Mining G.O.L.D. (Geothermal Opportunities Leveraged Through Data): Exploring Synergies Between the Geothermal and Mining Industries

Aaron Levine, Greg Rhodes, and Allison Kvien

National Renewable Energy Laboratory

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Acronyms

AML	abandoned mine lands
ARD	acid rock drainage
BAU	business as usual
BLM	Bureau of Land Management
CAPEX	capital expenditures
CX	categorical exclusion
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FLPMA	Federal Land Policy and Management Act of 1976
GDP	Geothermal Drilling Permit
GETEM	Geothermal Electricity Technology Evaluation Model
GML	General Mining Law of 1872
GSA	Geothermal Steam Act of 1970
GTO	Geothermal Technologies Office
LCOE	levelized cost of energy
MRT	maximum registering thermometer
NEPA	National Environmental Policy Act of 1969
NOI	notice of intent
NREL	National Renewable Energy Laboratory
USGS	U.S. Geological Survey

Executive Summary

The locatable mineral industry is shifting toward improving environmental performance and becoming more sustainable, with numerous mining companies shifting to renewable energy technologies to power mine operations[1] and at least one company pledging net-zero emissions by 2050.[2] One potential electricity source to help achieve improved environmental performance and decarbonization within the mining industry is geothermal energy. As part of a study into potential collaboration between the geothermal and locatable mineral industries (focused on the portion of the Basin and Range Province within Nevada), the National Renewable Energy Laboratory (NREL) with support from the U.S. Department of Energy (DOE) Geothermal Technologies Office (GTO), investigated data, economic, and regulatory factors that may contribute to or inhibit synergies between the two industries. The objectives of the study included analyzing:

- The type and quality of data collected by the locatable mineral industry to determine feasibility for geothermal resource exploration
- The regulatory pathways and potential barriers that could prevent development of geothermal resources discovered via a mining claim (and vice versa)
- The historical development of geothermal resources discovered via mineral exploration data
- The value propositions for both the locatable mineral and the geothermal industries to collaborate.

In furtherance of these objectives, this paper provides an overview of and analyzes foreseeable synergies between the geothermal and locatable mineral industries. In particular, this paper discusses: (1) the potential for the discovery of undiscovered hydrothermal geothermal resources through mining exploration data; (2) the regulatory processes associated with exploring for and developing locatable minerals and geothermal resources on federal (and some state) public lands; (3) case studies of synergies between mining data and operations with energy project development; and (4) techno-economic analysis of various locatable mineral and geothermal synergies.

This study found that many of the data collected by the mining industry as part of locatable mineral exploration (e.g., copper, gold, lithium) could also be useful for identifying and developing previously unknown geothermal resources (and in some notable cases, already have led to geothermal resource development). In addition, for minimal costs, the mining industry could catalogue these data and potentially monetize the data itself or use the data in the future to develop a geothermal project. Leveraging these locatable mineral data to develop geothermal resources and/or co-located minerals and geothermal resources could represent significant cost savings when compared to developing geothermal resources under a business-as-usual scenario as well as compared to current generating technologies (e.g., diesel-powered generators)

[1] Deign, J. 2020. "Mining Giants Embrace Renewables, But Decarbonization Remains a Steep Climb." *Green Tech Media*. https://www.greentechmedia.com/articles/read/mining-giants-embrace-renewables-but-decarbonization-remains-a-steep-climb.
[2] *2019 Climate Change Report: Our Approach to Climate Change*. 2019. Rio Tinto. https://www.riotinto.com/en/sustainability/climate-change.

employed at remote mining operations. Ultimately, leveraging mining industry data, knowledge, and expertise serves to effectively expand the geothermal exploration workforce, increase the rate of geothermal resource discovery, and potentially reduce geothermal electricity's levelized cost of energy (LCOE) by 23%–29%. The LCOE for geothermal electricity[3] under a business-as-usual scenario is approximately $87/megawatt-hour (MWh)[4], while the LCOE for geothermal electricity discovered through a mineral exploration scenario is approximately $65–$67/MWh. This compares favorably to the LCOE for diesel generation (used at many remote mining sites) of $109–$185/MWh. Overall, this represents a potentially significant cost savings for the locatable mineral industry.

In addition, geothermal projects may be favored at active mining sites with viable geothermal resource potential over other renewable sources because there are technical roadblocks associated with the intermittency of wind and solar generation.[5] Mining operations are typically designed to operate 24 hours per day and 365 days per year[6]; as a result, they require a stable source of baseload electricity, which pairs well with geothermal generation profiles.[7] When mining companies plan for mine site energy requirements, they must consider not only a 24-hour cycle of variability, but also variability across seasons and multiyear cycles, such as El Niño, to ensure power is always available.[8]

[3] LCOE assumes a binary hydrothermal powerplant.
[4] The findings of this study are generally consistent with the National Renewable Energy Laboratory's 2020 Annual Technology Baseline of $86/MWh. NREL. 2020. "2020 Annual Technology Baseline. 2020. Golden, CO: National Renewable Energy Laboratory. https:// atb.nrel.gov/.
[5] Maennling, N., and P. Toledano. 2018. *The Renewable Power of the Mine—Accelerating Renewable Energy Integration*. Columbia Center on Sustainable Investment. http://ccsi.columbia.edu/work/projects/the-renewable-power-of-the-mine/.
[6] *Id.*
[7] *Id.*
[8] *Id.*

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1 Introduction

The locatable mineral industry (e.g., copper, gold, lithium) is moving toward improving environmental performance and becoming more sustainable, with numerous mining companies shifting to renewable energy technologies to power mine operations[9] and at least one company pledging net-zero emissions by 2050.[10] One potential electricity source to help achieve improved environmental performance and decarbonization within the mining industry is geothermal energy. As part of a study into potential collaboration between the geothermal and locatable mineral industries (focused on the portion of the Basin and Range Province within Nevada), the National Renewable Energy Laboratory (NREL) with support from the U.S. Department of Energy (DOE) Geothermal Technologies Office (GTO), investigated data, economic, and regulatory factors that may contribute to or inhibit synergies between the two industries. The objectives of the study included analyzing:

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[9] Deign, J. 2020. "Mining Giants Embrace Renewables, But Decarbonization Remains a Steep Climb." *Green Tech Media*. https://www.greentechmedia.com/articles/read/mining-giants-embrace-renewables-but-decarbonization-remains-a-steep-climb.

[10] *2019 Climate Change Report: Our Approach to Climate Change*. 2019. Rio Tinto. https://www.riotinto.com/en/sustainability/climate-change.

2 Utility of Mineral Exploration Data to Discover Geothermal Resources

DOE's 2019 *GeoVision* report notes that each year, the geothermal industry discovers only ~1% of the estimated 23 gigawatts-electric (GWe) of undiscovered hydrothermal resources that are realistically available for development in the conterminous United States.[11] The *GeoVision* report found that by improving the discovery rate of these resources, the installed geothermal capacity in the United States could increase significantly.[12] To understand how mineral exploration data might accelerate geothermal resource discovery, Nevada was chosen because it hosts both extensive mineral exploration activities, resulting in more than 80% of annual U.S. gold production,[13] and extensive undiscovered geothermal resources estimated at more than 3,000 megawatts (MW).[14] As documented later in this report, several geothermal resources have been discovered through mineral exploration to date. NREL collected and reviewed public and private mining-related data, which are listed with links at the bottom of Section 2.3, to determine data quality and utility for geothermal resource discovery. However, NREL did not validate the accuracy of publicly available data identified by this study.

Numerous available public mining databases of varying data types contain information that is relevant to geothermal exploration and development. Also, as the locatable mineral industry is currently a significantly larger industry than geothermal[15], data collected through mineral exploration are both more extensive and cover a larger spatial distribution than those from geothermal. Much of the relevant information is related to the geology and alteration of mineral deposits in Nevada, but additional data useful to geothermal exploration may be available that provide temperature, fluid chemistry, remotely sensed properties, and local stress conditions. These data types would typically be collected as part of a geothermal exploration campaign and represent potential time and cost savings when available at project inception. Such data have the potential to inform both exploration for undiscovered geothermal resources and development of known resources by providing detailed site characteristics and direct or indirect evidence of a geothermal occurrence. Ayling (2020) estimates that only ~10% of the potential 5,755 megawatts-electric (MWe) hydrothermal resources in Nevada (enough to power roughly ~4.5M homes[16]) have been developed,[17] and some studies suggest up to 75% of these systems may have

[11] DOE. 2019. *GeoVision: Harnessing the Heat Beneath Our Feet*. DOE/EE-1306. https://www.energy.gov/eere/geothermal/downloads/geovision-harnessing-heat-beneath-our-feet.

[12] For general information on exploration methods for discovering hidden geothermal systems, see Dobson, Patrick F. 2016. "A Review of Exploration Methods for Discovering Hidden Geothermal Systems." *GRC Transactions, Vol. 40.* https://publications.mygeoenergynow.org/grc/1032385.pdf.

[13] Perry, R. 2018. Mineral Production Press Release, Nevada Division of Minerals.

[14] Williams, C.F., M.J. Reed, R.H. Mariner, J. DeAngelo, and P. Galanis. 2008. "Assessment of Moderate- and High-Temperature Geothermal Resources of the United States." U.S. Geological Survey Factsheet. https://pubs.usgs.gov/fs/2008/3082/.

[15] Muntean, J.L., D.A. Davis, and B. Ayling. 2018. *The Nevada Mineral Industry 2017: Nevada Bureau of Mines and Geology Special Publication.* MI-2017, 212 p.

[16] U.S. Energy Information Administration. 2019. "Frequently Asked Questions." https://www.eia.gov/tools/faqs/faq.php?id=97&t=3.

[17] Ayling, B.F. 2020. "35 Years of Geothermal Power Generation in Nevada, USA: A Review of Field Development, Generation, and Production Histories." Proceedings of the 45th Workshop on Geothermal Reservoir Engineering, Stanford University, 12p. https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2020/Ayling.pdf.

no active surface expression.[18] One MWe capacity is enough to power a gold mining operation producing ~22,000 ounces annually[19]. By leveraging mineral exploration data and efforts, it is possible to more thoroughly canvas an expansive state hosting abundant geothermal potential.

