by stimulation activities; 'Y' is dependent on the thermodynamics of the geothermal fluid and the physics of the energy conversion of the power plant; 'B' is dependent on the total amount and efficiency of the power production and cooling activities; the rate 'A' of heat conversion for power production or direct use is the major variable that can be adjusted and affects the sustainability of the reservoir's heat flow.

Classes of Geothermal Technologies

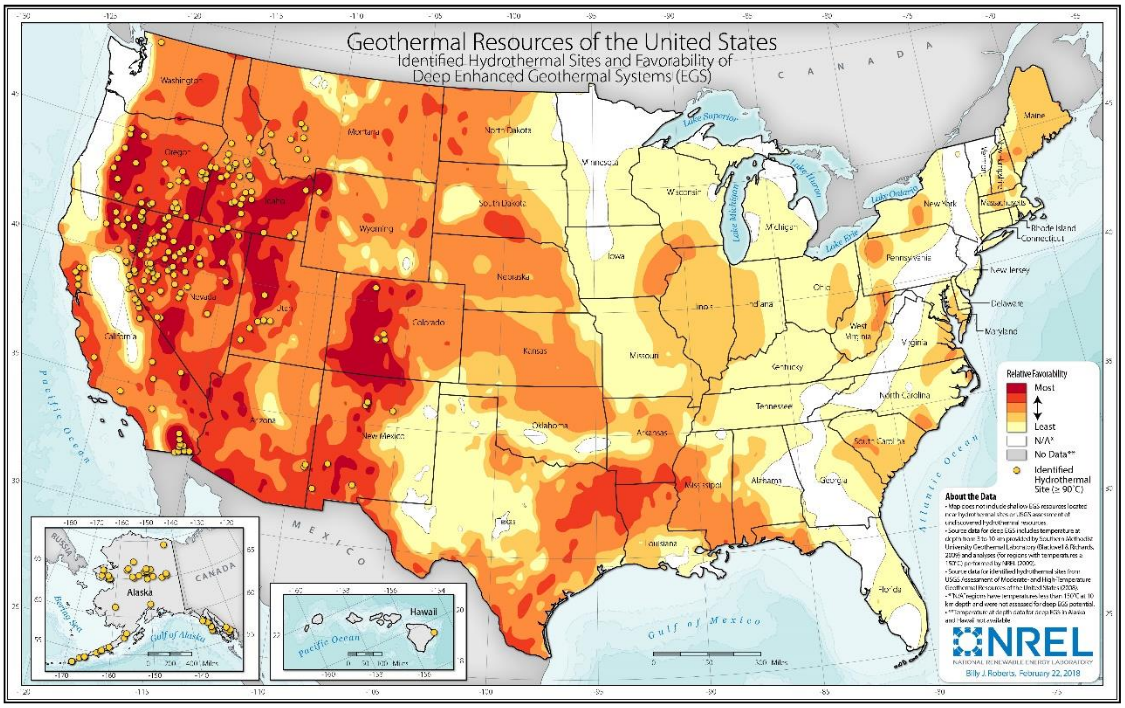
Conventional Hydrothermal

Conventional hydrothermal technologies access geothermal heat resources from underground hot water and steam for either direct use (from just above ambient temperature up to about 150°C/300°F) or to generate electricity (above 150°C to 375°C/300°F to 700°F).[27] These resources are generally geographically limited to areas with the right geological conditions including sufficient subsurface water, gaps in the rock for fluid flow, and subsurface temperature. These hydrothermal conditions are mostly limited to locations in the western United States,

[27] U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf.

including Alaska and Hawaii, as depicted in **Figure 4**.[28] Most hydrothermal resources[29] are only accessible through drilling technology.

Figure 4. Hydrothermal Resources Identified in the United States



Source: NREL, "Geothermal Resources of the United States—Identified Hydrothermal Sites and Favorability of Deep Enhanced Geothermal Systems," 2018.

Notes: Hydrothermal resources are identified by yellow dots; colored fields (i.e. red, orange, yellow) indicate favorability levels for EGS down to a depth of 10 kilometers (km)/6.2 miles (mi).
Legend from the original NREL image: "About the Data: Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources. Source data for deep EGS includes temperature at depth from 3 to 10 km [1.9 to 6.2 mi] provided by Southern Methodist University Geothermal Laboratory ([...]2009) and analyses (for regions with temperatures greater than or equal to 150°C[/300°F]) performed by NREL (2009). Source data for identified hydrothermal sites from USGS Assessment of Moderate- and High-Temperature Geothermal Resources of the United States ([...]2008). 'N/A' regions have temperatures less than 150°C[/300°F] at 10 km [6.2 mi] depth and were not assessed for deep EGS potential. Temperature at depth data for deep EGS in Alaska and Hawaii not available."

Enhanced Geothermal Systems

DOE supported the development of EGS technologies starting in the 1970s. The ongoing development of advanced drilling technologies in the O&G sector has further improved the technical viability of EGS and increased the potential for geothermal energy to contribute to U.S.

[28] National Renewable Energy Laboratory, "Geothermal Resources of the United States—Identified Hydrothermal Sites and Favorability of Deep Enhanced Geothermal Systems," 2018, https://www.nrel.gov/gis/geothermal.html.

[29] A hydrothermal resource is a naturally occurring combination of geothermal heat and water (or steam) in the subsurface that can be extracted to generate electricity or for direct use.

energy production. The key technologies include drilling technologies (like directional drilling[30]) and supporting technologies and processes such as stimulation and hydraulic fracturing.[31] The modern version of these technologies, developed starting in the 1990s, enabled the expansion of O&G production from previously inaccessible resources and has enabled EGS to potentially access more geothermal resources across a larger portion of the United States.[32]

EGS technology uses advanced drilling equipment and the injection of geothermal fluids into the subsurface to access geothermal resources that are not naturally located in reservoirs with the characteristics sufficient for conventional hydrothermal energy production. The development of EGS allows access to much more of the relatively low-temperature heat (from 150°C to 375°C/300°F to 700°F) available throughout the United States than is possible with hydrothermal technologies. Like hydrothermal resources, EGS resources are generally only accessible through drilling technology (as far down as 10 kilometers (km) or 6.2 miles (mi)).[33] The colored fields in **Figure 4** correspond to areas of EGS resource favorability. EGS were not generally recognized as viable, with significant energy potential and presence throughout the United States, until the mid-2000s.[34] This makes it a relatively new power technology within the industry. Thirty-six of the 48 contiguous states have some moderate EGS resource favorability above 150°C (300°F) at 7 km (4.3 mi) and all 48 have some moderate favorability at 10 km (6.2 mi).

Extracting Other Resources

Depending on the subsurface geology of a geothermal site, valuable minerals can potentially be extracted from the geothermal fluid while generating power. These valuable minerals—for example, lithium or other rare earth minerals—are in high concentration in some geothermal reservoirs.[35]

There are also geopressured or coproduced geothermal systems.[36] Geopressured systems include both geothermal energy and methane present in reservoirs which can be extracted and used as fuel. In coproduced systems, oil and/or natural gas are extracted for fuel, but there is sufficient coproduced water at high enough temperature that it can be used to generate electricity.

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[30] Directional drilling is accessing an underground resource by drilling in a non-vertical direction, also called horizontal drilling.

[31] Hydraulic fracturing is the injection of water (with additives) into an O&G reservoir at high pressure to fracture the bedrock and allow extraction of the hydrocarbon resource.

[32] John Manfreda, "The Origin of Fracking Actually Dates Back to the Civil War," BusinessInsider.com, April 14, 2015, https://www.businessinsider.com/the-history-of-fracking-2015-4.

[33] Scientific exploration wells have gone as deep as 12 kilometers. U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf.

[34] A study by the Massachusetts Institute of Technology (MIT) for the National Renewable Energy Laboratory from 2006 changed the industry's perspective on the viability and widespread potential for geothermal power. Massachusetts Institute of Technology, *The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century*, November 2006, from https://energy.mit.edu/wp-content/uploads/2006/11/MITEI-The-Future-of-Geothermal-Energy.pdf.

