The Future of Geothermal in New Mexico

A Land of Geothermal Enchantment

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(alphabetical order)

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Veit Matt is a petroleum systems analyst/modeler who specializes in geothermal evaluation of complex onshore basins at the mega-regional to prospect and reservoir scales. During his 20 years of supporting exploration, appraisal, and development in the oil and gas industry, he has worked on numerous basins in the United States and around the world. His work is grounded on realistic 3D Earth models that are designed and calibrated using diverse technical data sets. Matt is also interested in data modeling, databases, and data management, including developing custom workflows to improve efficiency by optimizing data access and enabling enhanced connectivity to analysis tools. Matt pursued postdoctoral studies at the University of Colorado Boulder's Energy and Minerals Applied Research Center. He earned his Ph.D. at Texas A&M University; an M.S. from Albert-Ludwigs-Universität in Freiburg, Germany; and an M.S. from Eastern Washington University.

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Drew Nelson is Vice President of Programs, Policy, and Strategy at Project InnerSpace. Prior to joining InnerSpace, Nelson served as Senior Program Officer at the Catena Foundation, where he oversaw the climate and clean energy program and managed a grant portfolio of more than $30 million. Prior to joining Catena, Nelson held a similar position at the Texas-based Cynthia and George Mitchell Foundation. Earlier in his career, Nelson spent seven years at the Environmental Defense Fund (EDF), where he undertook a variety of roles, including running EDF's international methane work. He began his career at the U.S. Department of State, where he served as a lead negotiator for the Conference of the Parties.

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Figures

Definitions

The terms defined in this section are used frequently throughout this report. There are no universally agreed-upon terminologies or definitions to describe geothermal technologies, particularly with emerging concepts and applications, so we have adopted prevailing terms consistent with those defined in *The Future of Geothermal in Texas: The Coming Century of Growth and Prosperity in the Lone Star State* (2023). We present the terms in categories to help show the relationships between them.

Conventional Hydrothermal System (CHS): Also known as a *traditional geothermal system* or *hydrothermal geothermal system*, a geothermal resource that is often accessible close to the surface and at times has surface manifestations, such as hot springs, volcanic rock formations, geysers, or steam vents, among others. A CHS has a combination of sufficient permeability in the subsurface, sufficient heat transfer into the system, and the natural presence of circulating water, which produces an exploitable geothermal resource. Heat flow is convection dominant (i.e., conduction and advection contribute to the movement of heat). Most of the world's developed geothermal capacity is currently produced from CHS resources.

Next-Generation Geothermal: An umbrella term for any geothermal extraction technology that harvests subsurface energy outside the geography of a conventional hydrothermal system. In most cases, next-generation geothermal technologies rely on advances from the oil and gas industry and expand the geographic potential of geothermal.

Sedimentary Geothermal System (SGS): A type of conduction-dominated geothermal resource found in sedimentary rock formations (with some convection cells in complex settings). These sedimentary rocks—including sandstone, shale, and limestone—often contain water within their pores that can be harvested for geothermal energy production. Most sedimentary basins are closed systems, unless they have experienced uplift, in which case surface springs may highlight geothermal potential.

Conventional Geothermal: A geothermal extraction method that requires a hydrothermal system and doesn't use hydraulic fracturing to artificially engineer a subsurface reservoir. Horizontal drilling may be used, but only to improve access to otherwise naturally occurring reservoirs and naturally occurring fluid.

Engineered/Enhanced Geothermal System (EGS): A geothermal technology that uses hydraulic fracturing to engineer a subsurface reservoir by creating or enhancing existing fractures in rock. Fluids are then circulated through the fracture network, where they heat up and are then brought to the surface for generating electricity or for direct use. This system can be deployed in various rock types and is considered scalable.

- **Traditional Engineered Geothermal System (Traditional EGS):** A system that uses hydraulic fracturing to engineer or enhance a subsurface reservoir to produce geothermal heat or electricity, but does not use advanced directional drilling or multistage fracturing techniques. This system is typically developed by drilling vertical or deviated wells and can be deployed in various rock types, but the development of the system has historically focused on basement rock formations.
- **Next-Generation Engineered Geothermal System (Next-Gen EGS):** Not to be confused with the umbrella next-generation geothermal concept, a subtype of EGS that still uses hydraulic fracturing to engineer or enhance a subsurface reservoir while also incorporating advanced drilling and/or fracking techniques, including but not limited to horizontal drilling and multistage fracturing. This system can be deployed in a variety of rock types.

Superhot Rock (SHR): A term given to geothermal technologies that aim to exploit hot-rock resources above approximately 703°F (373°C), the supercritical point of water. In volcanic regions of the world, SHR may be encountered relatively close to the surface; in other regions, SHR may require drilling to as deep as 6 miles (about 10 kilometers) or more, so SHR is sometimes referred to as *deep geothermal*.