One example of joint mineral geothermal exploration efforts currently underway involves an interagency agreement—the Geoscience Data Acquisition for Western Nevada, or GeoDAWN[20]— which partners GTO with the U.S. Geological Survey (USGS) of the U.S. Department of the Interior to help provide solutions to U.S. needs for both energy and critical minerals. Under the GeoDAWN collaboration, researchers from the USGS Earth Mapping Resource Initiative (Earth MRI) and the USGS 3D Elevation Program (3DEP) will gather new surface and subsurface data in the Walker Lane geologic zone in western Nevada. GeoDAWN researchers will apply machine learning to lidar and aeromagnetic data collection from this area that is rich in both geothermal and mineral resources to develop deeper understanding of the geologic conditions and stress regime that give rise to these resources. The work also aligns with GTO's mission to reduce the risks and costs associated with geothermal exploration and production, as well as with DOE's broader strategic commitment to provide complementary assessments of critical and strategic minerals.

This section describes available data as well as certain data that are collected by mining companies but were not available for this study due to their proprietary status. Because this study relied on the availability of mining-related data to determine relevance to geothermal exploration, any barrier to data acquisition limited this analysis. The main barriers when seeking mining data from mining companies are their reluctance to provide access to any proprietary information or a lack of knowledge about how to properly value data that are not currently perceived as immediately useful to the mining company for the purpose of locatable mineral exploration activities. This study aims to influence this thinking by demonstrating the unrealized value of these data, which could be used for other purposes (e.g., temperature data for geothermal resource exploration).

2.1 Temperature Data

Directly measured subsurface temperatures and gradients (i.e., temperature change with depth) are some of the most useful tools for geothermal exploration and predicting reservoir temperatures. Few measured temperatures are found in publicly available mining databases, but this study discovered several indirect references during the geologic data query. The State of Nevada Division of Water Resources Well Driller's report contains water quality categories including static water level, artesian flow rate, pressure, and temperature; however, mineral exploration holes that are not used as water supply wells are not regulated by the same reporting form. Mineral exploration companies are not required to notify the state of Nevada if they encounter hot fluid, and there is no requirement to collect a temperature log. However, indirect and often anecdotal indications of elevated temperatures can occasionally be found in drilling

[18] Coolbaugh, M.F., G.L. Raines, R.E. Zehner, L. Shevenell, and C.F. Williams. 2006. "Prediction and discovery of new geothermal resources in the Great Basin: Multiple evidence of a large undiscovered resource base." https://pubs.er.usgs.gov/publication/70028672.
[19] Bleiwas, D.I. 2011. *Estimates of Electricity Requirements for the Recovery of Mineral Commodities, with Examples Applied to Sub-Saharan Africa*. USGS Open-file Report 2011-1253, 100 p.
[20] https://www.usgs.gov/media/images/geodawn-geoscience-data-acquisition-western-nevada

records; for example, when recorded, references to steam, geysering, hot pipe, increased mud temperatures, artesian flow, and boiling can indicate anomalous geothermal activity in locations which may end up being subeconomic grade and otherwise overlooked from a mineral resource perspective.

In addition, many mines operate below the natural water table, which requires dewatering activities. The fluid associated with dewatering activities often has elevated temperatures, several examples of which have been identified during this study. If indications of temperature were more systematically documented throughout the mineral exploration process, they would serve to enhance the spatial resolution of geothermal gradient data. However, many mineral exploration holes are drilled at an angle, and most mining companies collect directional hole surveys and occasionally borehole image logs. Most surveying tools contain an internal temperature sensor to ensure the tool is not operating at temperatures above manufactured capability. Sensors record a temperature at the same time and depth as the directional measurement, thus providing an unequilibrated record of temperature with depth (i.e., geothermal gradient). For a more reliable measurement of subsurface temperatures, equilibration is preferred because drilling fluid can cool the natural formation temperatures. However, despite this, survey readings toward the bottom of the hole are least impacted by these drilling effects and may provide temperature data that more closely approximates equilibrated formation temperatures. These temperatures are typically included with the delivered directional survey data but are infrequently analyzed by the end user. Consequently, directional survey providers likely possess a vast database of unequilibrated subsurface temperature data and in some cases particularly useful bottom-hole temperature measurements, which is proprietary and may be publicly unavailable to analyze, but nevertheless of tremendous value to geothermal resource exploration. If these data can be accessed, this feature of surveying tools may represent a significant opportunity to identify undiscovered geothermal occurrences in Nevada and in other geographic regions with geothermal resource potential.

As part of this study, after being granted access by a claim holder, NREL reviewed a private database of deviation surveys for a mineral prospect in central Nevada that revealed increasing temperatures with depth and variability throughout the prospect (Figure 1). The variability likely represents differences in lithology, permeability, water level, fluid composition, degree of equilibration, thermal conductivity, and convective circulation; however, additional confidence and validation would require further site-specific geothermal analysis and—importantly—temperature equilibration. The two distinct near-surface populations were interpreted to represent two collection campaigns at different times of the year and different ambient temperature conditions; higher near-surface temperatures were measured during summer months, and the lower temperatures were measured during winter. The lower half of the temperature measurements, likely below the water table and insulated from ambient impacts, mostly indicates increasing temperatures with depth and a maximum temperature of 151°F with geothermal gradient of ~10.5°F/100'—significantly higher than background gradients in Nevada, which typically range from ~2–3°F/100'.[21] Assuming the gradient continues at depth, 10.5°F/100' would suggest that a temperature of 300°F (a typical power-producing temperature) could be reached approximately 1,400' deeper than the 151°F measurement. These temperatures and

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[21] Blackwell, D.D., Golan, B., and Benoit, D., 2000. "Thermal Regime in the Dixie Valley Geothermal System." *Proceedings World Geothermal Congress*, p. 991-996.

gradients can be contoured in map view and three-dimensionally to analyze thermal distribution in relation to lithology and fault structure. This favorable geothermal gradient identified through a single mineral exploration campaign is just one example of how valuable these abundant data might be to the geothermal industry.

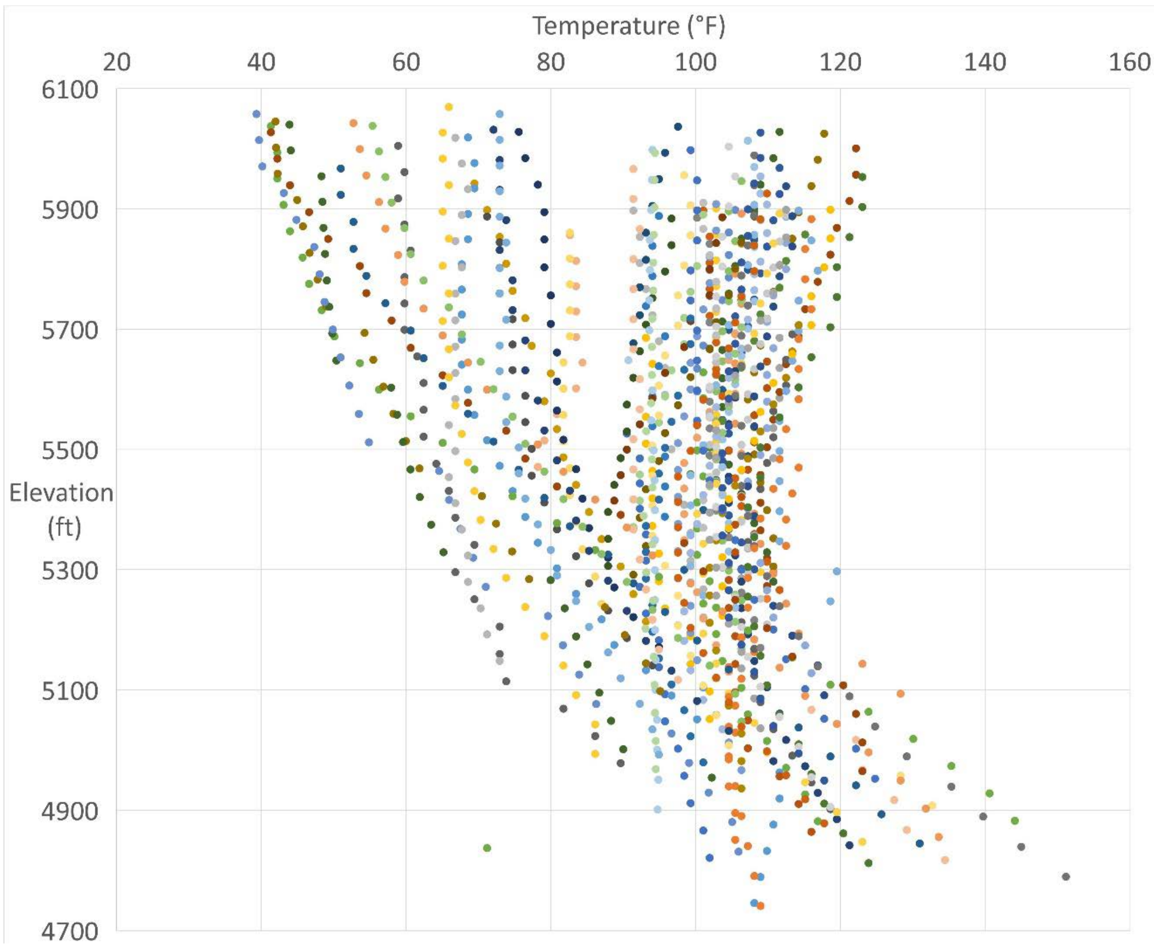

Figure 1. Temperatures in °F with elevations in feet recorded by directional survey tool for 74 mineral exploration holes. Holes are distinguished by color, but names are excluded for privacy.