[35] Companies such as BHE Renewables, EnergySource, and Controlled Thermal Resources are working on extracting lithium from geothermal plants at the Salton Sea. Katie Brigham, "The Salton Sea Could Produce the World's Greenest Lithium, If New Extraction Technologies Work," *CNBC.com*, May 4, 2022, https://www.cnbc.com/2022/05/04/the-salton-sea-could-produce-the-worlds-greenest-lithium.html.

[36] Argonne National Laboratory, "Geothermal Energy Resources," https://ezmt.anl.gov/energy_resources/geothermal.

Geothermal power also offers benefits for other energy production technologies via hybridization. Hybridization can improve the energy efficiency of the other technologies or can provide other, related cogeneration benefits (see "Resource Benefits" for details).

U.S. Geothermal Resources

Given the challenges associated with identifying and assessing subsurface resources, it is difficult to determine the total amount of domestic geothermal resources available, but estimates have been made based on models and existing geological data sets.

Levels of Resource Availability

The amount of geothermal resources available depend on what considerations are included in the calculation:

- Resource potential—total geothermal energy calculated from physical characteristics like rock volume and heat content.
- Technical potential—the portion that can technically be accessed, limited by land accessibility, physical accessibility to the resources, and equipment capability based on current technologies.
- Economic potential—the portion that is cost effective to access based on costs and anticipated revenues.
- Market potential—the portion and timeline for accessing resources given market conditions such as considering impacts from regulations, capital costs and availability, and investor and consumer interest.

Table 1 provides estimates from DOE of the electrical and thermal potential of geothermal resources in the United States.[37] As a point of comparison, according to the Energy Information Agency (EIA), EGS have the potential to provide about 450% of the 1,140 GW total installed utility-scale electricity generation capacity the United States had in 2021.[38] The United States also used 286,000 GWh of district energy annually as of 2018[39]—about 1/50,000th of the thermal potential of EGS.

Table 1. Technical Potential of Geothermal Resources in the United States

	Electricity Potential (GW)	Annual Thermal Potential (GWh)
Hydrothermal[a]	39	0.036 billion
EGS[b]	5,157	15 billion
Ground-source Heat Pumps (GHP)[c]	n/a	8 billion

37 U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf; National Renewable Energy Laboratory (2017), "Update to Enhanced Geothermal System Resource Potential Estimate," May 1, 2017, https://www.osti.gov/biblio/1357946-updates-enhanced-geothermal-system-resource-potential-estimate; National Renewable Energy Laboratory (2019), "GeoVision Analysis Supporting Task Force Report: Electric Sector Potential to Penetration," May 2019, https://www.nrel.gov/docs/fy19osti/71833.pdf; and U.S. Geological Survey, "Assessment of Moderate- and High Temperature Geothermal Resources of the United States," September 2008, https://pubs.usgs.gov/fs/2008/3082/.

38 Energy Information Administration, "Electricity Explained: Electricity Generation, Capacity, and Sales in the United States," April 19, 2022, https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php.

39 Energy Information Administration, "U.S. District Energy Services Market Characterization," February 2018, https://www.eia.gov/analysis/studies/buildings/districtservices/pdf/districtservices.pdf.

Source: GTO, *GeoVision: Harnessing the Heat Beneath Our Feet*, 2019; NREL, "Update to Enhanced Geothermal System Resource Potential Estimate," 2017; NREL, "GeoVision Analysis Supporting Task Force Report: Electric Sector Potential to Penetration," 2019; and USGS, "Assessment of Moderate- and High Temperature Geothermal Resources of the United States," 2008.

Notes: Identified resources are those that have "already been identified or are otherwise known to exist through application of conventional exploration technologies and methods"; undiscovered resources are estimates of additional resources that are "difficult to identify with existing exploration technologies and methods" (GeoVision, 2019).

a. Electricity potential of both identified (9 GW) and undiscovered (30 GW) heat resources above 90°C (195°F). Undiscovered estimates range from 8 to 73 GW. Assessed in 2008.

b. Electricity potential of heat resources down to a depth of 7 km (4.3 mi) and minimum temperature of 150°C (300°F) with current technology. Assessed in 2016.

c. GHPs use electricity to power the pumps and use the ground as a heat source or heat sink, and therefore the technical potential provided is the total heating potential if the heat pumps operated year round (8,760 hours per year); GeoVision reports the U.S. GHP annual heat capacity at 580,000 GW. Assessed in 2019.

Commercial Potential

EGS are potentially viable more widely than conventional hydrothermal technology, but their development costs are higher. Because of its wider availability, nearness to electricity demand and colocation with existing infrastructure (e.g., transmission lines) will contribute to cost savings and improved viability for EGS installations. **Table 2** summarizes levelized costs of electricity (LCOE) and levelized capital costs for select electricity generation technologies.[40]

Table 2. Levelized Costs for Select Electricity Generation Technologies

	Capacity Factor	Levelized Capital Costs ($/MWh)	Total LCOE ($/MWh)	LCOE including tax credits ($/MWh)
Combined Cycle Plants (e.g., natural gas-fired)	87%	8.56	37.05	37.05
Geothermal (conventional hydrothermal)	90%	21.80	39.61	37.43
Wind (onshore)	43%	27.45	37.80	37.80
Solar (photovoltaic)	29%	26.35	36.09	33.46

Source: Energy Information Agency, *Annual Energy Outlook 2022*.

Notes: Costs are capacity weighted by new capacity expected to come online in 2025 to 2027. Presented in dollars per megawatt-hour ($/MWh).

Estimates of current and potential EGS LCOE values range widely because few plants are currently operating. Analyses estimate values of $54 per megawatt-hour (MWh),[41] $70/MWh,[42]

[40] Levelized costs are total costs averaged over the total electricity production (in megawatt-hours (MWh)) for the lifetime of the plant. Energy Information Agency, *Annual Energy Outlook 2022*, 2022, https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf.

[41] Subir K. Sanyal et al., "Cost of Electricity from Enhanced Geothermal Systems," *Proceedings, Thirty-Second Workshop on Geothermal Reservoir Engineering*, January 22-24, 2007, https://geo.stanford.edu/ERE/pdf/IGAstandard/SGW/2007/sanyal1.pdf.

[42] Sandia National Laboratory, "Cost and Performance Analysis of Enhanced Geothermal Systems (EGS)," June 1, 2103, https://www.osti.gov/servlets/purl/1661353.

$150/MWh,[43] or as high as $100,000–300,000/MWh for some installations.[44] The costs vary depending on the site geology, difficulty in drilling and confirming the geothermal resources, and technology and operational costs. Drilling and well completion costs can account for 50% or more of the total capital costs for a geothermal power project.[45] but like other energy technology developments, these costs are likely to trend downward as the technologies are more widely implemented.

Federal Support for EGS Development and Deployment

While the commercial deployment of EGS is limited by technical challenges and high development costs, the federal government will likely continue to play a role in supporting EGS development and deployment. According to EIA, the EGS market is expected to grow as technologies and processes improve.[46] The number of EGS power plants may also increase as markets demand more low-carbon energy and place more value on the other grid benefits of geothermal power and as more governments and other entities seek to achieve power sector emissions-cutting targets.

Only a few commercial EGS systems are operating worldwide,[47] but several other demonstration projects have been successfully operated producing single-digit megawatts of electricity (for example, the Desert Peak II EGS plant in Nevada).[48]

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[43] Philipp Heidinger, "Integral Modeling and Financial Impact of the Geothermal Situation and Power Plant at Soultz-sous-Forêts," Comptes Rendus Geoscience, vol. 342, no. 7-8, July-August 2010, https://www.sciencedirect.com/science/article/pii/S163107130900248X?via%3Dihub.

[44] Nikolay Belyakov, "Chapter Twenty—Geothermal Energy," in *Sustainable Power Generation: Current Status, Future Challenges, and Perspectives* (Academic Press, 2019), https://www.sciencedirect.com/science/article/pii/B9780128170120000347.