Advanced Geothermal System (AGS): Occasionally referred to as *closed-loop geothermal systems*, a geothermal technology (with many configurations) that allows the circulation of fluid in the subsurface without fluid leaving the wellbore. Fluid is pumped from the surface, picks up heat from the surrounding formation (primarily through conduction), and flows back to the surface, where the heat is harvested for direct-use or power applications. AGS can be deployed in various rock types, can use engineered fluids such as supercritical carbon dioxide (sCO_2) to improve efficiency, and is considered scalable.

Ground-Source (Geothermal) Heat Pump (GSHP): Pump that harvests the ambient temperature in the top 1 to 2 meters of the subsurface, where the ground remains at a relatively constant temperature of 55°F (13°C). GSHPs have traditionally been used to heat and cool buildings but these pumps are increasingly used in higher-temperature industrial and commercial applications.

Direct-Use Geothermal System: Instead of using geothermal heat to generate electricity, uses the heat contained in geothermal fluids to enable various heating and cooling applications. This system can be shallow or deep.

- **Shallow direct-use** applications typically use a ground source heat pump to harvest the constant temperature of the shallow subsurface for a variety of low-temperature applications, including heating and cooling buildings.
- With **deep direct-use,** wells are drilled to reach higher subsurface temperatures which can be used for various applications, including industrial and commercial direct heating or numerous industrial and manufacturing processes. Deep direct-use applications may still use heat pumps but do so at much higher temperatures. Wells can target deep aquifers or human-made places filled with water, like mines.

Thermal Energy Networks (TEN): When direct-use geothermal energy is supplied to a large area, clusters of buildings, or in a district from a central location. This type of network is also referred to as *district heating*.

Geothermal Energy Storage (GES) System: A technology that stores mechanical and/or thermal energy in any of a variety of settings. Underground thermal energy storage uses the subsurface for energy storage. Aquifer thermal energy storage injects hot water into porous underground aquifers and retrieves it when needed. Borehole thermal energy storage uses a network of boreholes drilled into the ground and filled with heat exchangers to store thermal energy. Mine thermal energy storage, popular in Europe, uses abandoned mines filled with water as heat storage reservoirs.

Hybrid Geothermal System or Multisystem Hybrid: A geothermal application that couples two different technologies, such as solar and geothermal, direct air capture and geothermal, hydrogen and geothermal, energy storage and geothermal, and others. This system can be deployed in a variety of rock types and may or may not be scalable, depending on the system combination.

Oil and Gas Well Reuse (Well Reuse): A geothermal application in which geothermal energy is produced from existing oil and gas wells. There are two possibilitiesfor energy production. First, an existing hydrocarbon well could be repurposed to produce geothermal energy only, known as *conversion*. Second, an existing well could produce hydrocarbons and heat simultaneously, known as *coproduction*.

Working Fluid: The fluid used to harvest geothermal heat from the subsurface and deliver it to the surface in geothermal applications. Working fluids can be, and historically have been, water or brine. Next-generation geothermal concepts seek to use novel, nonwater "engineered working fluids" with lower boiling points than water to increase system efficiencies and performance, particularly in lower-temperature geothermal resources. Examples of engineered working fluids that are currently in research and development include supercritical carbon dioxide (sCO_2), combinations of organic fluids, or combinations of both sCO_2 and organic fluids. Binary-cycle power plants also use engineered working fluids to drive the turbines in their second stage.

Geothermal Anywhere: A colloquial term used to refer to scalable geothermal concepts—EGS, AGS, or SHR—that could enable the development and production of geothermal energy anywhere in the world.

Scalable Geothermal: A term used for any geothermal resource that has few, if any, geographic limitations to its ability to scale globally (as opposed to locally or regionally) or to any geothermal technology that, once proven through field trials, could feasibly be deployed anywhere in the world. Advanced geothermal systems, engineered geothermal systems, and some hybrid geothermal system concepts are considered scalable geothermal technologies. A conventional hydrothermal system is not considered a scalable geothermal resource according to this definition.