2.2 Geochemical Data

Chemical geothermometry is also an important exploration technique used by the geothermal industry to estimate reservoir conditions from fluid or gas samples.[22] This technique is an inexpensive tool for estimating geothermal reservoir temperatures and identifying temperatures that have electricity-generating potential. The National Uranium Resource Evaluation Program (see link below in Section 2.3) is a geochemical database that can be used to estimate geothermal reservoir temperatures using chemical geothermometry. In addition, the USGS Core Library and Data Center (see link below in Section 2.3) in Mercury, Nevada, houses hydrologic data for the Nevada National Security Site and surrounding area. Depending on the phase of exploration and permitting, mineral exploration companies presumably have aqueous geochemical data from environmental monitoring and drilling activities including water supply wells, artesian holes, mine dewatering, etc. These data, depending on quality and fluid sample collection methods, should be analyzed using geochemical forensics to understand reservoir hydrology and, when possible, to estimate geothermal reservoir temperatures using geothermometry techniques.

2.3 Geologic Data

Finding and developing geothermal resources requires sufficient understanding of regional and local geology, hydrology, and hydrothermal alteration. This study identified multiple public databases containing geologic surface and subsurface information useful for geothermal exploration. Most of the databases are free of charge, though a few require a usage fee. Data consist of rock, cutting, and core samples and descriptions; well logs; surface maps; reports; photographs; and geochemical analyses. This study queried these databases for potential geothermal-related terminology and successfully identified several prospective areas warranting additional analysis, which were not previously well known to the geothermal community. Due to the long history of the Nevada mining industry, there is significant variation in data descriptions and quality in addition to antiquated terminology,[23] which can present challenges when relating these data to geothermal exploration. Queries for terms indicative of elevated temperatures must reflect such variability. Some of the databases leveraged in this study have been used by geothermal project developers at specific prospects, but a systematic review may provide additional geologic knowledge for the known geothermal resource inventory. The data can be used to better understand regional geology, explore for target rock and alteration types, and provide site-specific geology, alteration, and rock properties. These geologic data can then inform geophysical surveys and modeling (e.g., density values for gravity or magnetic susceptibility for magnetic surveys) as well as geochemical analyses (e.g., fluid equilibration based on host rock or alteration types as a proxy for reservoir temperature). Alteration age as well as alteration type can potentially indicate geothermal potential because many epithermal mineral deposits younger than ~7–10 million years are spatially associated with active

[22] Ellis, A.J. 1979. "Chemical Geothermometry in Geothermal Systems." *Chemical Geology*, Vol. 25, p 219–226; Giggenbach, W.F. 1991. "Chemical techniques in geothermal exploration." *Application of Geochemistry in Geothermal Reservoir Development.* UNITAR/UNDP Center on Small Energy Resources, p. 119–44; Reed, M.J. 2007. "Geothermometer Calculations for Geothermal Assessment." *GRC Transactions*, Vol. 31, p. 89–92; Peiffer, L., Wanner, C., Spycher, N., Sonnenthal, E., and Kennedy, B.M. 2013. "Multicomponent vs. Classical Geothermometry: An Evaluation Using Reactive Transport Modeling." *Procedia Earth and Planetary Science*, Vol. 7, p. 665–668.

[23] For example, potential hydrothermal silica terms include: opal, chalcedony, sinter, amorphous, siliceous, quartz, fiorite, perlite, amatite, geyserite.

geothermal systems.[24] This association likely results from the relative consistency of Basin and Range tectonism and regional stress state during that time. This spatial association also means that geothermal exploration data have the potential to inform mineral exploration (e.g., cuttings assay).

Applicable databases include:

- Nevada Bureau of Mines and Geology (NBMG) Great Basin Science Sample and Records Library
- NBMG Nevada Mining District Database
- NBMG Mineral Industry and Exploration Reports
- County Mineral Reports
- Anaconda Mining Database at University of Wyoming
- USGS Core Library and Data Center, Mercury, Nevada
- USGS Core Library, Denver, Colorado
- USGS Mineral Resources Data System
- University of Utah Energy & Geoscience Research Catalog
- Core Database Utah Geological Survey
- Hydrothermal alteration in the Basin and Range, western US
- National Mine Map Repository
- National Uranium Resource Evaluation Program

2.4 Remote Sensing Data

Hydrothermal alteration maps of the central Basin and Range Province within Nevada generated by the USGS from multispectral Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data obtained by NASA's Terra satellite were originally intended to aid mineral exploration[25]. These same publicly available data can guide geothermal exploration by remotely indicating hydrothermal clay and silica alteration and precipitant products. Relative ages and recency of hydrothermal activity can be estimated by identifying hydrothermal indicator minerals and spatially relating them to Holocene faulting, alluvial deposits, and former lake shorelines.[26] Most of these datasets are hosted by the USGS, but more recent flights in 2014 that include coverage over western Nevada are available through the National Aeronautics and Space Administration (NASA). In support of a new satellite called Hyperspectral Infrared Imager (HyspIRI), NASA flew a high-altitude aircraft mounted with the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and the MODIS/ASTER Airborne Simulator

[24] Coolbaugh, M.F., G. Arehart, F. Faulds, L. Garside, and L. Shevenell. 2005. "Active Geothermal Systems and Associated Gold Deposits in the Great Basin." *GRC Transactions*, Vol. 29, p. 215–221.
[25] Mars, J.C., 2013, Hydrothermal alteration maps of the central and southern Basin and Range province of the United States compiled from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data (ver. 1.1, April 8, 2014): U.S. Geological Survey Open-File Report 2013–1139, 5 p., 13 plates, scale 1:1,300,000, http://dx.doi.org/10.3133/ofr20131139.
[26] Kratt, C., W. Calvin, and M. Coolbaugh. 2004. "Hyperspectral Mineral Mapping for Geothermal Exploration on the Pyramid Lake Paiute Reservation, Nevada." *GRC Transactions*, Vol. 29, p. 273–275;
Silver, E., R. MacKnight, E. Male, W. Pickles, P. Cocks, and A. Waibel. 2011. "LiDAR and Hyperspectral Analysis of Mineral Alteration and Faulting on the West Side of the Humboldt Range, Nevada." Geological Society of America.

(MASTER). This project is no longer operational, but preliminary partially processed data are currently being used by the mineral exploration industry to identify hydrothermal alteration. Additional processing customized for geothermal exploration would provide a useful regional exploration tool.

2.5 Stress Data

Stress indicators and measurements are collected by exploration geologists and geomechanical contractors in the mining industry to help guide open pit construction and underground operations. These data are not available publicly, but could help the geothermal industry understand the regional stress state, local controls on fracture permeability in co-located geothermal reservoirs, and how the stress state might influence geothermal operations including drilling, production, and injection. Examples of useful geomechanical data include fault surface kinematic indicators, laboratory tests on core samples, rock quality data, and borehole image logs used to interpret drilling-induced fractures. Regional stress data have been used to inform permeability favorability and geothermal exploration efforts such as DOE's Play Fairway Analysis. Any additional data points will help to further improve the resolution of regional stress maps. Ideally, the mining industry should share this type of information with the USGS, the Nevada Bureau of Mines and Geology, or the World Stress Map, a project to compile stress-field data throughout the world[27].

[27] http://www.world-stress-map.org/

3 Regulatory Overview of Geothermal and Locatable Mineral Development

Because locatable mineral resources and geothermal resources both lie beneath the surface, the locatable mineral and geothermal industries frequently engage in a similar resource exploration process. Although the exploration process for the two industries is similar and often involves drilling, each industry is subject to a different set of laws and regulations governing prospecting and obtaining rights to use their respective resources. As discussed in Section 3.2, a mining claim with a federally approved plan of operations is entitled to exercise a noncompetitive right to geothermal resources included within an approved plan of operation for a mining claim.[28] However, the same is not the case for locatable minerals located within a geothermal lease because a geothermal operator is not entitled to the locatable minerals (e.g., copper, gold, lithium) and any party can stake a mining claim over the geothermal lease.[29] This results in the mining claim holder being entitled to locatable minerals within the staked area. One caveat to this regulatory structure is that the mining claim holder cannot interfere with existing geothermal operations, which in some cases could prevent extraction of the locatable mineral. Under these circumstances, a geothermal operator and mining claim holder may need to work together to both produce the geothermal power and extract the mineral resources. Sections 3.1 and 3.2 provide an overview of the federal and Nevada state regulatory structures that govern geothermal and mineral resource extraction.

3.1 Mining Industry Regulation

The laws and regulations that govern the mining industry's exploration and extraction of minerals vary depending on the type of land being used: federal public lands, state public lands, or private lands. Laws and regulations governing the mining industry also vary depending on the types of minerals that are being extracted. This section reviews the relevant processes governing the exploration of locatable minerals on federal and state public lands in Nevada.

3.1.1 Federal Public Lands

Mineral extraction from federal public lands has been an economically significant activity since at least 1848.[30] The laws governing the mining industry are among the oldest in the United States. The U.S. Department of Interior's Bureau of Land Management (BLM) is the federal

[28] 43 C.F.R. § 3204.12.

[29] The GSA defines "geothermal resources" as (i) all products of geothermal processes, embracing indigenous steam, hot water and hot brines; (ii) steam and other gases, hot water and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (iii) heat or other associated energy found in geothermal formations; and (iv) any byproduct derived from them (30 U.S.C. § 1001(c)). Further, the GSA defines "byproduct" as any mineral or minerals (exclusive of oil, hydrocarbon gas, and helium) which are found in solution or in association with geothermal steam and which have a value of less than 75 per centum of the value of the geothermal steam or are not, because of quantity, quality, or technical difficulties in extraction and production, of sufficient value to warrant extraction and production by themselves (30 U.S.C. § 1001(d)).