[45] Sandia National Laboratory, "GeoVision Analysis: Reservoir Maintenance and Development Task Force Report," August 1, 2017, https://www.osti.gov/servlets/purl/1394062.

[46] In its Annual Energy Outlook 2022, EIA only projects small geothermal additions in the next decade (100-300 MW per year) after which more advanced EGS technologies could become commercialized. Another market analysis estimates the global EGS market at $1,841.4 million in 2020 and projects it to reach $3,673.1 million by 2030 (an annual growth rate of 7.1%). Energy Information Administration, "Annual Energy Outlook 2022," March 3, 2022, https://www.eia.gov/outlooks/aeo/; BIS Research, "Enhanced Geothermal Systems Market—A Global and Regional Analysis: Focus on Resource Type, End User, Depth, Simulation Method, Power Station Type, Supply Chain Analysis, Country-Wise Analysis, and Impact of COVID-19—Analysis and Forecast, 2020-2030," January 2022, https://www.reportlinker.com/p06219256/Enhanced-Geothermal-Systems-Market-A-Global-and-Regional-Analysis-Focus-on-Resource-Type-End-User-Depth-Simulation-Method-Power-Station-Type-Supply-Chain-Analysis-Country-Wise-Analysis-and-Impact-of-COVID-19-Analysis-and-Forecast.html.

[47] Two plants (one providing 1.7 MW of electricity and one providing 24 megawatts-thermal (MWth) of heat are operating in Soultz-sous-Forêts and Rittershoffen, France). Insheim, Germany, has an operational EGS plant producing 4.8 MW. Justine Mouchot, Albert Genter, Nicolas Cuenot, Julia Scheiber, Olivier Seibel, Clio Bosia, and Guillaume Ravier, "First Year of Operation from EGS Geothermal Plants in Alsace, France: Scaling Issues," *Proceedings, 43rd Workshop on Geothermal Reservoir Engineering*, February 12-14, 2018, https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2018/Mouchot.pdf; BESTEC GmbH, "The Insheim Geothermal Project," 2018, https://www.bestec-for-nature.com/index.php/en/projects-en/insheim-en.

[48] The Desert Peak II EGS plant was installed and started operations in 2013, providing an additional 1.7 MW of power to an existing geothermal plant. It was not operational in 2021. National Renewable Energy Laboratory, "2021 U.S. Geothermal Power Production and District Heating Market Report," July, 2021, https://www.nrel.gov/docs/fy21osti/78291.pdf.

As for ongoing development of EGS technologies and resources, DOE's Geothermal Technologies Office (GTO) is supporting a number of technology demonstration projects.[49] These projects are designed to prove the technical viability of EGS in a variety of geologies and reservoir conditions and to demonstrate and refine individual EGS processes and technologies.

- Ormat Technologies project at Desert Peak, NV, increased power output by 38% within an operating geothermal field.
- Altarock Energy project at the Newberry Volcano in Oregon demonstrated the creation of three separate zones of fluid flow from a single well where no flow had been before—a "greenfield" site.[50]
- Calpine Corporation project at the Geysers in California demonstrated stimulation of an abandoned well on the margin of a geothermal field (i.e., "near field").
- University of Utah's Raft River project reworked a well and prepared it for thermal and hydraulic stimulation.
- Ormat Technologies project at Brady's Field in Nevada demonstrated improved well injectivity to commercial levels.

Additionally, DOE is supporting the Frontier Observatory for Research in Geothermal Energy (FORGE) program to develop and test multiple EGS technologies in a working, permitted, and drilled test field.[51] The end goal of FORGE is to create technical solutions enabling reproducible EGS methodology for renewable energy. The project explored several potential FORGE sites before selecting the final site at Utah FORGE. That site has progressed to drilling and subsurface characterization, including having successfully concluded a large-scale, 10-day stimulation test in 2022.[52] The current phase of the project is anticipated to conclude in mid-2024. The project is focused on drilling, stimulation, and injection-production technologies as well as subsurface imaging technologies with the goal to improve fluid flow and energy transfer from EGS reservoirs.

Potential Benefits and Challenges

Supporters and opponents have claimed a number of benefits and challenges associated with geothermal power technology. Some of these are relative to other renewable power technologies, fossil fuel power technologies, and other thermal power technologies like nuclear. Some are technical; some are economic, health and safety, or environmental; and some are related to how

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[49] U.S. Department of Energy, Geothermal Technologies Office, "Enhanced Geothermal Systems Demonstration Projects," May 25, 2022, https://www.energy.gov/eere/geothermal/enhanced-geothermal-systems-demonstration-projects.

[50] "Greenfield—A geothermal site where no previous development of any type has occurred. Brownfield—A geothermal site that has had previous development of some type (e.g., former manufacturing site). Near-field EGS resources consist of the areas around existing hydrothermal sites that lack sufficient permeability and/or in-situ fluids. [compare to in-field and deep-EGS]." GTO, *GeoVision: Harnessing the Heat Beneath Our Feet*, 2019.

[51] U.S. Department of Energy, Geothermal Technologies Office, "FORGE, U.S. Department of Energy," accessed May 25, 2022, https://www.energy.gov/eere/forge/forge-home; UtahFORGE, "Frontier Observatory for Research in Geothermal Energy—FORGE," https://utahforge.com/.

[52] Sonal Patel, "Large-Scale Enhanced Geothermal System Trial Successfully Completed," PowerMag.com, June 21, 2022, https://www.powermag.com/large-scale-enhanced-geothermal-system-trial-successfully-completed.

EGS integrates with the power grid. **Table 3** lists a selection of these potential benefits and challenges.

Table 3. Select Benefits and Challenges of EGS

Benefits	Challenges
• Provides baseload power	• Reservoir characterization and management is complex
• Operational costs are low compared to fossil fuel power technologies	• Capital costs are high compared to other (non-nuclear) power technologies
• No fuel needed	• Well blow-outs are a risk
• Flexible generation	• Geothermal resources are difficult to identify and confirm compared to other renewables technologies
• Colocation, cogeneration, geopressured, coproduced, and hybridization opportunities	• Complex geochemistry (salinity, temperature, reactive chemical constituents) can cause problems like corrosion and scaling in power plant systems
• Zero to low emissions compared to fossil fuel power technologies	• Emissions can be higher than other renewable power technologies
• Generates low amounts of waste and requires low amounts of waste treatment compared to other thermal power technologies	• Chemicals used for reservoir or fluid management and for valuable minerals recovery require additional handling, cleanup, or disposal
• Relatively low land use compared to other renewables	• Project development timelines are longer than other (non-nuclear) power technologies (projects can take up to 10 years)
• EGS is widely available geographically	• Can cause induced seismicity
• Operational water needs can be low	• Geological conditions (depth, temperature, rock conditions, geochemistry) can make well drilling difficult and expensive
• Valuable minerals can potentially be extracted from the geothermal fluid while generating power	• Needs large volumes of water for stimulation activities
	• Commercial implementation is currently limited

Source: CRS analysis.

Supporters of geothermal power generation note its benefits in supporting the grid and power supplies, that it has the potential to synergize with other technologies or contribute to non-power-generation-related goals and needs, and that it is relatively safe and has environmental benefits. Critics of geothermal power generation note the challenges in accessing and managing geothermal resources compared to other renewables, challenges in commercialization, and challenges involving safety and environmental issues.[53] In the sections below this selected set of

[53] Solarreviews.com, "Geothermal Energy Pros and Cons," March 8, 2022, https://www.solarreviews.com/blog/geothermal-energy-pros-and-cons; Union of Concerned Scientists, "Environmental Impacts of Geothermal Energy," March 5, 2013, https://www.ucsusa.org/resources/environmental-impacts-geothermal-energy; Vincent Gonzales, "Geothermal Energy 101," Resources for the Future, July 21, 2022, https://www.rff.org/publications/explainers/geothermal-energy-101/.

issues is examined, highlighting potential benefits or challenges raised by supporters or critics of geothermal power.