Abbreviations

AGS: advanced geothermal system

BLM: Bureau of Land Management

CHS: conventional hydrothermal system

CO2: carbon dioxide

DOD: U.S. Department of Defense

DOE: U.S. Department of Energy

ECAM: Energy Conservation and Management Division

EGS: engineered or enhanced geothermal system

EMNRD: Energy, Minerals, and Natural Resources Department

FORGE: Frontier Observatory for Research in Geothermal Energy

GEODE: Geothermal Energy from Oil and Gas Demonstrated Engineering

GES: geothermal energy storage

GPDF: Geothermal Projects Development Fund

GPRLF: Geothermal Projects Revolving Loan Fund

GSHP: ground source heat pump

IEA: International Energy Agency

IRENA: International Renewable Energy Agency

kWh: kilowatt-hour

MARP: Mining Act Reclamation Program

MECS: Manufacturing Energy Consumption Survey

MWh: megawatt-hour

NCG: noncondensable gas

NMGC: New Mexico Gas Company

NMOGA: New Mexico Oil and Gas Association

NMPRC: New Mexico Public Regulation Commission

NMSU: New Mexico State University

NMT: New Mexico Institute of Mining and Technology

NREL: National Renewable Energy Laboratory

PNM: Public Service Company of New Mexico

RETA: Renewable Energy Transmission Authority

RPS: renewable portfolio standard

SGS: sedimentary geothermal system

SHR: superhot rock

SIC: State Investment Council

SLO: State Land Office

SPS: Southwestern Public Service Company

TEN: thermal energy network

TWh: terawatt-hour

UNM: University of New Mexico

Executive Summary

Unlocking New Mexico's Geothermal Potential

New Mexico's combination of abundant subsurface heat, technical expertise from the oil and gas and geothermal industries, and support from political leaders make the state well suited to exponentially grow its geothermal development. It has the potential to produce 163 gigawatts of geothermal power, more than 15 times the state's installed capacity in 2023.

The Land of Enchantment is beautifully and geographically diverse. Across its nearly 78 million acres are wide deserts, broken mesas, high peaks, and forested wilderness. Beneath the surface—oil, gas, minerals, and heat. Lots of heat. At the top of the state lies a chain of Cenozoic volcanic fields called the Jemez Lineament. Cutting through the state's middle is the Rio Grande rift, a geologic zone that separates the Colorado Plateau from an old, stable part of the Earth's continental lithosphere.

In large part because of those two ancient geologic formations, New Mexico and its Tribal lands are also a place of extraordinary geothermal potential—sixth in the nation, in fact.[1] So much of that potential lies in traditional hydrothermal power generation. But the state also has rich potential for next-generation geothermal energy—accessing the Earth's heat in locations without subsurface water via advanced drilling and other technologies. Taken all together—the geologic attributes and the technologies—it is possible to develop one or another kind of geothermal energy solution in every location across all of New Mexico.

In late 2024, the International Energy Agency published an analysis of the technical heat energy provided by geothermal resources around the world (using data calculations from Project InnerSpace's GeoMap tool). The report calculated the recoverable quantities of

GEOTHERMAL OPPORTUNITIES IN NEW MEXICO

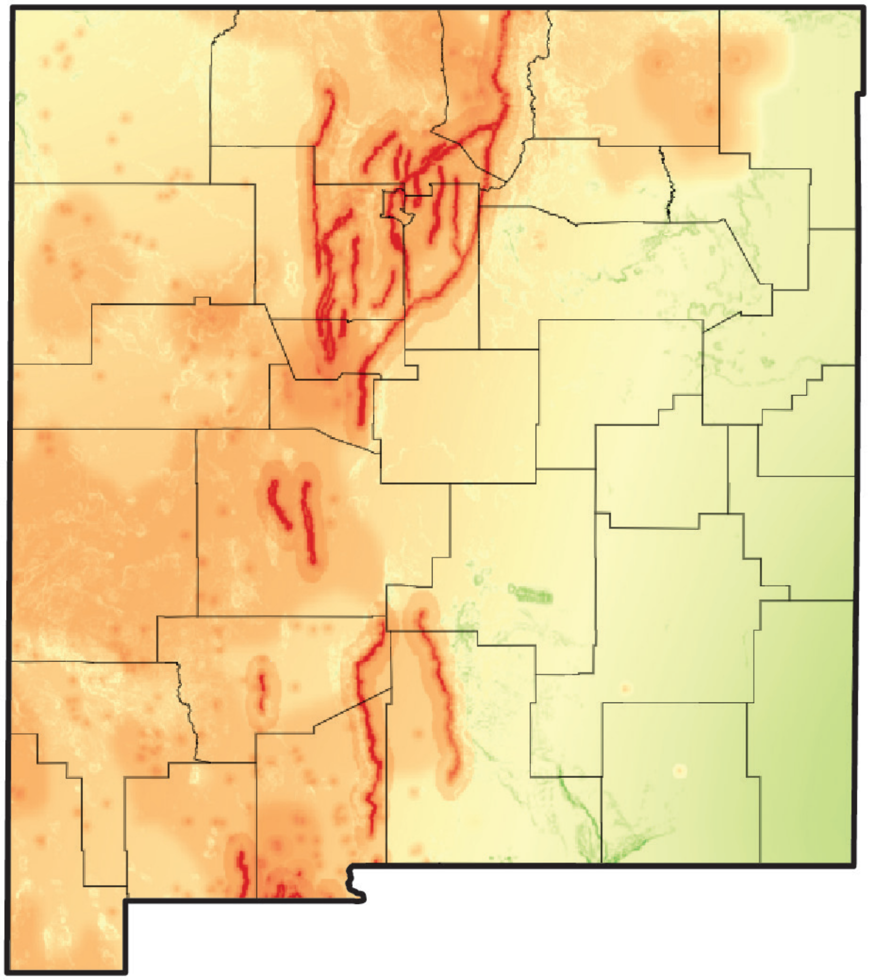

Figure ES.1: Geothermal opportunities in New Mexico.Source: *The Geothermal Exploration Opportunities Map Beta (GeoMap).* https://geomap.projectinnerspace.org/map-selection/.

geothermal energy at various price points given today's technology.[2] Assuming that New Mexico developed all available geothermal resources within the first 16,400 feet of subsurface, the state would have a geothermal potential of 163.32 gigawatts, or more than 15 times its installed capacity in 2023.[3]

No other state combines such favorable geology, oil and gas expertise, political will, and raw potential as does the Land of Enchantment.