[30] Glicksman, R., and C. Coggins. 2012 (4th edition). *Modern Public Land Law: In a Nutshell*, p. 162–63, West Academic Publishing.

agency responsible for administering the subsurface mineral resources of approximately 700 million acres of federal public land in the United States.[31]

Laws and regulations governing mineral extraction on federal lands vary depending on the type of mineral being extracted. Federal regulations distinguish between: (1) "locatable" minerals, also known as "hardrock" minerals, such as gold, copper, and lithium; (2) "leaseable" minerals, which are typically minerals used for fuel or fertilizer; and (3) "saleable" minerals that are common, such as gravel.[32] Rights to extract locatable minerals on federal subsurface mineral estates are obtained through the General Mining Law of 1872 (GML), and rights to extract non-locatable minerals on federal public lands are obtained through a number of statutes, most notably the Mineral Leasing Act of 1920 and the Materials Act of 1947.[33] The Federal Land Policy and Management Act of 1976 (FLPMA) also plays an important role in governing the exercise of mining rights on lands administered by federal agencies. *This section focuses on the regulation of locatable minerals.*

The General Mining Law of 1872

The GML is the principal law governing locatable minerals on federal lands.[34] Under the GML, citizens of the United States or domestic corporations may explore, discover, and purchase mineral deposits on federal lands that are open for mineral entry.[35] All valuable mineral deposits on these lands are "free and open to exploration and purchase" by citizens and domestic corporations pursuant to GML Section 22.[36] The GML created a self-initiation system under which a person may go physically stake a claim on open public land, post a location notice, and describe the boundaries of the claim.[37] Those who locate valuable minerals on open public lands have the *exclusive* right of possession of the surface for mineral extraction and all minerals within that location, within certain size limitations.[38]

Locators of valuable mineral deposits are entitled to possessory interests through either unpatented mining claims or patented mining claims. Unpatented mining claims provide the locator an exclusive possessory interest in surface and subsurface lands and the right to develop

[31] "Mining Claims and Sites on Federal Lands." 2011. U.S. Bureau of Land Management. https://www.blm.gov/or/programs/minerals/files/claims-pamphlet.pdf.
[32] See: 43 C.F.R. Part 3800 (regulations under the General Mining Law governing locatable minerals); 43 C.F.R. Parts 3000–3100, 3400–3500 (regulations under the Mineral Lands Leasing Act governing leaseable minerals); and 43 C.F.R. Part 3600 (regulations under the Mineral Materials Act governing saleable minerals).
[33] 30 U.S.C. §§ 22 et seq. (General Mining Law); 30 U.S.C. §§ 181–287 (Mineral Lands Leasing Act); 30 U.S.C. §§ 601–604 (Materials Act). The Outer Continental Shelf Lands Act authorizes and governs offshore leasing of submerged lands for production of oil, gas, sulfur, and other minerals. 43 U.S.C. §§ 1331–56.
[34] 30 U.S.C. §§ 22 et seq.
[35] 30 U.S.C. § 22. Some federal lands are off-limits for locatable mineral development, including: national parks, wilderness areas, part of river corridors; acquired lands; wildlife refuges that have not been reopened for development; withdrawals of lands in any management system; lands that are subject to valid pre-existing location claims; and lands designated by Congress as off-limits. See Glicksman and Coggins, *Modern Public Land Law*, *supra* note 30 at 164–65.
[36] 30 U.S.C. § 22; see also 30 U.S.C. §§ 24–25 (proof and affidavit of citizenship).
[37] "Minerals & Mining Law." FindLaw. https://corporate.findlaw.com/business-operations/minerals-amp-mining-law.html.
[38] 30 U.S.C. § 23 (describing mineral claim size limitations).

the minerals.[39] In order to retain the rights to an unpatented claim, claimants must pay a nominal annual claim maintenance fee, which the BLM may adjust for inflation.[40] Patented claims pass title from the federal government to the locator, converting the property to private land, but a congressional moratorium has been in place since 1993 that prevents the issuance of any new patented claims.[41] Where mineral veins of mining claims intersect, Section 41 of the GML provides that the older claim is entitled to all ore or minerals within the intersection, and the subsequent claim is entitled to a right-of-way through the intersection.[42]

Federal Land Policy and Management Act of 1976

The FLPMA governs federal land use, including access to and exercise of mining rights on lands administered by the BLM and the Forest Service. Since FLPMA's adoption in 1976, persons seeking to record a mining claim must file a notice of intent (NOI) with the BLM in order to hold the claim with the federal government.[43] Failure to file a NOI is presumed to be an abandonment of the claim under FLPMA.[44] The BLM regularly cancels mining locations because no NOI was filed or because the NOI was not filed timely within 90 days of location.[45] The BLM requires that any documents filed under state law accompany the official record of notice filed with the BLM.[46]

FLPMA states that mining authorizations must not "result in unnecessary or undue degradation of public lands."[47] The BLM and the U.S. Forest Service have promulgated extensive FLPMA mining regulations.[48] The BLM's mining regulations divide mining operations into three groups: plan mines, notice mines, and casual mines.[49] Plan mines disturb more than five acres per year, notice mines disturb less than five acres per year, and casual mines cause only negligible disturbance.[50] Plan mines must submit a mining plan of operations to the BLM for its approval,

[39] Pursuant to the Surface Resources Act of 1955, mining rights are subject to the rights of the federal government to manage surface resources on claims and to the right of the government, its permittees, and licensees to use the surface for access so long as it does not materially interfere with mining operations. See 30 U.S.C. § 612.
[40] There are exceptions to this claim maintenance fee for small claimants. Before 1992, the GML required that the locator of the unpatented claim perform at least $100 of assessment work each year, which was intended to ensure the maximum development of the mineral resource. See 30 U.S.C. § 28f. For claims located on or after September 1, 2019, the annual claim maintenance fee is $165 for lode claims, mill sites, and tunnel sites and $165 for each 20 acres or portion thereof for placer claims. See Mining Claim Fees, U.S. Bureau of Land Management. https://www.blm.gov/programs/energy-and-minerals/mining-and-minerals/locatable-minerals/mining-claims/fees.
[41] Glicksman and Coggins, *Modern Public Land Law*, supra note 30 at 176.
[42] 30 U.S.C. § 41.
[43] Federal recording regulations specify the information required to record a claim in 43 C.F.R. § 3833.
[44] 43 U.S.C. § 1744(c).
[45] 43 U.S.C. § 1744; 43 C.F.R. § 3833.1.
[46] "Recording a Mining Claim or Site." U.S. Bureau of Land Management. https://www.blm.gov/programs/energy-and-minerals/mining-and-minerals/locatable-minerals/mining-claims/recording. State governments may separately require that claimants file location notice with a county recorder's office, county clerk's office, or borough office, in varying timeframes. *Id.*
[47] 43 C.F.R. § 3809.411(d)(3)(iii).
[48] See 36 C.F.R. §§ 228.1–228.116 (Forest Service minerals regulations); 43 C.F.R. §§ 3000.0–3936.40 (BLM minerals regulations).
[49] 43 C.F.R. § 3809.10 (defining requirements for casual use, notice, and plan operations).
[50] 43 C.F.R. §§ 3809.5 (defining casual use); 3809.11 (plan mines); 3809.21 (notice mines).

notice mines must inform the BLM of operation commencement but do not need to obtain approval, and casual mines do not need to notify BLM of any activity.[51]

The National Environmental Policy Act of 1969

In addition to the GML and FLPMA, one of the most significant areas of regulation that mining development faces is compliance with National Environmental Policy Act of 1969 (NEPA). NEPA establishes a national framework for protecting, maintaining, and enhancing the environment by ensuring that the federal government consider environmental impacts in project planning and decision-making.[52] NEPA review is required for major federal actions, which significantly affect the quality of the human environment.[53] NEPA review may be necessary for a mining project if that project is on federal land, the project receives federal funding or support, or the project requires a federal permit.[54] However, NEPA compliance is not always required for mining projects on federal land. Small notice-level mining operations on BLM-managed federal land do not require NEPA compliance because the BLM does not make a discretionary decision about whether to allow the mining operation.[55] Many initial mining exploration projects fall under the notice-level five-acre threshold and therefore do not have to comply with NEPA.

3.1.2 State Public Lands

States have the authority to lease, sell, exchange, or otherwise manage state-owned mineral lands.[56] Leasing is the most common way that developers obtain mining rights on state-owned mineral lands.[57] A few states provide for both mining claims and permits, other states allow prospecting rights under mineral leases, and some states require neither.[58] Once a developer locates and describes valuable minerals on state-owned lands, the developer is usually able to apply for and obtain a preferred right to a mineral lease.[59] In some states, developers may have to enter a competitive bidding process to secure a mineral lease.[60]

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[51] 43 C.F.R. §§ 3809.5 (defining casual use); 3809.11 (plan mines); 3809.21 (notice mines).
[52] 42 U.S.C. §§ 4321, 4332.
[53] NEPA requires environmental review of "major federal actions" that significantly affect the quality of the human environment. 42 U.S.C. § 4332(c). The definition of "major federal action" is defined NEPA implementing regulations as including "actions with effects that may be major and which are potentially subject to Federal control and responsibility." 40 C.F.R. § 1508.18.
[54] 42 C.F.R. § 1508.15.
[55] 43 C.F.R. § 3809.21; see also 43 C.F.R. Subpart 3809, Subgroups 178–79.
[56] USA: Mining 2020, The International Comparative Legal Guide (February 10, 2019). https://iclg.com/practice-areas/mining-laws-and-regulations/usa.
[57] *Id.*
[58] *Id.*
[59] *Id.*
[60] *Id.*

Nevada State Public Lands
Nevada state lands and parks are not open to mining claim location.[61] Nevada does, however, issue leases on state lands for geothermal resources and leasable minerals, including oil, coal, and gas.[62]

3.2 Geothermal Industry Regulation

The laws and regulations that govern the geothermal industry's exploration and development vary depending on the type of land being used: federal public lands, state public lands, or private lands. This section reviews the relevant processes governing the exploration and development of geothermal resources on federal and state public lands in Nevada.

3.2.1 Federal Public Lands

Geothermal projects developed on federally managed surface and mineral estates are governed by a number of federal laws and regulations. For the purposes of federal mineral regulations, geothermal resources are considered "other minerals," and the BLM oversees their development as the manager of the federal mineral estate.[63] In 1970, Congress created a separate leasing system for geothermal resources on federal public lands through the Geothermal Steam Act of 1970 (GSA).