Grid Benefits

Supporters identify a number of properties of EGS that may provide benefits to the power grid. EGS provide baseload power which can complement other variable renewable energy (VRE) sources like wind and solar in the grid.[54] Geothermal power has a high capacity factor—up to 95% for modern plants[55]—so it can potentially provide continuous power on an "around-the-clock" basis. The EIA reports that in 2021, at utility-scale, geothermal power's overall annual capacity factor (71.0%) was second only to nuclear power (92.7%) and ahead of biomass (63.5%), combined cycle natural gas (54.4%), coal (49.3%), wind (34.6%), and solar (24.6%).[56]

Supporters note that geothermal electricity production is dispatchable, meaning it can be started or stopped as needed, to support power grid reliability and flexibility.[57] Geothermal generation can also be started (or restarted) without an external supply of electricity to initiate startup ("black start"), if, for example, there is a large-scale power outage requiring a restart of the grid. Geothermal power, as a renewable energy source, requires no input fuels to operate, so its operational costs are low and not subject to fluctuations in fuel prices; it is reliable; and it is available domestically.[58]

Resource Benefits

Supporters of EGS note the potential for simultaneous cogeneration of process heat and electric power which can be used for greenhouse heating, water heating, and industrial or commercial heating and drying.[59] EGS also has the potential to hybridize with other renewables technologies (like solar) to either improve the overall efficiency of the geothermal plant or provide other operational or efficiency benefits for both sources.[60] EGS can also be combined with geopressured resources, such as methane which when present within a geothermal reservoir can be extracted for use as a fuel. EGS can also be coproduced with O&G—when geothermal fluid at

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[54] U.S. Department of Energy, "5 Things to Know About Geothermal Power," February 14, 2018, https://www.energy.gov/eere/articles/5-things-know-about-geothermal-power.

[55] The capacity factor can be considered to be a percentage of time a power source is in operation at full capacity over a given time period. Fynn Hackstein, Reinhard Madlener, "Sustainable Operation of Geothermal Power Plants: Why Economics Matters," *Geothermal Energy* 9, 10, 2021, https://geothermal-energy-journal.springeropen.com/articles/10.1186/s40517-021-00183-2.

[56] Energy Information Administration, *Electric Power Monthly: Table 6.07.A. Capacity Factors for Utility Scale Generators Primarily Using Fossil Fuels*, March 2022, https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_a; Energy Information Administration, *Electric Power Monthly: Table 6.07.B. Capacity Factors for Utility Scale Generators Primarily Using Non-Fossil Fuels*, March 2022, https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b.

[57] National Renewable Energy Laboratory, "Grid Integration Modeling for Geothermal Power," https://www.nrel.gov/geothermal/grid-integration-modeling.html.

[58] U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf.

[59] Making use of the cogenerated heat provides additional capabilities not available from electricity production alone and increases overall system energy efficiency.

[60] National Renewable Energy Laboratory, *Hybridizing a Geothermal Plant with Solar and Thermal Energy Storage to Enhance Power Generation*, June, 2018, https://www.nrel.gov/docs/fy18osti/70862.pdf.

sufficient pressure and temperature is present at an O&G extraction site, it can be used for simultaneous geothermal power production.[61]

Hybridization with hydrogen production is another opportunity noted by supporters. Because geothermal power operates steadily, when the demand for electricity is lower than the grid's generation potential, the excess power generation capacity of the geothermal plant can be used for green hydrogen production via electrolysis.[62] Hydrogen production could also be an alternative for geothermal plants installed where electricity transmission infrastructure is unavailable, limited, or too costly to expand.[63]

Supporters note that valuable mineral recovery processes could provide additional economic benefits for geothermal plants as well as access to critical materials for industry. Geothermal fluids in some locations like the Salton Sea contain valuable minerals, for example lithium carbonate, in sufficient concentrations that they could be economically extracted while cycling the fluid through the plant for power generation.[64]

Supporters of geothermal power claim it has a lower land use footprint than other power technologies. The land footprint that utility-scale geothermal electricity production requires is important because it affects how much total energy can likely be generated (at either a single installation or nationwide), where installations can be sited, and the likely total impact on the local environment. One analysis determined that geothermal power has a smaller land footprint (404 square meters per GWh) compared to wind (1,335), solar photovoltaic (3,237), solar thermal (3,561), and coal (3,642). The analysis considered total land used for fuel sourcing, generation, and maintenance. This is also less than the 620 m^2 per GWh for natural-gas-fired generation (from similar life cycle land use calculations).[65]

Supporters also claim that geothermal power is amenable to colocation with other power sources or colocation alongside or with other land uses such as livestock grazing or other agricultural

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[61] U.S. Department of Energy, Geothermal Technologies Office, "Geothermal Energy Production with Co-produced and Geopressured Resources," July, 2010, https://www1.eere.energy.gov/geothermal/pdfs/low_temp_copro_fs.pdf.

[62] Green hydrogen is hydrogen produced from water using renewable energy sources. This renewably sourced hydrogen could be used in hard-to-electrify sectors such as transportation or long-term energy storage (for use in fuel cells), some industrial sectors (like chemicals, refining, and iron and steel manufacturing), and those relying on existing gas grids (like buildings). Energy Information Administration, *The Future of Hydrogen: Seizing Today's Opportunities*, June, 2019, https://www.iea.org/reports/the-future-of-hydrogen; K. Ota et al., "Advances in Hydrogen Production, Storage and Distribution," Woodhead Publishing, 2014, https://www.sciencedirect.com/science/article/pii/B978085709768250002X.

[63] This would require additional on-site equipment for hydrogen storage and transport or an on-site use.

[64] Two demonstration projects were awarded by the California Energy Commission in 2020 to prove these capabilities. DOE awarded funds in 2021 for related projects on conversion to industrial products. California Energy Commission, "Geothermal, Lithium Recovery Projects Get Boost from California Energy Commission," Energy.ca.gov, May 13, 2020, https://www.energy.ca.gov/news/2020-05/geothermal-lithium-recovery-projects-get-boost-california-energy-commission; Janet Wilson and Erin Rode, "Lithium Valley: A Look at the Major Players near the Salton Sea Seeking Billions in Funding," Desertsun.com, May 14, 2022, https://www.desertsun.com/story/news/2022/05/13/lithium-valley-look-major-players-near-salton-sea-seeking-billions-funding/9665978002/.

[65] These values differ from some other analysis. There is no standard approach or methodology for evaluating the land use footprint of electricity generation technologies. Depending on the metrics being calculated, and the assumptions and boundaries used in those calculations, different analyses can produce different values and comparisons between technologies. Compounding this problem is a lack of universal data recording and reporting for power generation projects. These challenges make comparison and agreement on land use metrics difficult. For more information on issues with uniform land use calculations, see CRS Report R46196, *Solar Energy: Frequently Asked Questions*, coordinated by Ashley J. Lawson; National Renewable Energy Laboratory, *Understanding the Life Cycle Surface Land Requirements of Natural Gas-Fired Electricity*, October 2, 2017, https://www.osti.gov/biblio/1398873.

purposes.[66] Due to the broad potential geographic availability of EGS, new geothermal plants could be colocated with VRE sources and could share use of any new transmission lines—maximizing the productivity of those lines and the investments made to construct them. The relative low impact of the geothermal plant itself—minimal visual impact, limited emissions or waste products, and no fuel imports—means it can be potentially sited close to other installations and uses including urban, scenic, recreational, or wildlife areas.

Safety and Environmental Benefits

Supporters note that because geothermal power does not need input fuels (unlike fossil fuel or nuclear power plants) it doesn't have costs and risks associated with fuel transportation and storage.[67] Also, depending on the plant configuration, geothermal energy can generate minimal waste.[68]

Supporters note that EGS have overall safety risk levels similar to offshore wind (in the worst case scenario) or better than solar photovoltaic (in the best case scenario) and, in general, better than fossil, hydropower, hydrogen, and biogas energy.[69]

Similar to other renewables, geothermal power has few atmospheric emissions. The exact levels of emissions depend on the system configuration and the natural characteristics of the geothermal reservoir. For example, closed-loop and binary systems have practically no emissions, whereas flash steam systems have relatively small emissions from the steam cycle when the hydrothermal fluid is exposed to the atmosphere during cooling.[70] Mitigation measures—for example, at The Geysers plants in California—have been able to remove more than 99% of these emissions.