Because of its vast hydrothermal resources, New Mexico is one of just seven states in the United States that has an active geothermal plant—the Lightning Dock plant in Hidalgo County—supplying electricity to its grid.[4] That the plant exists gives New Mexico a head start on expanding the development of this firm, secure, clean energy: The state already has a set of regulations and laws—new and old—to help govern the industry. **In fact, New Mexico is the only state in the nation that includes the word *geothermal* in its constitution and directly works to facilitate its development.**

Today, with this framework, and thanks to the advancement of technologies that unlock next-generation geothermal power, heat, and energy storage potential, policymakers could do so much more to expand the industry and help New Mexico meet its energy and climate goals.

As explored in this report, New Mexico is on the cusp of a geothermal boom—one that could create environmental and economic benefits in cities and rural communities; leverage the state's oil and gas industry know-how; and

GEOTHERMAL POLICY RECOMMENDATIONS FOR NEW MEXICO

Create clear pathways and legal and regulatory certainty for industry

- Clarify heat ownership
- Streamline and simplify legal definitions of *geothermal energy*
- Further enable geothermal reuse of depleted or abandoned oil and gas wells
- Identify priority leasing areas and create geothermal Special Economic Zones at the State Land Office
- Proactively plan for and prepare transmission for geothermal electricity projects
- Produce and maintain a "developer tool kit," a one-stop shop for geothermal project development

Create the conditions that will accelerate geothermal production in New Mexico

- Set a regulatory goal of 5 gigawatts of geothermal energy on the New Mexico grid by 2035
- Work with the federal government to catalyze geothermal deployment on federal lands

Expand state geothermal incentives

- Expand the grant and revolving fund to include commercial and private sector projects on state lands
- Establish targeted grants and loans for geothermal power and industrial process heat
- Incentivize geothermal-powered data centers

Catalyze the development of geothermal heating and cooling

- Allow utilities to build, own, and operate Thermal Energy Networks (TENs)
- Improve utility efficiency with expanded geothermal heating and cooling (GSHP)

Expand educational programs for energy workers and the public

- Expand geothermal-specific apprenticeships and workforce trainings
- Update public education materials and improve outreach for funding opportunities

establish clean, secure, always-on power sources with the smallest footprint of any energy source across the Land of Enchantment.

LEGISLATION, REGULATION, AND RECOMMENDED POLICIES TO EXPAND NEW MEXICO'S GEOTHERMAL INDUSTRY

About 20 years ago, New Mexico adopted an ambitious renewable portfolio standard that has since been updated to ensure that 40% of the state's electricity comes from clean energy sources by 2025 and 80% comes from these sources by 2040; by 2045, 100% of electricity should come from zero-carbon resources.

Over the past decade, as the state has worked toward those goals, the New Mexico Legislature has made a number of changes to enhance and improve the use of geothermal across the state, including several bills that create geothermal incentives for implementing geothermal power generation and using ground source heat pumps.[5] In its 2025 session, the legislature took action on two more geothermal-related bills: HB 2 increased the money available for the Geothermal Projects Development Fund from $5 million to $15 million for studies on the costs and benefits of a proposed geothermal project, and HB 361 allows for the conversion of oil or gas wells into facilities that develop geothermal energy or provide energy storage. Combined with the significant production of wind and solar in New Mexico, HB 361 makes geothermal storage is an exciting opportunity in the state.

However, there is more work that can be done.

As explained in detail in Chapter 7, "Policy and Regulatory Pathways to Catalyze Geothermal in New Mexico," this report identifies 15 policies across five categories that, if enacted, would catalyze the expansion of New Mexico's clean and abundant geothermal resources. Taken together, these policies can help New Mexico meet its climate targets, increase economic development, and create jobs. In fact, **by implementing a 5 gigawatt goal, New Mexico would create nearly 2,000 construction jobs, 750 indirect and induced jobs, and more than 125 permanent operations and maintenance jobs and would help ensure the state meets its climate targets.**

15 Recommendations to Improve Geothermal Development in New Mexico

Create Clear Pathways and Legal and Regulatory Certainty for Industry.

1. Clarify heat ownership in the state's legal and regulatory language.
2. Streamline and simplify legal definitions of *geothermal energy*.
3. Further enable geothermal reuse of depleted or abandoned oil and gas wells.
4. Identify priority leasing areas and create geothermal Special Economic Zones at the State Land Office.
5. Proactively plan for and prepare transmission for geothermal electricity projects.
6. Produce and maintain a "developer tool kit," a one-stop shop for geothermal project development.