The Geothermal Steam Act of 1970
The GSA is central to federal geothermal law because it provides the means for leasing and developing geothermal resources on most federally managed public lands.[64] In fact, an estimated 90% of geothermal resources in the United States are located on federally managed lands.[65] Areas under the Department of Defense's jurisdiction are authorized for geothermal development separately, and offshore land is authorized for geothermal development under the Outer Continental Shelf Lands Act.[66] The FLPMA governs the use of federal land for geothermal activities when the project uses a non-federal mineral estate and federally managed surface lands.[67] The BLM's geothermal regulations under the GSA, contained within 43 C.F.R. §§ 3200–3279, permit developers to conduct exploration operations, obtain leasing rights, drill

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[61] Mining Claim Procedures for Nevada Prospectors and Miners. 2019. Nevada Bureau of Mines and Geology. ("Lands not open to mining claim location include, but are not limited to the following: … state parks and other state lands … .")
http://minerals.nv.gov/uploadedFiles/mineralsnvgov/content/Programs/Mining/Mining%20Claim%20Procedures%20Sixth%20Ed%20sp006.pdf;
see also Mineral Royalties: Royalties in the Western States and in Major Mineral-Producing Countries. 1993. GAO/RCED-93-109. U.S. Government Accounting Office. ("Of the 12 western mining states, all except Nevada, which owns only a fraction of a percentage of the land in the state, allow mining on state-owned lands.")
https://www.gao.gov/assets/220/217639.pdf.
[62] NRS §§ 322.010; 322.050.
[63] See Glicksman and Coggins, *Modern Public Land Law*, supra note 30 at 210 (citing United States v. Union Oil Co. of California, 549 F.2d 2171 (9th Cir. 1977); Rosette Inc. v. United States, 277 F.3d 1222 (10th Cir. 2002)).
[64] 30 U.S.C. § 1002.
[65] Young, K., Witherbee, K., Levine, A., Keller, A., Balu, J., and Bennett, M. 2014. "Geothermal Permitting and NEPA Timelines." 38 GRC Transactions 893. http://pubs.geothermal-library.org/lib/grc/1033639.pdf.
[66] See 10 U.S.C. § 2917 (Department of Defense lands); 43 U.S.C. § 1337(k) (Outer Continental Shelf Lands Act leasing).
[67] 43 U.S.C. §§ 1701 et seq.

geothermal wells, and produce power (i.e., utilize) the geothermal resource on public lands open to geothermal leasing.

The BLM issues two types of leases for geothermal development: (1) geothermal leases (i.e., electric generation), which are issued either competitively or noncompetitively, and (2) direct use leases (e.g., commercial heating, agricultural production, fish farming).[68] The GSA generally requires geothermal leases to be awarded competitively to the highest-qualified, responsible bidder.[69] Lands already subject to a locatable minerals mining claim with a federally approved plan of operations, however, may be available to the mining claim holder for noncompetitive geothermal leasing, but may still be nominated for competitive lease if the noncompetitive right is not exercised.[70] Lands that do not receive a bid at a competitive lease sale are also available for noncompetitive leasing for two years following the lease sale.[71] The BLM may issue a direct use lease to an applicant if: (1) the lands included are open to geothermal leasing, (2) the BLM determines that the lands are appropriate for exclusive direct use operations, (3) the acreage in the application is appropriate, (4) the land has gone through a 90-day period of notice during which it was not nominated for a competitive lease sale, (5) there is no competitive interest in the resource, and (6) the applicant is the first qualified applicant.[72]

In order to conduct geothermal exploration operations[73], developers must first receive an approved NOI to conduct exploration operations (available even without obtaining a geothermal lease).[74] The BLM has the discretion to attach conditions of approval to the NOI, limit the depth of temperature gradient well drilling, or deny the NOI.[75] If the BLM issues an approved NOI, that NOI—together with any conditions that the BLM attaches—constitutes a developer's geothermal exploration permit.[76] The BLM's regulations limit what constitutes exploration activities; if a developer wishes to make direct contact with the resource, the developer must first obtain lease rights to the land and a Geothermal Drilling Permit (GDP).[77] Geothermal developers may obtain permission to perform well flow tests, produce geothermal fluids, and inject fluids into a geothermal reservoir by obtaining a GDP.[78] The BLM also has the discretion to approve or deny a GDP, as well as issue conditions of approval.[79]

[68] 43 C.F.R. § 3200.6.
[69] 30 U.S.C. § 1003(c); see also 43 C.F.R. § 3203.5.
[70] 43 C.F.R. § 3204.12.
[71] 43 C.F.R. § 3204.5.
[72] 43 C.F.R. § 3205.6.
[73] 43 C.F.R. § 3200.1 defines "exploration operations" as any activity relating to the search for evidence of geothermal resources, where you are physically present on the land and your activities may cause damage to those lands. Exploration operations include, but are not limited to, geophysical operations, drilling temperature gradient wells, drilling holes used for explosive charges for seismic exploration, core drilling or any other drilling method, provided the well is not used for geothermal resource production. It also includes related construction of roads and trails, and cross-country transit by vehicles over public land. Exploration operations do not include the direct testing of geothermal resources or the production or utilization of geothermal resources.
[74] 43 C.F.R. §§ 3250.10–3250.14.
[75] 43 C.F.R. §§ 3251.12; 3252.12.
[76] 43 C.F.R. § 3200.1.
[77] 43 C.F.R. § 3200.1.
[78] 43 C.F.R. § 3260.10.
[79] 43 C.F.R. § 3261.20.

The National Environmental Policy Act of 1969

In addition to the GSA—and similar to the mining industry—one of the most significant areas of regulation that geothermal development faces is compliance with NEPA. As previously mentioned, 90% of geothermal resources in the United States are located on federally managed lands[80]; therefore, analysis under NEPA is required for the development of most geothermal resources. Geothermal projects have unique compliance responsibilities with respect to NEPA.[81] Each phase of a geothermal project could trigger a separate NEPA analysis, conceivably up to six times at a single project.[82]

Some geothermal development activities, however, qualify for a categorical exclusion (CX). A CX is a "category of actions which do not individually or cumulatively have a significant effect on the human environment and which have been found to have no such effect in procedures adopted by a Federal agency … and for which, therefore, neither an environmental assessment nor an environmental impact statement is required."[83] The BLM's regulations include a CX for geothermal exploration that applies to exploration activities covered by an NOI to conduct geothermal resource exploration operations.[84] The BLM uses this CX for all geophysical activities and temperature gradient wells where the activity does not make contact with the resource, does not include new surface disturbance and does not trigger any extraordinary circumstances preventing usage of the CX.[85] This CX is only applicable where the exploration operations do not include temporary or new road construction.[86]

[80] Young, K., K. Witherbee, A. Levine, A. Keller, J. Balu, and M. Bennett. 2014. "Geothermal Permitting and NEPA Timelines." 38 GRC Transactions 893. http://pubs.geothermal-library.org/lib/grc/1033639.pdf.
[81] *Id.*
[82] Those six potential NEPA reviews include the following phases: (1) agency land use planning, (2) pre-leasing, (3) Notice of Intent to Conduct Geothermal Resource Exploration Operations, (4) "exploration drilling" requiring a GDP, (5) well field development requiring a GDP, and (6) power plant and transmission line development requiring a Plan of Operation/Utilization. *Id.*
[83] 40 C.F.R. § 1508.4.
[84] 43 C.F.R. § 3250.11.
[85] Extraordinary circumstances are listed in 43 C.F.R. § 46.215.
[86] *Departmental Manual, National Environmental Policy Act of 1969, Managing the NEPA Process – Bureau of Land Management*. 2008. Department of the Interior, Part 516 DM 11.9. https://www.doi.gov/sites/doi.gov/files/elips/documents/516-dm-11-signed-508.pdf.

3.2.2 State Public Lands

States have the authority to lease, sell, exchange, or otherwise manage state-owned lands or subsurface rights for the purpose of geothermal development. Many states with geothermal resource potential, such as California and Nevada, have defined authorities and procedures governing geothermal development on state-owned lands.[87]

Nevada State Public Lands

The Nevada Division of State Lands may lease any land owned by the State of Nevada, except contract land, for the purpose of geothermal energy development.[88] The Nevada Division of Minerals is the state's authority for all geothermal wells drilled in the state.[89] All geothermal wells drilled in Nevada, even if drilled on federally managed lands, must be permitted by the Nevada Division of Minerals.[90] Though the state of Nevada allows geothermal development on state lands, in practice, there are no current state land mineral leases because Nevada owns very little available land.[91]

[87] E.g., Geothermal Permitting and Leasing Procedures. 2017. California State Lands Commission, Mineral Resources Management Division. https://www.slc.ca.gov/wp-content/uploads/2018/10/04-PermitandLeaseProcedures.pdf.
[88] NRS § 322.010.
[89] "Geothermal." 2020. Nevada Division of Minerals, http://minerals.nv.gov/Programs/Geo/Geo/.
[90] *Id.*
[91] GAO. 2009. Testimony Before the Committee on Energy and Natural Resources, U.S. Senate, Hardrock Mining: Information on State Royalties and the Number of Abandoned Mine Sites and Hazards, Statement of Robin M. Nazzaro, Director Natural Resources and Environment, GAO-09-854T. https://www.gao.gov/assets/130/123013.pdf.

4 Geothermal and Locatable Mineral Case Studies

4.1 Case Studies: The Development of Power Plants at Blind Geothermal Systems in Nevada

This section explores case studies in Nevada where undiscovered geothermal resources have been located and developed into power generation projects as a result of initial locatable mineral exploration. Understanding the pathways for the discovery of these geothermal resources and development, especially within the context of the federal regulations that govern the two resources, can be instructive for how the geothermal and mining industries might collaborate in future endeavors to develop resources in a mutually beneficial way.

The geothermal industry typically builds power plants in known geothermal resource areas after conducting sufficient exploration to confirm that an economically viable resource exists in that location. Three geothermal power plants in Nevada, however, were developed from undiscovered or "blind" resources: the McGinness Hills, Blue Mountain, and Don A. Campbell power plants. Undiscovered geothermal resources are generally considered to lack active surface thermal manifestations, such as hot springs or fumaroles. Currently, no reliable ways exist to identify these geothermal resources except using temperature data from exploration holes or 2-meter temperature probes, though a few systems have anecdotally been found by mapping relatively rapid snowmelt. The three power plants noted herein were all developed after receiving initial data that the mining industry collected while conducting mineral exploration. This exploration uncovered uneconomic (subgrade) mineral resources, but economically viable geothermal resources, which were ultimately developed by geothermal companies. Learning from the development of these three power plants and exploring more opportunities to discover and develop "blind" resources could prove to be a boon to both the mining and geothermal industries. This section explores the discovery of the resources beneath McGinness Hills, Blue Mountain, and Don A. Campbell, and the power plants' development, including the regulatory approval process that was necessary to achieve development.