Resource Access and Management Challenges

Critics of geothermal power note that it has some of the same challenges as the O&G industry in identifying and accessing resources and operating wells.[71] Critics also note additional challenges related to the high temperatures and reactive chemistry of the geothermal resources. High temperatures and high salinity of the geothermal fluids cause faster wear of well drilling equipment, make it challenging to operate sensors and related equipment down in the wells, and cause faster wear and corrosion of the well casings and the power plant systems during operation. The materials used in constructing geothermal wells and plants are designed to be resistant to the

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[66] U.S. Department of Energy, Geothermal Technologies Office, "Geothermal Power Plants—Minimizing Land Use and Impact," June 23, 2022, https://www.energy.gov/eere/geothermal/geothermal-power-plants-minimizing-land-use-and-impact.

[67] Damian Carrington, "Geothermal Energy: All the Benefits of Nuclear—But None of the Problems," January 18, 2011, https://www.theguardian.com/environment/damian-carrington-blog/2011/jan/18/geothermal-energy-nuclear.

[68] Many have no waste. Geothermal Energy Association, "A Guide to Geothermal Energy and the Environment," April 22, 2005, https://www.osti.gov/servlets/purl/897425; Annette Evans, Vladimir Strezov, and Tim Evans, "Comparing the Sustainability Parameters of Renewable, Nuclear and Fossil Fuel Electricity Generation Technologies," 21st World Energy Congress, Montreal, Quebec, September 15, 2010, https://www.osti.gov/etdeweb/servlets/purl/21396864.

[69] Matteo Spada, Emilie Sutra, and Peter Burgherr, "Comparative Accident Risk Assessment with Focus on Deep Geothermal Energy Systems in the Organization for Economic Co-operation and Development (OECD) Countries," *Geothermics*, 95, September, 2011, https://www.sciencedirect.com/science/article/pii/S0375650521001024.

[70] U.S. Department of Energy, "Geothermal Power Plants—Meeting Clean Air Standards," accessed July 18, 2022, https://www.energy.gov/eere/geothermal/geothermal-power-plants-meeting-clean-air-standards.

[71] Payam Allahvirdizadeh, "A Review on Geothermal Wells: Well Integrity Issues," *Journal of Cleaner Production*, vol. 275, December 1, 2020, https://www.sciencedirect.com/science/article/pii/S0959652620340543.

temperature and chemistry of the reservoir and are designed for long-term operation, which increases capital costs. For EGS, these systems must also accommodate any chemical additives used for well stimulation and maintenance. Particular challenges include a greater potential for scaling,[72] dealing with non-compressible gases in the geothermal fluid,[73] and the precipitation of chemicals at bottom of the well and within the narrow fractures in the rock leading to the well. These chemical reactions can affect the circulation within the reservoir and well and can impact operation of the power plant systems and limit efficiency.

Critics note reservoir management is a challenge for the development of geothermal power overall.[74] Management challenges include understanding, controlling, and adjusting the chemistry of the reservoir; understanding the physical structure of the reservoir; and understanding and managing the heat flow, fluid levels, and fluid flow to maximize and sustain power generation and prevent drying out of sections of the fracture network and/or collapse of those fractures.[75] Management activities include adjusting power plant operations to maintain production and reservoir conditions.

Commercialization Challenges

Critics of geothermal power have noted that implementation of EGS is limited. While hydrothermal electricity generation has existed for more than 100 years,[76] and ground-source heat pumps have been commercially available since the 1940s,[77] market acceptance for EGS technologies and installations is still a challenge.[78] There are a number of successful demonstration projects proving viability of the individual elements. Other projects are helping to develop more effective EGS technologies or processes[79] but only a few commercial EGS power plants are currently operating (e.g., in Soultz-sous-Forêts and Rittershoffen, France, and in Insheim, Germany).

Compared to other renewable power technologies like solar and wind, geothermal has a more challenging project development path. The challenges relating to identifying, accessing, developing, and managing geothermal resources make project timelines longer and costlier, and

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[72] Scaling is a buildup of chemicals on the surfaces of pipes and other equipment exposed to the working fluids which can interfere with efficient operation of the plant.

[73] Füsun S. Tut Haklıdır, "The Importance of Long-Term Well Management in Geothermal Power Systems Using Fuzzy Control: A Western Anatolia (Turkey) Case Study," *Energy (Oxford, England)*, vol. 213, no. 118817, December 15, 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7490243/.

[74] Moses Jeremiah Barasa Kabeyi, "Geothermal Electricity Generation, Challenges, Opportunities and Recommendations," International Journal of Advances in Scientific Research and Engineering, 5, August, 2019, https://www.researchgate.net/publication/334988672_Geothermal_Electricity_Generation_Challenges_Opportunities and Recommendations.

[75] See **Figure 3** for illustration of reservoir heat flow.

[76] U.S. Department of Energy, Geothermal Technologies Office, "A History of Geothermal Energy in America," accessed May 25, 2022, https://www.energy.gov/eere/geothermal/history-geothermal-energy-america.

[77] U.S. Department of Energy, "Energy Saver: Geothermal Heat Pumps," https://www.energy.gov/energysaver/geothermal-heat-pumps.

[78] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "U.S. Department of Energy Announces $14.5 Million to Accelerate Deployment of Geothermal Electricity," June 10, 2021, https://www.energy.gov/eere/articles/us-department-energy-announces-145-million-accelerate-deployment-geothermal.

[79] See "Commercial Potential**Error! Reference source not found.**" for more details. U.S. Department of Energy, G eothermal Technologies Office, "Enhanced Geothermal Systems Demonstration Projects," https://www.energy.gov/eere/geothermal/enhanced-geothermal-systems-demonstration-projects.

involve more regulatory oversight (e.g., resource access rights laws, environmental impact reviews, and permitting steps).

For federal projects or projects on federal lands or supported by federal funds,[80] a variety of factors contribute to longer geothermal development timelines which, in turn, increase direct development costs, administrative costs, and related financing costs due to the longer time before a potential return on investment. Limitations on the availability of federal oversight resources is one such factor. Federal agencies and offices, such as the Bureau of Land Management and individual U.S. Forest Service offices, are integral to processing leasing applications and permits. Staffing limitations have been identified as an issue that can delay the advancement of a geothermal project.[81] Additionally, federal regulations can require as many as six National Environmental Policy Act (NEPA)/environmental impact reviews during development of a geothermal project.[82] Ultimately, federal permitting review for geothermal projects can take three times as long as equivalent O&G project reviews.[83] Categorical exclusions are one option to decrease project development times.[84] Similar O&G activities have existing categorical exclusions that have been used extensively to speed up project development.[85]

State laws apply on state and private lands but can also apply to federal lands, potentially adding an additional layer of compliance. Relevant laws include state permitting and environmental impact assessments. Western states in particular have water access regulations and rights laws that can potentially impact geothermal development, and 12 western states have regulations addressing geothermal projects specifically.[86] The remaining states do not have specific

[80] An analysis by National Renewable Energy Laboratory (NREL) of 2008 United States Geological Survey data calculated that 63% of the identified and undiscovered geothermal resources are located on federal land, 9% on state land, and 28% on private land. Aaron Levine and Katherine Young, "Efforts to Streamline Permitting of Geothermal Projects in the United States," *Rocky Mountain Mineral Law Foundation Journal*, vol. 55, no. 1 (January 1, 2018), https://www.osti.gov/pages/servlets/purl/1467102.

[81] National Renewable Energy Laboratory, "GeoVision Analysis Supporting Task Force Report: Barriers—An Analysis of Non-Technical Barriers to Geothermal Deployment and Potential Improvement Scenarios," May 2019, https://www.nrel.gov/docs/fy19osti/71641.pdf.

[82] U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May, 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf.

[83] U.S. Government Accountability Office, "Oil and Gas Permitting: Actions Needed to Improve BLM's Review Process and Data System," March, 2020, https://www.gao.gov/assets/gao-20-329.pdf.