Create the Conditions That Will Accelerate Geothermal Production in New Mexico.

7. Set a regulatory goal of 5 gigawatts of geothermal energy on the New Mexico grid by 2035.
8. Work with the federal government to catalyze geothermal deployment on federal lands.

Some of these recommendations are based on actions that other states have successfully implemented, and some are built off policies that New Mexico already has in place for other sectors—in other words, the geothermal wheel does not need to be reinvented.

Expand State Geothermal Incentives.

9. Expand the grant and revolving fund to include commercial and private sector projects on state lands.
10. Establish targeted grants and loans for geothermal power and industrial process heat.
11. Incentivize geothermal-powered data centers.

Catalyze the Development of Geothermal Heating and Cooling.

12. Allow utilities to build, own, and operate thermal energy networks.
13. Improve utility efficiency with expanded geothermal heating and cooling.

Expand Educational Programs for Energy Workers and the Public.

14. Expand geothermal-specific apprenticeships and workforce training.
15. Update public education materials and improve outreach for funding opportunities.

Some recommendations can be undertaken quickly; indeed, two of them dovetail with recently passed laws. Others require government-initiated changes. Acting on these policies will help the state deliver on the promise it set up when it included "for the development and operation of geothermal" in its constitution in 1967.

WHERE AND WHAT TO BUILD

As mentioned, the Rio Grande rift slices north to south, almost straight through the state, and the Jemez Lineament cuts across the top of the state, east to west. These two formations have helped create a subsurface landscape with temperatures that exceed 212°F (100°C)—at 3,000 meters deep—in almost every county in the state and on Tribal lands. Some counties also have temperatures above 482°F (250°C). Put simply, there's enough heat in the rocks for *some* use of geothermal energy across *nearly all* of New Mexico. (See **Figure ES.1**.)

Just north of Santa Fe, the Rio Grande rift and the Jemez Lineament intersect.[6] At this intersection, you'll find Valles Caldera in Sandoval County, a supervolcano that formed 1.2 million years ago, leaving active, classic geothermal systems such as hot springs and fumaroles throughout the region. As the Jemez Lineament travels south into Santa Fe County, Sierra County (particularly around the city of Truth or Consequences),[7] the Hondo Valley in Lincoln County, and the Tularosa Basin in Otero County, it offers up plenty of other locations with classic hydrothermal energy.

And thanks to advances from the oil and gas sector, much of New Mexico's heat outside of these hydrothermal areas can now also be tapped for power and heat.

Almost all of the western half of the state has enough heat potential for power generation. These areas also have potential for direct-use heat and geothermal energy storage for excess production of solar and wind, which can then be put back on the grid when demand is higher.

Tribal and Pueblo Land

Native American Tribes and Pueblos are significant landholders in New Mexico and essential stakeholders in the development of energy resources. A significant amount of Tribal land sits on top of some of the best subsurface heat in the region (see **Figure ES.2**). Developing geothermal energy could offer Tribes new revenue streams through royalties, land leases, and generated electricity for Native-owned utilities.[8,9] It could also offer employment opportunities during the exploration, construction, and operation phases of a project[10,11,12] and enhanced energy sovereignty from external generating stations and utilities.[13]

A number of Tribes and Pueblos have explored or are currently exploring the use and expansion of geothermal energy. Working with Tribes and Pueblos must be approached with the recognition that each Tribe may pose a distinct set of questions and will offer unique perspectives on energy development, reflecting these communities' cultural, historical, and political heterogeneity.[14] (See Chapter 8, "New Mexican Stakeholders," for more details.)