4.1.1 The McGinness Hills Geothermal Power Plant

In 2012, Ormat Technologies, Inc. opened the McGinness Hills geothermal power plant in Lander County, Nevada.[92] As of 2020, the power plant has completed three phases totaling 140 MW and is in the process of receiving permit approval for an expansion to a fourth phase, making it one of the largest geothermal power plants in the United States.[93] The McGinness Hills power plant is located on both BLM-managed lands and private lands, across a lease of 7,680 acres.[94]

[92] Nordquist, J. and B. Delwiche. 2013. "The McGinness Hills Geothermal Project." 37 *GRC Transactions* 61. http://pubs.geothermal-library.org/lib/grc/1030549.pdf.

[93] Featherston, S. 2018. "Ormat to Expand Austin Geothermal Complex." Elko Daily. https://elkodaily.com/mining/ormat-to-expand-austin-geothermal-complex/article_3e3f5fde-2428-5903-ad2a-71cb95dd5467.html.

[94] McGinness Hills Geothermal Development Phase III Project, Finding of No Significant Impact. 2018. U.S. Department of the Interior, Bureau of Land Management. https://eplanning.blm.gov/public_projects/nepa/82574/131154/160200/20180116_McGinness_Hills_FONSI_signed_508.pdf.

The McGinness Hills site was initially explored for locatable mineral resources during the early 1980s[95]: Anaconda Minerals Company drilled four holes in 1982 and FMC Corporation drilled 12 reverse circulation holes in 1984.[96] These holes did not reveal the economic-grade precious metals the companies sought, but they did reveal hot water in some of the holes.[97] Newcrest Resources, Inc. conducted more mineral exploration in the area in 2004.[98] During that exploration, Newcrest found near-boiling waters up to 190°F at 980–1,200 feet deep beneath a sinter mound and observed some geysering.[99] Newcrest also collected two fluid samples from its drill holes, which yielded silica geothermometry up to 346°F.[100]

After reviewing these data collected by the mining industry, Ormat conducted its own exploration activities on the McGinness Hills site.[101] Ormat obtained federal geothermal leases for the McGinness Hills site in August 2007 through a competitive geothermal lease auction.[102] The company received permitting approval for the exploration phase in April 2009 and initial the development phase in July 2011.[103]

4.1.2 The Blue Mountain Geothermal Power Plant

The Blue Mountain geothermal power plant is located on federal lands managed by the BLM in Humboldt County, Nevada. Nevada Geothermal Power Inc. opened the power plant in 2009.[104] Blue Mountain is a binary cycle power plant with an installed nameplate capacity of 49.5 MW.[105]

The geothermal resource beneath the Blue Mountain geothermal power plant was unknown until hot water was discovered by epithermal gold exploration drilling in the early 1990s.[106] After acquiring the federal geothermal leases noncompetitively from the BLM, the mineral exploration company then shared this discovery at a Geothermal Resources Council meeting in 1991. The federal geothermal leases, as well as useful exploration data, were then purchased by a geothermal developer and have since changed ownership multiple times.[107]

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95 *Id.*
96 *Id.*
97 *Id.*
98 *Id.*
99 *Id.*
100 *Id.*
101 Nordquist and Delwiche, *supra* note 92.
102 McGuiness Hills Geothermal Development Phase III Project*, Environmental Assessment.* 2017. U.S. Department of the Interior, Bureau of Land Management. http://clearinghouse.nv.gov/public/Notice/2018/E2018-065.pdf.
103 *Id.*
104 "The Blue Mountain Geothermal Power Plant, USA." 2019. Power-Technology. https://www.power-technology.com/projects/bluemountaingeotherm/.
105 The net summer operating capacity for Blue Mountain is approximately 38 MW based on a review of 2018 EIA f860 form submissions.
106 "Recent Geothermal Projects/Exploration Activity." 2020. Nevada Bureau of Mines & Geology. http://www.nbmg.unr.edu/Geothermal/Exploration.html. (citing Parr and Percival, 1991).
107 Personal communication with Brian Fairbank, formerly of Blue Mountain Power Company.

4.1.3 The Don A. Campbell Geothermal Power Plant

Ormat developed the Don A. Campbell geothermal power plant in Mineral County, Nevada, on federal lands managed by BLM. The power plant opened in 2013, and it has a total capacity of 42 MW.

The site of Don A. Campbell has no apparent surface thermal features or related mineralization that would have suggested geothermal development potential.[108] Geologists identified this property as housing a geothermal resource using data from mineral exploration campaigns that took place in the early 1990s.[109] The mineral prospectors conducting exploration on the site did not find commercial quantities of precious metals, but the data they collected suggested a possible commercial-grade geothermal system.[110] Specifically, the miners' data showed "the coincidence of propyllitic alteration in young Quaternary rocks with very anomalous shallow temperatures and the presence of hot fluids and steam."[111] The miners' exploration wells also indicated strong flow of 140°–190°F fluids and 203°F vapors at shallow depths over an area of approximately 46 square kilometers.[112]

Data in an aeromagnetic survey conducted by the mining industry also helped confirm the geothermal resource.[113] The survey delineated a large magnetic-low anomaly along gently northward sloping alluvial fans.[114] According to Ormat, the magnetic anomaly trended NE-SW, with a length of 4 km and a width of 1.5 km, and the anomaly was inferred to correlate with strong argillic alteration observed over depth ranges of ~50–500 feet.[115]

After reviewing the mining industry's data at no cost, Ormat nominated the Don A. Campbell site for geothermal leasing in 2001, and, in August 2007, Ormat secured site control through a BLM competitive geothermal lease auction.[116] Immediately after obtaining a lease, Ormat embarked on a 4-year exploration campaign.[117] While conducting exploration drilling, Ormat began the permitting process for developing the power plant.[118] Construction of Don A. Campbell began in the spring of 2013, after the power purchase agreement was approved by regulators.[119]

4.2 Case Study: Florida Canyon and International Co-Location of Active Mines and Geothermal Energy Projects

Geothermal and mining interests may also align at active mining sites with nearby geothermal resource potential. The Florida Canyon Geothermal Power Plant produced power as a DOE-private industry pilot-demonstration project for the Florida Canyon open pit gold mine in

[108] Orenstein, R., and B. Delwiche. 2014. "The Don A. Campbell Geothermal Project," 38 *GRC Transactions* 91, 92.
[109] *Id.*
[110] *Id.*
[111] *Id.*
[112] *Id.*
[113] *Id.*
[114] *Id.*
[115] *Id.*
[116] *Id.*
[117] *Id.*
[118] *Id.*
[119] *Id.*

Pershing County, Nevada, from 2013 to 2014. Mine water supply wells flowing 160 gpm at 223°F provided >500 kW of available heat to two 50-kW organic Rankine cycle generating units. The project was decommissioned following completion of the pilot demonstration, likely due to a change in mine ownership and mineral scaling of fluid piping caused by intermittent operation.

International examples of geothermal energy powering active mining operations also exist. The Lihir gold mine in Papua, New Guinea, developed a 56-MW geothermal power plant to supply the mine with approximately 75% of its power.[120] The Lihir operation has been successfully using geothermal energy as a source of power for more than 15 years.[121] Newcrest Mining, which operates the Lihir mine, also registered its geothermal project as a UN Clean Development Mechanism project, which generates international carbon credits that are financially valuable.[122] The Veladero gold mine in Argentina also explored the possibility of developing an 8- to 20-MW geothermal power plant 12 km away from the mine to replace 66%–100% of the mine's operational requirements.[123] Based on available information, however, it appears that the Veladero geothermal project was never constructed.[124]

[120] Maennling, N., and P. Toledano. 2018. *The Renewable Power of the Mine—Accelerating Renewable Energy Integration*. Columbia Center on Sustainable Investment. http://ccsi.columbia.edu/work/projects/the-renewable-power-of-the-mine/.
[121] *Lihir Gold Mine 2018 Sustainability Report*. 2018. Newcrest Mining Ltd.
[122] *Id.*
[123] Boynton, K. et al. 2019. "Geothermal Energy in Mining—A Renewable and Reliable Energy Solution." *GRC Bulletin*; see also "Barrick's Joint Venture with EPSE & Geotermina Andina for a 20MW Geothermal Plant at Veladero Gold Mine." 2013. BNamericas.
[124] Boynton, K. et al. 2019. "Geothermal Energy in Mining—A Renewable and Reliable Energy Solution." *GRC Bulletin*.

5 Other Scenario Analysis: Utilizing Former Mining Lands for Geothermal Projects

A mining operation and geothermal developers may potentially have interests that are aligned. For example, a mining operator may be able to use geothermal data collected during the operation of a mine to encourage further use of the mining land during reclamation or once the mine is reclaimed.[125] This section discusses a number of such opportunities and considerations developers may need to weigh when pursuing a cooperative relationship.

Former mining lands—including abandoned mine lands (AMLs), lands in the process of being reclaimed, and already-reclaimed lands—may be used for renewable energy projects, including geothermal projects. AMLs include "abandoned mines and the areas adjacent to or affected by the mines."[126] According to the U.S. Environmental Protection Agency (EPA), a majority of these sites have never been considered for any type of reuse and have remained idle.[127] Mining lands that are in the process of being reclaimed are lands that are currently being restored from the lands' former mining use to a previous natural resource setting and being monitored.[128] Already-reclaimed mining lands have completed that restoration process.[129]

5.1 The Development of Geothermal Energy on Abandoned Mine Lands

The following subsections provide an overview of issues associated with geothermal development on AMLs and reclaimed mine lands, including policies, economic considerations, and environmental liabilities.