[84] Categorical exclusions are a part of larger National Environmental Policy Act (NEPA) analyses and are applicable to certain activities involving federal funds, lands, or projects and to some geothermal development activities. They define classes of activities a federal agency has determined do not have a significant impact on the human environment. Exclusions allow some steps of the NEPA review process to be skipped to speed up development time. Current BLM categorical exclusions for geothermal projects do not cover all drilling activities sufficient to confirm geothermal resources, therefore additional activities and thus permitting and assessments are required. U.S. Department of the Interior, "Existing Categorical Exclusions," December 21, 2020, https://www.doi.gov/sites/doi.gov/files/doi-and-bureau-categorical-exclusions-dec2020.pdf.

[85] A U.S. Government Accountability Office (GAO) analysis of BLM data from FY2006 to FY2008, covering 6,900 O&G activities approved using categorical exclusions, showed nearly 6,100 were for drilling activities, though not without controversy. U.S. Government Accountability Office, "GAO Highlights: Energy Policy Act of 2005–BLM's Use of Section 390 Categorical Exclusions for Oil and Gas Development," September 9, 2011, https://www.gao.gov/assets/gao-11-941t-highlights.pdf; Dustin Bleizeffer, "Judge Freudenthal Rules in Favor of Categorical Exclusions for Oil and Gas Drilling," *WyoFile.com*, August 12, 2011, https://wyofile.com/judge-freudenthal-rules-in-favor-of-categorical-exclusions-for-oil-and-gas-drilling/.

[86] Alaska, California, Colorado, Hawaii, Idaho, Montana, Oregon, Nevada, New Mexico, Texas, Utah, and Washington. Brent Chicken and Joseph Negaard, "Renewable Energy Webcast Series: Legal Considerations of Geothermal Projects," January 5, 2022, https://www.steptoe-johnson.com/sites/default/files/

geothermal regulations but federal lands within would be covered by federal law (particularly the Geothermal Steam Act of 1970, P.L. 91-581).[87] The expansion of EGS in these states could experience challenges from existing state regulations (or lack thereof), regulatory processes, and interactions or combinations of federal and state regulations.

The longer project development timelines for geothermal make some federal tax incentives (e.g., the Investment Tax Credit (ITC), 26 U.S.C. §48 and the Production Tax Credit (PTC), 26 U.S.C. §45) less effective than they are for other renewables like solar and wind.[88] These incentives have historically been authorized in increments of about 5 years at a time, while geothermal projects can take as long as 10 years, making it more difficult for geothermal project planners to estimate project costs and secure project financing.

Safety and Environmental Challenges

Induced Seismicity

Induced seismicity is one of the most common concerns expressed related to EGS technologies. Seismic events can occur during well construction, well stimulation, and power plant operations; with the stimulation-related events being of most concern by critics of the technology. This type of induced seismicity is the result of subsurface injections or extractions of fluids.[89] These fluids can lead to movement in the earth's crust along pre-existing faults resulting in seismic activity. In the case of geothermal stimulation, this activity is often small enough that it is undetectable without seismic equipment but it can also be significant.[90] A stimulation project in Basel, Switzerland, was halted after significant induced seismic activity, and other geothermal stimulation projects in California, Oregon, and Nevada have been studied to help minimize the impacts of induced seismicity.[91] A complete understanding of the dependencies, risk levels, and severity levels for induced seismicity from EGS stimulation is not known due to the newness of the technology and the limited number of operational EGS sites.[92]

Renewable%20Webcast%20-%20Geothermal.pdf.

[87] The Geothermal Steam Act of 1970 gave the Secretary of the Interior the authority to lease federal lands and other public lands for geothermal exploration and development while protecting the public interest, water quality, and other environmental interests.

[88] U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf.

[89] Including extraction of groundwater and O&G, as well as injection for wastewater disposal, or O&G fracking activities.

[90] Katrin Breede et al., "A Systematic Review of Enhanced (or Engineered) Geothermal Systems: Past, Present and Future," *Geothermal Energy* vol. 1, November 5, 2013, https://geothermal-energy-journal.springeropen.com/articles/10.1186/2195-9706-1-4; Ning Li et al., "A Critical Review of the Experimental and Theoretical Research on Cyclic Hydraulic Fracturing for Geothermal Reservoir Stimulation," *Geomechanics and Geophysics for Geo-Energy and Geo-Resources*, vol. 8, issue 1, November 27, 2021, https://link.springer.com/article/10.1007/s40948-021-00309-7.

[91] National Renewable Energy Laboratory, "Geothermal Induced Seismicity National Environmental Policy Act Review," October 3, 2017, https://www.nrel.gov/docs/fy18osti/70203.pdf.

[92] The mechanisms and dependencies relating to induced seismicity are not fully understood because of the current limitations of knowledge on subsurface geological structures, stress, the impacts of fluid injection, and the propagation of seismic activity. For more information on induced seismicity, see CRS Report R43836, *Human-Induced Earthquakes from Deep-Well Injection: A Brief Overview*, by Peter Folger and Mary Tiemann; Evelina Trutnevyte and Inês Azevedo, "Induced Seismicity Hazard and Risk by Enhanced Geothermal Systems: An Expert Elicitation Approach," Environmental Research Letters, vol. 13, no. 3, February 16, 2018, https://iopscience.iop.org/article/

In an effort to address concerns about induced seismicity from EGS projects, Lawrence Berkeley National Laboratory (LBNL) developed a seismicity protocol to reduce the risk to project developers and the general public from induced seismicity associated with EGS.[93] The protocol has been implemented as part of NEPA reviews of EGS projects[94] and in addition to helping reduce or mitigate the impacts of seismicity, it helps inform agencies and stakeholders of any seismic events and potential mitigation activities.

Emissions and Waste

Critics note that emissions are an issue associated with geothermal power plants. In geothermal power systems employing open-loop cooling, the geothermal fluid is cooled and condensed via exposure to cooler, circulated water. The process involves evaporation and exposes the geothermal fluid to the atmosphere.[95] Emissions from open-loop geothermal systems can include hydrogen sulfide, carbon dioxide, ammonia, methane, and boron.[96] In closed-loop systems (which are often used in binary EGS plants, illustrated in **Figure 1**),[97] the geothermal fluid is not exposed to the atmosphere and thus the systems have practically zero emissions. Compared to other renewable power plants, such as solar or wind, open-loop geothermal power has higher emissions, but it has lower emissions compared to similarly-sized fossil fuel plants.[98]

While geothermal power does not generate the amounts of solid wastes of coal mining[99] or the solid waste byproducts from burning fossil fuels (e.g., fly ash, bottom ash, boiler slag and particulates removed from flue gas),[100] it does generate solid waste from both well drilling operations (e.g., drill cutting, scale, domestic waste, silica sludge, and organic waste)[101] and wastes from power plant operations (e.g., scale, flash tank solids, precipitated solids from brine

10.1088/1748-9326/aa9eb2.

[93] U.S. Department of Energy, Geothermal Technologies Office, *Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems*, January 2012, https://www.energy.gov/sites/prod/files/2014/02/f7/geothermal_seismicity_protocol_012012.pdf.

[94] National Renewable Energy Laboratory, *Geothermal Induced Seismicity National Environmental Policy Act Review*, October 3, 2017, https://www.nrel.gov/docs/fy18osti/70203.pdf.

[95] Nicola Ferrara, Riccardo Basosi, and Maria Laura Parisi, "Data Analysis of Atmospheric Emission from Geothermal Power Plants in Italy," Data in Brief, vol. 25, Spetember 27, 2019, https://www.researchgate.net/publication/334805922.

[96] Union of Concerned Scientists, "Environmental Impacts of Geothermal Energy," March 3, 2013, https://www.ucsusa.org/resources/environmental-impacts-geothermal-energy.

[97] Muhammad Rayyan Fazal and Muhammad Kamran, "Chapter 9—Geothermal Energy" in *Renewable Energy Conversion Systems*, Academic Press, 2021, https://www.sciencedirect.com/science/article/pii/B9780128235386000063.