KNOWN TRIBAL AREAS IN NEW MEXICO AND GEOTHERMAL OPPORTUNITIES

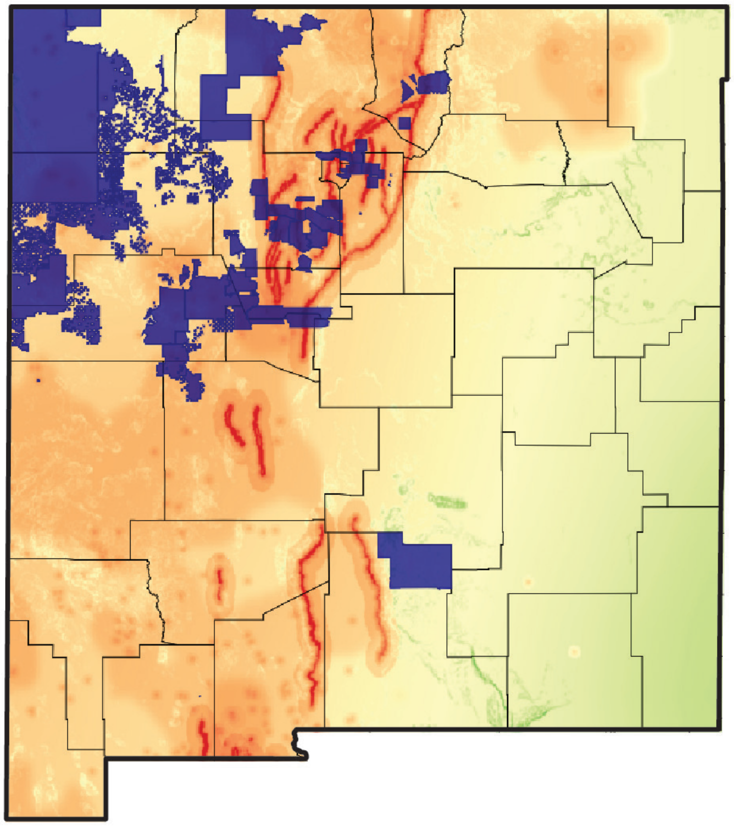

Figure ES.2: Map of known Tribal areas in New Mexico, including 19 Pueblos, 3 Apache Tribes, and part of the Navajo Nation, and the subsurface potential in the region. Source: GeoMap

New Mexico's Federal Lands

New Mexico is home to a vast swath of federal land with some of the state's—and nation's— highest potential geothermal resources. On those lands are a number of energy-intensive federal facilities, including research centers such as Sandia and Los Alamos National Laboratories and U.S. Department of Defense bases (e.g., Fort Bliss, White Sands Missile Range, and Kirtland and Holloman Air Force Bases).[15]

Geothermal works 24/7/365—it's nearly always on, unlike other renewables. It also enjoys capacity factors far above intermittent wind and solar—as high as 90%.

In its first few months, the Trump administration has made it clear that next-generation geothermal is a priority.[16] The Department of Defense is already pursuing the development of geothermal at some military installations to improve the security, reliability, and resilience of energy consumed on the properties.[17]

New Mexico and the Coming AI Data Center Boom

Earlier in 2025, research from Goldman Sachs projected that there would be a staggering 165% growth in demand for data center power by 2030.[18] Driving that demand is the rapid advancement of artificial intelligence (AI). The U.S. Department of Energy (DOE) estimated that the amount of energy that data centers use in the United States could more than double in five years, from just below 5% of the total electricity used in the country to up to 12%.[19,20]

The opportunity is clear: With its 163 gigawatts of potential, New Mexico is ranked as one of the best states for geothermal data centers (**Figure ES.3**).[21] (A study by RAND projected that a single data center could need 1

GEOTHERMAL-POWERED DATA CENTER POTENTIAL

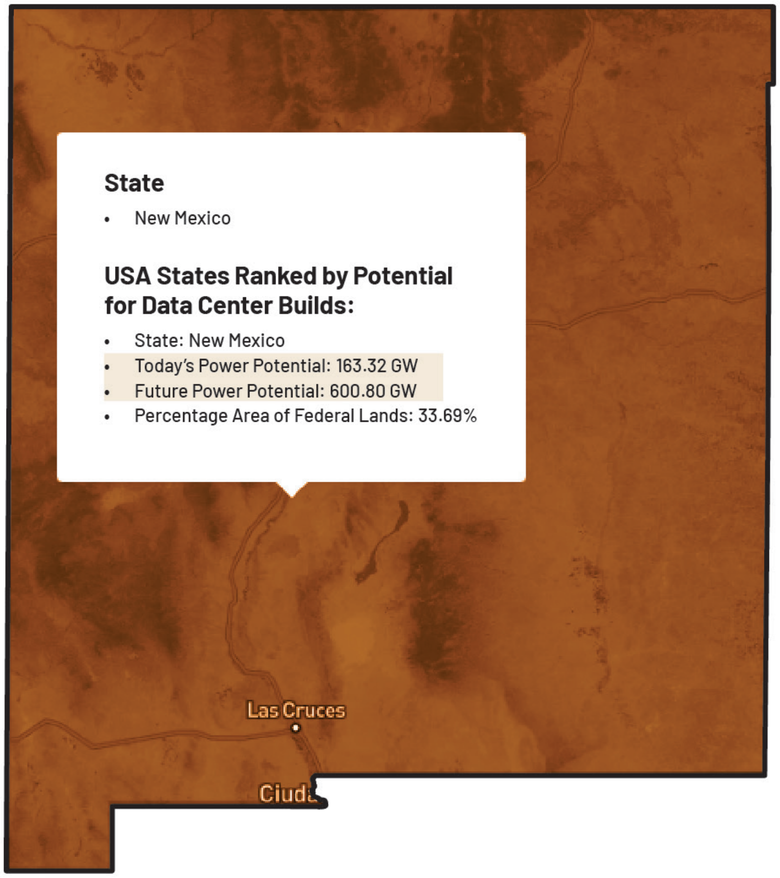

Figure ES.3: According to data from GeoMap, New Mexico is one of the top states in the country for geothermal data center potential, with 163 gigawatts of power potential down to 5,000 meters. Source: GeoMap.

gigawatt in just a few years.[22]) The state is also centrally located between major markets in the Pacific, Mountain, and Central regions. And it has competitive electricity costs and it has a low risk of natural disasters.[23,24]

The Trump administration recently issued a Request for Information for building AI infrastructure on DOE land and included a list of 16 federal sites that it deems a priority for this development, including New Mexico's Los Alamos and Sandia National Laboratories.[25,26]

HOW TO BUILD IT

Here is another auspicious benefit from New Mexico's rich geology: The state is the second-largest producer of oil and gas in the nation. This means that both the technology and expertise needed to develop everything required for next-generation geothermal energy—from geoscientists to drillers to service providers to legislators—are already there. These potential contributors are invested residents, and their oil and gas skills are driving down geothermal's costs.