5.1.1 State Policies: Nevada

Some states have started to encourage the use of former mining sites for renewable energy development. Based on EPA data about brownfield sites in Nevada, the Rocky Mountain Institute identified more than 2.8 million acres of land that are already disturbed and could be used for renewable energy development.[130] In 2018, Nevada's regulations were updated to encourage the use of old mining sites for renewable energy projects.[131] As a result, the Administrative Code of Nevada lists "renewable energy development and storage" as an

[125] For example, a mining company operating in Montana completed a six-turbine wind farm to replace its diesel generators used for mining operations as well as to provide power to a local utility. A Breath of Fresh Air for America's Abandoned Mine Lands. 2012. U.S. Environmental Protection Agency (EPA).
[126] A Breath of Fresh Air for America's Abandoned Mine Lands. 2012. U.S. EPA.
[127] *Id.*
[128] See generally Abandoned Mine Lands: A Decade of Progress Reclaiming Hardrock Mines. 2007. U.S. Bureau of Land Management and U.S. Forest Service. https://www.blm.gov/sites/blm.gov/files/uploads/AML_PUB_DecadeProgress.pdf.
[129] See generally *Id.*
[130] Richter, A. 2018. "Old Mines Could Provide Opportunities for Geothermal Energy Development in Nevada." ThinkGeoEnergy.com. https://www.thinkgeoenergy.com/old-mines-could-provide-opportunities-for-geothermal-energy-development-in-nevada/.
[131] Brean, H. 2018. "Nevada's Mines Could Hold Key to Question 6 Energy Standard." Las Vegas Review-Journal. https://www.reviewjournal.com/business/energy/nevadas-mines-could-hold-key-to-question-6-energy-standard-1524958/.

acceptable post-production use of closed mining operations.[132] Contaminated property often has zoning designations compatible with renewable energy facility needs, which may greatly reduce the cost and timeline for land use approvals.[133] According to interviews of developers conducted by EPA, some developers have seen permitting processes take only a few months compared to an average of 18–24 months.[134]

5.1.2 Economic Considerations and Environmental Liabilities

Developers considering the potential for constructing a geothermal project on former mining land may benefit from the availability of existing infrastructure from the previous mining activities.[135] Other renewable energy projects have already leveraged such infrastructure successfully. For example, the Somerset Wind Farm in Pennsylvania was able to use the prior mining operation's roads and power transmission lines, which reduced project costs.[136]

At the same time, geothermal developers may need to conduct additional analysis of the former mining site to ensure that it is structurally sound to support the weight of the geothermal operations (e.g., drill rigs or power plant) and to ensure that the operation of the geothermal project will not cause or contribute to any mining-related pollution.[137] While many renewable energy project developers may be deterred from contaminated property for liability reasons, some states' environmental cleanup programs aim to facilitate the reuse of contaminated properties by providing liability protections for new owners.[138]

Developing geothermal projects (along with other co-located renewables) on top of AMLs may also require increased engineering and compliance considerations. For example, geothermal developers that may wish to use abandoned or former mining sites should consider the impact of development on existing mining works, particularly because many metalliferous mine sites have legacy facilities with the potential to generate acid rock drainage (ARD).[139] Conversely, these same sites may have pump and treat requirements in perpetuity, requiring a steady and constant supply of electricity which would pair well with a potential geothermal generation profile. Opportunities for geothermal development that can provide both renewable energy and carbon credits to the mining operator as well as assist in mitigating an environmental and financial liability as a result of long-term ARD treatment requirements.

Additional funding from federal or state governments may be available to mitigate costs associated with developing on both reclaimed lands and still-contaminated lands, such as AMLs

[132] Richter, A. 2018. "Old Mines Could Provide Opportunities for Geothermal Energy Development in Nevada." ThinkGeoEnergy.com. https://www.thinkgeoenergy.com/old-mines-could-provide-opportunities-for-geothermal-energy-development-in-nevada/.
[133] *RE-Powering America's Land: Potential Advantages of Reusing Potentially Contaminated Land for Renewable Energy.* 2012. U.S. EPA.
[134] *Id.*
[135] *A Breath of Fresh Air for America's Abandoned Mine Lands.* 2012. U.S. EPA.

[136] *Id.*
[137] *Id.*
[138] Liability Reference Guide for Siting Renewable Energy on Contaminated Properties. 2014. U.S. EPA. https://www.epa.gov/sites/production/files/2014-07/documents/liability-renew-energy-contamprop-2014.pdf.
[139] Personal communication with Daniel White, Bureau of Land Management.

and brownfields. For example, developers of a 3.5-MW solar project in Virginia, which was built on an AML that was a former coal mine, received a $500,000 federal grant.[140]

Tax incentives may also be available to geothermal projects on contaminated lands. A federal brownfield tax incentive may be available to developers; such an incentive allows cleanup costs at eligible properties to be fully deductible in the year incurred, rather than capitalized and spread over a period of years.[141] In addition to this federal tax incentive, many states also have a tax incentive for developing contaminated property.[142]

5.2 The Development of Geothermal Energy on Mining Lands in the Process of Being Reclaimed

Developers may also be able to construct a geothermal operation on mining land that is still in the process of being reclaimed. Because the reclamation of mining sites can be quite lengthy; can occur in stages or phases targeted at specific, prioritized facilities; and typically includes decades of groundwater monitoring, it is possible that a geothermal developer could want to use a former mining site without waiting for the reclamation process to be complete. In order to use this type of land, the mining operator would need to fully transfer liability to the geothermal developer during the course of the mine's reclamation. As a result, the geothermal developer would need to demonstrate enough knowledge to be able to successfully complete the reclamation of the site. Depending on the type of mine at issue, there could be issues with hazardous wastes, mine adits, open pits, waste rock facilities, tailings facilities, and heap leach pads, all of which require technical expertise to properly manage.[143]

[140] McGowan, E. 2019. "Federal Funds to Help Turn Virginia Coal Mine into Solar Farm." *Energy News*. https://energynews.us/2019/03/08/southeast/virginia-solar-farm-among-10-projects-to-receive-mineland-reuse-funds/.
[141] *RE-Powering America's Land: Potential Advantages of Reusing Potentially Contaminated Land for Renewable Energy*. 2012. U.S. EPA.
[142] *Id.* For example, Colorado offers up to $100,000 of income tax credits for eligible entities bringing contaminated land back to productive reuse. *Id.*
[143] Personal communication with Daniel White, Bureau of Land Management.

6 Techno-Economic Analysis

As part of this analysis, NREL examined the potential reductions in geothermal electricity generation cost, financing, and schedule that might be achieved through developing a geothermal resource discovered through mineral exploration activity, geologic characterization, and development. In order to estimate geothermal power plant development costs, the study used the Geothermal Electricity Technology Evaluation Model (GETEM),[144] a Microsoft Excel-based bottom-up cost analysis tool that utilizes user-specified adjustments to default inputs to calculate capital costs and LCOE. GETEM calculates costs for each phase of geothermal development including permitting, exploration, drilling, power plant construction, and operation and maintenance. The study used a modified 2016 version of GETEM, similar to the version used in the DOE *GeoVision* report,[145] to analyze two main scenarios:

1. A geothermal resource discovered through mineral exploration and development on BLM-managed land

2. A geothermal resource discovered through mineral exploration and development on private mine-owned land.

These scenarios were compared in GETEM to a business-as-usual (BAU) scenario, representing a typical geothermal exploration and development cost and timeline. Scenarios 1 and 2 assumed that resources were co-located with a mining operation (either an active or abandoned mine), power would be used for on-site demand (where an active mine exists), and geothermal leases were obtained through the noncompetitive right to geothermal resources included within an approved plan of operation for a mining claim.[146] The impact on power generation cost was also considered if transmission infrastructure were to be required (e.g., if power production were to exceed on-site demand of the mine or if the mine was abandoned). The potential impact of added costs or schedule delays due to a competitive lease nomination, BLM evaluation, and lease sale were not modeled.

To model cost and schedule reductions in GETEM, the study selected a representative and reasonable hypothetical resource based on known hydrothermal systems in Nevada as well as temperatures at depths identified by mining activity (e.g., 330°F at the Meikle mine).[147] Higher temperatures might be found deeper but this would require confirmation through geochemical analyses or additional measured temperatures. The modeled resource assumes a 330°F temperature at a depth of ~2,000 feet, with pumped wells averaging ~1,750 gpm supplied to a 20-MW binary power plant. These resource characteristics as well as the water-limited and arid setting of Nevada are typically best matched to air-cooled binary power plants.[148]

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[144] DOE. 2016. "Geothermal Electricity Technology Evaluation Model." https://www.energy.gov/eere/geothermal/geothermal-electricity-technology-evaluation-model.

[145] DOE. 2019. *GeoVision: Harnessing the Heat Beneath Our Feet*. DOE/EE-1306. https://www.energy.gov/eere/geothermal/downloads/geovision-harnessing-heat-beneath-our-feet.

[146] 43 C.F.R. § 3204.12.

[147] Proulx, R.P., and D.S. Scovira. 2001. "Drilling and blasting in hot and reactive ground conditions at Barrick Goldstrike's Meikle mine." *CIM Bulletin*, Vol. 94, p. 71–74.

[148] Binary plants use a heat exchanger and secondary working fluid with a boiling point below that of water to transfer geothermal energy through an organic Rankine cycle.

The adjusted GETEM parameters, showing ranges for various assumptions, and timeline and cost impacts are detailed in Table 1 and include the following:

- **Exploration Duration**: Geologic characterization and drilling performed as part of a mineral exploration and mine development campaign can significantly shorten geothermal discovery and analysis timelines. The shorter exploration duration value in Table 1 represents only long-term (3 months) flow testing and reservoir modeling. The longer duration in Table 1 represents additional exploration and confirmation drilling and testing that may be necessary to fully delineate the geothermal system. This value excludes exploration that was completed solely for mineral exploration. In the BAU scenario, the 4-year exploration duration consists of permitting; geologic, geochemical, and geophysical characterization; well planning; core, slim, and full-size well drilling; long-term well testing; and reservoir modeling.

- **Exploration Costs with Early Drilling**: The scenarios assumed that abundant drilling data collected as part of mineral exploration would limit the need for early drilling (e.g., core and slim holes) specific to geothermal delineation. The scenarios also assumed that these data and detailed geologic analyses would decrease the risk and increase the success rate of full-sized wells drilled during the exploration phase. The lower cost in Table 1 represents cost savings realized through repurposing full-sized wells drilled as part of mine development (e.g., dewatering or water supply wells). For example, dewatering wells at the Lihir deposit[149] are used to generate geothermal power, and dewatering wells at the Meikle mine[150] are constructed similarly to typical full-sized geothermal wells. The higher cost in Table 1 represents the need for full-sized well drilling to enable long-term testing and reservoir modeling.