[98] Open loop geothermal plants have 97% less sulfur compound emissions and 99% less carbon dioxide emissions. Energy Information Administration, "Geothermal Explained: Geothermal Energy and the Environment," November 19, 2020, https://www.eia.gov/energyexplained/geothermal/geothermal-energy-and-the-environment.php.

[99] Hossain Anawar, Vladimir Strezov, and Tanveer Adyel, "The Reuse and Recycling of Coal Mining Waste with Zero-Waste Approach by Technological Development and Integrated Management for Sustainable Growth and Benefits," *Sustainable and Economic Waste Management: Resource Recovery Techniques*, pp. 31-46 (CRC Press, 2002), https://doi.org/10.1201/9780429279072-3.

[100] U.S. Environmental Protection Agency, "Special Wastes," June 22, 2022, https://www.epa.gov/hw/special-wastes#fossil.

[101] Ayu Utami et al., "Geothermal Energy Solid Waste Management: Source, Type of Waste, and the Management," AIP Conference Proceedings 2245, issue 1, July 8, 2020, https://aip.scitation.org/doi/10.1063/5.0007299.

treatment, hydrogen sulfide, and cooling-tower-related waste).[102] These wastes need to be contained and treated or disposed of.[103] Additional sources of solid waste related to plant management or resource extraction may also exist. These include chemical additives used for reservoir or power plant management; waste associated with the precipitation of metals, sulfides, and naturally occurring radioactive materials; and by-product gases, solids, and salts associated with valuable minerals recovery.

Other Safety and Environmental Challenges

Critics note that EGS projects can use as much as 9.8 million gallons of water for stimulation, and lifetime water use for EGS operations could be as high as 10 billion gallons (as high as 0.72 gallons per kilo-watthour (kWh) produced).[104] Make-up water for cooling towers is an additional water need, but since the majority of EGS plants are anticipated to use binary, closed-loop dry cooling, this amount is expect to be relatively small. Like any other thermal power plant, a geothermal power plant that uses open-loop evaporative cooling would have higher cooling makeup water needs.[105] Though there have been no known cases of contamination of groundwater from geothermal activities,[106] the management of water supply, treatment of water or wastewater, and disposal of wastewater is an issue affecting the steam-electric power generation sector broadly.

Similar to the O&G sector, well blow-outs are a risk due to high-pressure, high-temperature geothermal fluids, and most countries have strict regulations to ensure safety.[107]

Issues for Congress

Congress has established laws on accessing, leasing, and regulating geothermal resources and on related project elements including funding for RD&D. There are additional areas that Congress

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[102] Molly Finster et al., "Geothermal Produced Fluids: Characteristics, Treatment Technologies, and Management Options," Renewable and Sustainable Energy Reviews, vol. 50, October 2015, https://www.sciencedirect.com/science/article/abs/pii/S1364032115005298.

[103] Ayu Utami et al., "Geothermal Energy Solid Waste Management: Source, Type of Waste, and the Management," AIP Conference Proceedings 2245, issue 1, July 8, 2020, https://aip.scitation.org/doi/10.1063/5.0007299.

[104] However, this water supply does not need to be high quality or potable; for example, geothermal installations can use treated wastewater for stimulation and operations. This is important since some geothermal plants in the West are in areas experiencing drought conditions. Rafał Moska, Krzysztof Labus, and Piotr Kasza, "Hydraulic Fracturing in Enhanced Geothermal Systems—Field, Tectonic and Rock Mechanics Conditions—A Review," *Energies*, vol. 14, no. 5725 (September 2021), https://www.mdpi.com/1996-1073/14/18/5725/pdf; Alyssa Kagel, "The State of Geothermal Technology. Part II: Surface Technology," Geothermal Energy Association, January, 2008, https://geothermalcommunities.geonardo.com/assets/elearning/7.34.Geothermal%20Technology%20-%20Part%20II%20(Surface).pdf; Argonne National Laboratory, "Water Use in the Development and Operation of Geothermal Power Plants," September 9, 2010, https://www.osti.gov/biblio/1013997-ui59Ky/.

[105] GTO projects in a scenario where geothermal power provides 8.5% of electricity capacity of the United States, it would only account for 1.1% of power sector water withdrawals. U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf.

[106] National Renewable Energy Laboratory, "Renewable Electricity Futures Study," National Renewable Energy Laboratory, NREL/TP-6A20-52409, Golden, CO, https://www.nrel.gov/analysis/re-futures.html.

[107] Ron DiPippo, *Geothermal Power Plants: Principles, Applications and Case Studies* (Elsevier Science, 2005), https://www.sciencedirect.com/book/9781856174749/geothermal-power-plants.

may wish to consider that could impact the development and deployment of EGS. The major areas of consideration are outlined below.

Federal Tax Incentives

Investment in geothermal technologies is currently supported by federal tax incentives. There is a permanent 10% investment tax credit for taxpayers investing in geothermal property, defined as "equipment used to produce, distribute, or use energy derived from a geothermal deposit."[108] Geothermal energy technologies also qualify for the renewable electricity PTC, a per-kWh tax credit for electricity generated using qualified energy resources.[109] Currently, the PTC is available for qualifying facilities that began construction before the end of 2021. In the past, this construction deadline has been changed as part of "tax extenders" legislation.[110] Taxpayers are also allowed a five-year cost recovery period for investments in geothermal energy property. Most electricity-generating property is depreciated over 20 years; thus, five-year cost recovery benefits taxpayers by allowing investments costs to be recovered more quickly.

Congress could consider whether to modify and extend tax credits supporting geothermal energy projects. One option would be to allow tax credits to be received as direct payments. Depending on how these payments are structured, they could be designed to accommodate tax-exempt entities, including government and tribal entities (for example, municipal power producers).[111] Congress might also examine the duration of the tax credits and their incentive periods to ensure they accommodate the longer project development timeframes of geothermal projects.

Improving Coordination for Federal Leasing and Permitting Processes and Regulatory Requirements

There are opportunities where Congress could establish or otherwise support communication and coordination between multiple federal, state, local, and tribal entities and non-governmental entities for geothermal projects. This could include addressing common definitions and qualifications for renewable energy projects, portfolio standards, or renewable electricity standards.[112] It could also include coordinating subsurface resource access rights across or between states, and coordinating partnerships including federally-supported research institutes, public-private-partnerships, and others.

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108 Internal Revenue Code (IRC) Section 48. For additional information, see CRS In Focus IF10479, *The Energy Credit or Energy Investment Tax Credit (ITC)*, by Molly F. Sherlock.

109 IRC Section 45. For more information, see CRS Report R43453, *The Renewable Electricity Production Tax Credit: In Brief*, by Molly F. Sherlock.

110 For more information, see CRS Report R46451, *Energy Tax Provisions Expiring in 2020, 2021, 2022, and 2023 ("Tax Extenders")*, by Molly F. Sherlock, Margot L. Crandall-Hollick, and Donald J. Marples.

111 DOE's Office of Indian Energy Policy and Programs provides financial assistance for energy development. For more information, see CRS In Focus IF11793, *Indian Energy Programs at the Department of Energy*, by Corrie E. Clark and Mark Holt.

112 Electricity portfolio standards require utilities to procure a percentage of electricity from specified eligible sources and are designed to change the set of energy sources used to generate electricity over time. Similarly, renewable electricity standards require that a minimum share of electricity is generated from eligible renewable sources. For more information see CRS In Focus IF11316, *A Brief History of U.S. Electricity Portfolio Standard Proposals*, by Ashley J. Lawson, and CRS Report R46691, *Clean Energy Standards: Selected Issues for the 117th Congress*, by Ashley J. Lawson.