The growth of the geothermal sector will not only offer careers to highly skilled workers but also create vocational training opportunities for in-state workers in plant operations and maintenance, as well as the multitude of sectors that can implement direct-use heat processes. The well-developed supply chain and skilled workforce already create 1,000 new wells per year in the state. Expanding their purview into geothermal energy offers a path to diversify revenue and stabilize communities. As mentioned earlier in this summary, by implementing a 5 gigawatt goal, New Mexico would create nearly 2,000 construction jobs, 750 indirect and induced jobs, and more than 125 permanent operations and maintenance jobs. (See **Figure ES.5.**)

2022 NEW MEXICO ENERGY CONSUMPTION BY END-USE SECTOR

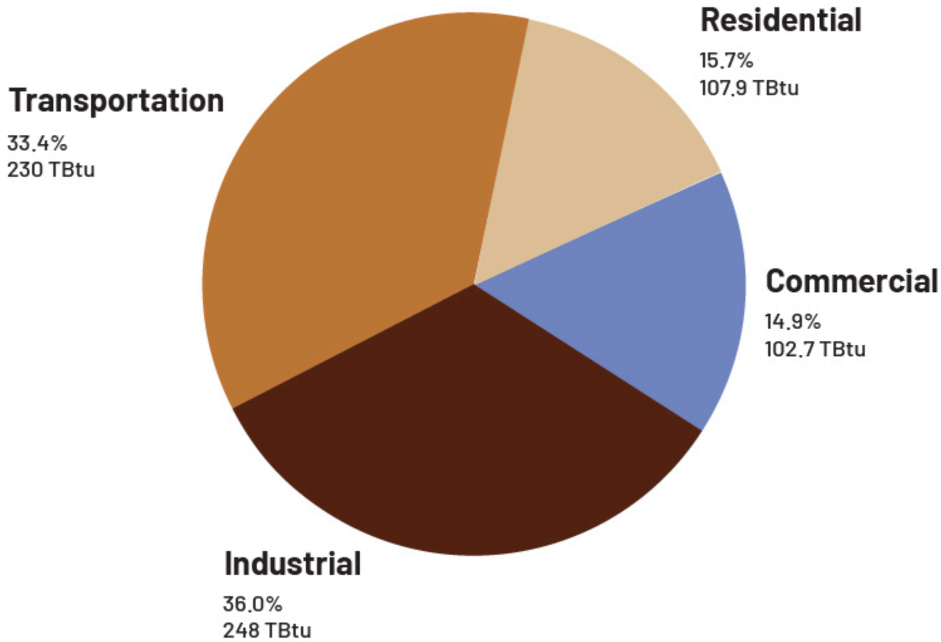

Figure ES.4: Energy consumption in New Mexico by sector. Source: U.S. Energy Information Administration (EIA). *New Mexico state profile and energy estimates: Profile overview.* https://www.eia.gov/state/?sid=NM

By using the skill set from the state's robust oil and gas industry, New Mexico can also accelerate the adoption of geothermal and lower the cost of development. By one estimate, in 10 years, the state could be producing 5 gigawatts of geothermal energy—enough to power millions of homes.[27] (See Chapter 5, "Leveraging Oil and Gas Technologies, Labor, and Workforce to Advance Geothermal in New Mexico.")

DIRECT USE

Through most of the state, there is enough heat to make a major dent in New Mexico's industrial heat demand through direct-use geothermal systems. New Mexico is 18th in the nation for energy consumed per capita.[28] In that amount consumed, though, is a vast amount of energy used by the state's businesses in the manufacturing, agriculture, forestry, mining (including oil and gas extraction), and construction sectors, among others.[29] (See Chapter 4, "Geothermal Heating and Cooling.")

The good news is that many of these activities use temperatures below 300°F (150°C) to produce energy. And that figure aligns with much of the subsurface heat where these businesses—and homes—exist. As shown in **Figure ES.1**, many of New Mexico's counties have subsurface temperatures that can support their industries. Take Chaves County, which is home to the world's largest mozzarella cheese factory and has hot enough subsurface temperatures to use geothermal direct-use heat for all of the facility's needs.