- **Drilling Costs**: Development drilling costs for full-sized production and injection wells increase slightly in the modeled scenarios due to fewer full-size exploration and confirmation wells during the abbreviated exploration phase. These costs are realized during the development drilling phase as the same total number of successful full-size wells are required to supply the 20-MW plant capacity.

- **Royalty Rates and Leasing Costs**: The initial geothermal royalty rate on federally leased BLM lands is 1.75%. Competitive leasing costs are estimated at $20/acre,[151] and noncompetitive leasing costs are $1/acre. The study assumed no royalty or leasing costs on mine-owned lands, but these may apply if the private land is leased from a third party. Again, beyond the BAU scenario, costs per acre as part of a competitive lease sale were not considered.

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[149] White, P., G. Ussher, and D. Hermoso. 2010. "Evolution of the Ladolam geothermal system on Lihir Island, Papua New Guinea." IGA, World Geothermal Congress 2010, Bali, Indonesia, 25–29 April 2010, Proceedings, 7 p.
[150] Zahn, J. 2012. "Mine Dewatering and Water Management at Barrick Goldstrike Mine in the Carlin Trend, Nevada." Presented at the U.S. EPA Hardrock Mining Conference.
[151] Based on the highest bid of the 2019 geothermal lease sale. https://www.blm.gov/press-release/blm-nv-geothermal-lease-sale-takes-in-record-amount.

- **Transmission Costs**: The geothermal resources in both the BLM-managed land and private land scenarios were co-located with a mineral deposit to maximize the benefit of thorough mineral exploration and geologic characterization. However, based on industry guidance, existing costs for transmission infrastructure to a 20-MW geothermal power plant are roughly $750k–$1M per mile. This capital expenditure cost range results in an additional $0.60–$0.80/MWh added to LCOE. This transmission cost would need to be considered if a closed or abandoned mine did not have a source of load in perpetuity and/or otherwise needed to export power.

- **Period to Project On-Line**: In the BAU scenario, the modeled total project length is 8.3 years. In the BLM-managed land scenario, the modeled total project development length is reduced ~43%-37% to 4.7–5.2 years. In the private land scenario, the modeled total project development length is reduced by ~49%–42% to 4.2–4.75 years. Such significant schedule reductions can substantially impact project financing availability and rates.

- **Capital Expenditures (CAPEX)**: In the BAU scenario, the modeled project CAPEX is $8,615 per kW. In the BLM-managed land scenario, the modeled project CAPEX is reduced by ~38%–34% to $5,372–$5,647 per kW. In the private land scenario, the modeled project CAPEX is reduced by ~39%–35% to $5,292–$5,636 per kW. These reductions are proportionately greater than for total capital cost because they capture the lower financing costs assumed for the discovery through mining scenarios. The study assumed lower financing rates could be secured throughout project development and construction due to the reduced timeline, risk, and uncertainty achieved by leveraging thorough geologic characterization as part of mine development.

- **Levelized Cost of Energy**: In the BAU scenario, the modeled project LCOE is $87/MWh. In the BLM-managed land scenario, the modeled project LCOE is reduced by ~25%–23% to $65–$67/MWh. In the private land scenario, the modeled project LCOE is reduced by ~29%–26% to $62–$65/MWh.

- **Total Capital Cost**: In the BAU scenario, the modeled total project cost is $116M. In the BLM-managed land scenario, the modeled total project cost is reduced by ~13%–8% to $101–$107M. In the private land scenario, the modeled total project cost is similarly reduced by ~15%–9% to $99–$106M. These are overnight capital costs, which exclude interest costs incurred from project financing.

Table 1. GETEM input parameter adjustments and estimated costs for BAU and modeled scenarios of geothermal development through mineral exploration

GETEM Input		Business-as-Usual	Discovery Through Mining: BLM Land	Discovery Through Mining: Private Land
RESOURCE EXPLORATION AND DEVELOPMENT INPUTS	Exploration Duration	4 yrs	0.75–1 yrs	0.75–1 yrs
	Exploration Costs with Early Drilling ($/project)	$18M	$1.1–8.8M	$1.1–7.6M
	Drilling Costs ($/project)	$12.6M	$14.8M	$14.8M
	Royalty	1.75%		0%
	Leasing Costs $/acre	$20	$1	0
	Transmission Costs $/mile	$750k–1M	0	0
RESULTS	Period to Project On-Line	8.25 yrs	4.7–5.2 yrs	4.2–4.75 yrs
	CAPEX $/kW	$8.6k	$5.4k–5.6k	$5.3k–5.6k
	LCOE $/MWh	$87	$65–67	$62–65
	Total Capital Cost	$116M	$101–107M	$99–106M

In addition to modeling geothermal electricity under the described scenarios, this study analyzed geothermal in comparison to diesel power generation. Fuel costs were estimated for a 20-MW off-grid mining scenario, which would require ~11M gallons[152] of fuel annually and at least 763 round-trip deliveries. Based on USGS estimates of power consumption per ounce of gold recovered in the United States,[153] 20 MWe could meet the needs of a gold mine producing between 350,000 to 515,000 ounces annually, depending on mine type and recovery methods. Diesel fuel prices[154] for Nevada for the years 2014–2018 (Table 2) were obtained from the U.S. Energy Information Administration.[155] Annual fuel cost estimates—excluding transportation premiums and using the 2014–2018 low and high prices—range from $18–$32M and $93–$166/MWh. Based on fuel industry input, transportation costs to remote sites in Nevada could

[152] This total does not include delivery fuel consumption or degradation of capacity factor.
[153] Bleiwas, D.I. 2011. *Estimates of Electricity Requirements for the Recovery of Mineral Commodities, with Examples Applied to Sub-Saharan Africa*. USGS Open-file Report 2011-1253, 100 p.
[154] These prices do not include a premium for site transportation or road conditions.
[155] U.S. Energy Information Administration. 2020. "Refiner Petroleum Product Prices by Sales Type." https://www.eia.gov/dnav/pet/PET_PRI_REFOTH_A_EPD2_PTG_DPGAL_A.htm

add ~15%–30% to fuel costs depending on distance and road condition. NREL's LCOE Calculator [156] yields LCOE estimates using the analyzed fuel prices of $109–$185/MWh.

Table 2. Cost estimates for a 20-MWe diesel power plant

20-MWe Diesel Plant		2014–2018 Low	2014–2018 High
FUEL	Annual fuel usage (gallons/year)	10,680,677	10,680,677
	Cost ($/gallon)	1.683	2.985
RESULTS	FUEL COST $/MWh	93	166
	LCOE $/MWh	109	185
	ANNUAL FUEL COST	$18M	$32M

[156] NREL's LCOE calculator is available at: https://www.nrel.gov/analysis/tech-lcoe.html.

7 Conclusion

Mining and mineral exploration data have the potential to inform geothermal exploration and development by providing direct or indirect evidence of a geothermal occurrence and detailed site characteristics. The case studies described in this paper, which total roughly 200 MW net power, may never have been discovered had it not been for mining exploration activities. Additionally, geothermal exploration data have the potential to inform mineral exploration, provide mining companies with a sustainable energy resource, and reduce overall costs.

Though one of the key exploration methods for discovering geothermal resources is temperature gradient drilling,[157] the geothermal industry drilled only 31 wells in Nevada in 2017,[158]—many of which were development wells at identified geothermal fields. In comparison, the mining industry drills more than 2,000 holes in Nevada per year[159] to depths similar to those of temperature gradient holes. Additional exploration activities common to both geothermal and mining include surface mapping, geophysical and geochemical analysis, remote sensing, and geologic and conceptual modeling. Leveraging mining industry data, knowledge, and expertise serves to effectively expand the geothermal exploration workforce, increase the rate of geothermal discovery, and potentially reduce geothermal electricity LCOE by 23%–29%.

Conversely, because many data points collected by the mining industry may be of use to geothermal exploration and development, this presents an opportunity to monetize data that is not immediately useful for mining companies. In addition, co-location of geothermal power plants at active remote mines presents an opportunity for the mining industry to both lower its electricity costs and achieve decarbonization goals.

The following list of recommendations is provided to mining and geothermal stakeholders to help maximize the collective value of their exploration activities:

- Collect temperature with depth surveys in mineral exploration holes just prior to plugging and abandonment, or at a minimum, insert a maximum registering thermometer (MRT) to total depth.
- Collect temperature with depth surveys in dewatering wells prior to beginning operation.
- Chemically analyze subsurface fluids encountered in mineral exploration holes and dewatering wells, or at a minimum, collect and store a fluid grab sample.
- Analyze and document alteration age due to potential spatial associations between mineral deposits younger than ~7–10 million years and active geothermal systems.
- Assay core and cuttings from geothermal exploration and development drilling.
- Consider joint development opportunities upon encountering elevated temperatures.
- Report fluid level and temperature of fluid bearing zones to the appropriate State agency (e.g., Nevada Division of Water Resources).
- Consider direct use applications for fluids with elevated temperatures.

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[157] Doughty, C., P. Dobson, A. Wall, T. McLing, and C. Weiss. 2018. *GeoVision Analysis Supporting Task Force Report: Exploration*. Berkeley, CA: Lawrence Berkeley National Laboratory. LBNL-2001120. https://escholarship.org/uc/item/4v7054cw.

[158] Muntean, J.L., D.A. Davis, and B. Ayling. 2018. *The Nevada Mineral Industry 2017: Nevada Bureau of Mines and Geology Special Publication.* MI-2017, 212 p.

[159] Personal communication with John Muntean, Nevada Bureau of Mines and Geology.

Specific to BLM-managed land, existing mines with an approved plan of operations may exercise a noncompetitive leasing right to the geothermal resources within the plan of operations, which may further simplify the exploration and development of geothermal resources discovered through mining data.

Ultimately, synergies between the geothermal and mining industries could lead to mutually beneficial cost reductions and assist mining companies in achieving environmental and sustainability goals, including decarbonization, in the process.