Congress established and has updated the qualifications and regulations regarding leasing of resources on federal lands, and as EGS technologies enable access to more resources in more locations these regulations will likely need to be revisited to accommodate new developments. The Mineral Leasing Act of 1920 (P.L. 66-146) established the federal regulations relating to leasing federal land for minerals, including hydrocarbons. The Geothermal Steam Act of 1970 (P.L. 91-581) expanded these regulations to cover geothermal energy, and since then these acts have been updated to expand and refine the definitions and regulations to include further developments such as EGS and resource extraction from geothermal brines.[113]

In the 117th Congress, several bills, including the Enhancing Geothermal Production on Federal Lands Act of 2021 (S. 2824, H.R. 5350), have sought to address categorical exclusions. Current categorical exclusions under NEPA attempt to decrease the review time needed for some geothermal power development projects by reducing the number of environmental impact reviews required.[114] The current exclusions are not as effective as similar exclusions available to O&G,[115] so geothermal projects—when compared to similar O&G projects—require additional drilling permits and environmental impact assessments. Revising these categorical exclusions could reduce the length of the geothermal project development lifecycle. Alternatively, Congress could consider narrowing the exclusions to ensure that the impacts of geothermal projects are considered.

Congress could consider various amendments to federal leasing and permitting processes. Federal agencies, such as DOE GTO, and industry organizations, such as the Atlantic Council, have identified a need for dedicated funding for agencies which process geothermal leasing and permitting applications (e.g., Bureau of Land Management and Forest Service offices) to address bottlenecks in those processes.[116]

Congress could consider establishing or expanding frameworks for memoranda of understanding (MOU). MOUs explain how two or more agencies (including state authorities) interact when their authorities or responsibilities overlap. They can reduce duplication of effort when entities seek to meet multiple regulatory requirements, can reduce conflicts between regulatory requirements, and can coordinate data collection or other actions supporting regulatory oversight to speed up permitting and other development activities.[117]

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113 Energy Independence and Security Act of 2007 (P.L. 110-140) and the Energy Act of 2020 (Division Z of P.L. 116-260).

114 Categorical exclusions are "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 U.S.C. §1508.4.

115 U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf.

116 U.S. Department of Energy, Geothermal Technologies Office, *GeoVision: Harnessing the Heat Beneath Our Feet*, May 2019, https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf; Zachary Strauss, "Unearthing Potential: The Value of Geothermal Energy to US Decarbonization," The Atlantic Council, March 2022, https://www.atlanticcouncil.org/in-depth-research-reports/report/unearthing-potential-the-value-of-geothermal-energy-to-us-decarbonization/.

117 One example MOU was created by multiple agencies in October 2021 to improve renewable energy project permitting coordination. Another MOU implements Section 225 of the Energy Policy Act of 2005 Regarding Geothermal Leasing and Permitting. U.S. Department of the Interior, "MOU to Establish a Program to Improve Public Land Renewable Energy Project Permit Coordination," October 1, 2021, https://www.doi.gov/sites/doi.gov/files/mou-esb46-04208-pub-land-renewable-energy-proj-permit-coord-doi-usda-dod-epa-doe-2022-01-06.pdf.

Supporting Technology Transitions and Adaptations from Fossil Fuel Sectors

O&G assets often become stranded when wells, plant infrastructure, or other equipment with remaining service lifetimes are no longer economically viable to operate. Similarly, in these circumstances jobs in these sectors can be lost, and the skilled and experienced workforce is idled or gets other jobs that do not use its energy production knowledge. EGS can potentially make use of some of the technologies, equipment, tools, and infrastructure the fossil fuel industry has already developed or is developing (e.g., well drilling equipment, support equipment like down-well sensors, installation and stimulation technology, power plant systems, pipelines, old wells, well right-of-ways, and offshore drilling platforms), while also potentially leveraging the knowledgeable and experienced workforce from the legacy fossil energy sectors. With some retraining or refocusing, EGS could use workers with experience in areas such as underground resource identification, well drilling and completion, infrastructure installation, and power plant operation. Congress could consider laws supporting and encouraging technology transfer and adaptation from fossil fuel sectors, including reuse of idled assets, retraining of skilled workforce, and RD&D to adapt technologies for use in geothermal energy conditions.[118]

Federal Support for Geothermal Technologies via RD&D

Congress has provided funding for RD&D of geothermal energy technologies via many federal agencies and programs. As EGS are a relatively new technology, they will require considerable additional investment to develop, adapt, and prove new technologies to enable greater deployment and to mitigate potential negative impacts of implementation. The major technology RD&D areas for EGS include:

- resource discovery/detection, sensing, characterization, and measurement;
- advanced drilling technologies, like new bit materials, high-temperature motors, and alternative drilling technologies;[119]
- data-driven drilling optimization methods;
- reservoir modeling, simulations, and management tools;
- advanced stimulation strategies and processes; and
- critical materials extraction/recovery technologies.

The IIJA (P.L. 117-58) included some provisions relating to geothermal power.[120] It provided $84 million for EGS pilot demonstration projects. DOE has since issued a request for information to support EGS pilot demonstration project funding.[121] The IIJA also included broader programs and

[118] One current law that supports this kind of transition is the Inflation Reduction Act of 2022 (P.L. 117-169), which includes an extension of the Renewable Electricity Production Tax Credit (Section 45) and adds a 10% bonus for renewable energy facilities in "energy communities"—brownfield sites or fossil fuel communities.

[119] Millimeter wave technology and other drilling technologies could improve geothermal project economics and allow access to a greater depth of resources including supercritical geothermal resources. Alexander Richter, "Disruptive Drilling Technology to Help Geothermal Power the World," ThinkGeoEnergy.com, June 18, 2021, https://www.thinkgeoenergy.com/disruptive-drilling-technology-to-help-geothermal-power-the-world/.

[120] CRS Report R47034, *Energy and Minerals Provisions in the Infrastructure Investment and Jobs Act (P.L. 117-58),* coordinated by Brent D. Yacobucci.

[121] U.S. Department of Energy, "DOE Launches $84 Million Program to Demonstrate Enhanced Geothermal Energy Systems," Energy.gov, April 19, 2022, https://www.energy.gov/articles/doe-launches-84-million-program-demonstrate-

funding support for building long-distance electric power transmission lines which could support more geothermal development. It also established the DOE Office of Clean Energy Demonstrations (Section 41201), which can include geothermal projects (as well as other projects in renewables, nuclear, and carbon capture and storage). The IIJA appropriated $21.456 billion for this new office, though none of the current funds are specifically dedicated to geothermal projects. The number and extent of EGS demonstration projects are currently limited by their relatively high costs compared to other energy demonstration projects.

Funding for other DOE offices and other federal agencies also supports geothermal technology development, workforce training, and deployment. The Consolidated Appropriations Act, 2022 (P.L. 117-103, Division D) provided funding for DOE's Office of Energy Efficiency and Renewable Energy (EERE) totaling $3.20 billion for FY2022.[122] The joint explanatory statement recommended that of the total funding for EERE, $109.5 million be directed to geothermal technologies. For FY2023, the budget request for GTO is $202 million.[123]

Congress could consider coordinating geothermal power RD&D projects with other federal activities like carbon capture and storage, carbon capture and utilization, or subsurface energy storage projects.[124] These other projects could benefit from the subsurface data collection, sensing technologies, or subsurface management technologies (such as geochemical modeling and control) critical to geothermal projects. This could include dedicated research funding for geothermal projects coordinating with other RD&D programs like those within DOE's Office of Fossil Energy and Carbon Management (formerly the Office of Fossil Energy).

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enhanced-geothermal-energy-systems.

[122] For more information, see CRS In Focus IF11948, *DOE Office of Energy Efficiency and Renewable Energy FY2022 Appropriations*, by Corrie E. Clark and Melissa N. Diaz.

[123] U.S. Department of Energy, *Department of Energy FY2023 Congressional Budget Request*, March, 2022, https://www.energy.gov/sites/default/files/2022-03/doe-fy2023-budget-in-brief-v2.pdf. For appropriations within U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), see CRS In Focus IF11948, *DOE Office of Energy Efficiency and Renewable Energy FY2022 Appropriations*, by Corrie E. Clark and Melissa N. Diaz.

[124] The Energy Act of 2020 (part of the Consolidated Appropriations Act, 2021; P.L. 116-260) prioritized carbon capture and storage and carbon capture and utilization and increased funding for research, development, and deployment projects on those technologies.

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