New Mexico's major cities also use a substantial amount of energy for residential and commercial heating and cooling (see **Figure ES.4)**. Established geothermal systems such as ground source heat pumps, geothermal district heating, and thermal energy networks (TENs) can help meet those demands efficiently.[30] TENs are especially well suited for New Mexico's urban areas, including Albuquerque, Las Cruces, Santa Fe, Roswell, Farmington, Hobbs, and Carlsbad. Taken together, these cities comprise about half of New Mexico's population.

Heating City Hall with geothermal has saved the town of Española nearly $42,000 a year in heating and cooling costs. One intensely cold winter, it was the only public building in town that remained heated.[31]

TRANSFERABLE SKILL SETS FROM THE OIL AND GAS INDUSTRY

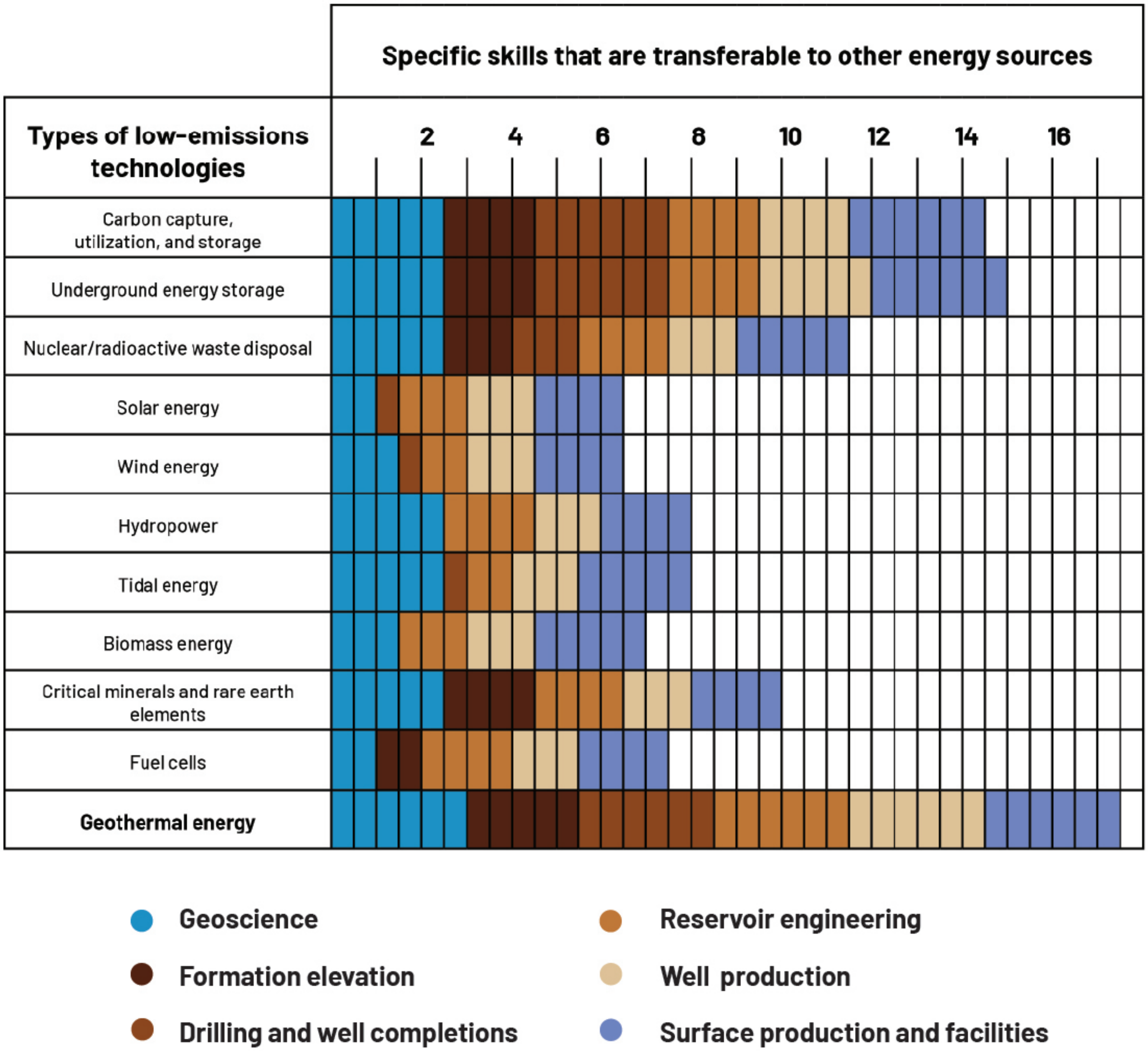

Figure ES.5: Geothermal ranks highest when considering the potential impact of transferring oil and gas skills into other energy transition and low-carbon technologies. Source: Tayyib, D., Ekeoma, P. I., Offor, C. P., Adetula, O., Okoroafor, J., Egbe, T. I., & Okoroafor, E. R. (2023, October). *Oil and gas skills for low-carbon energy technologies* [Paper presentation]. SPE Annual Technical Conference and Exhibition, San Antonio, TX, United States. https://doi.org/10.2118/214815-MS

A 2023 study from Oak Ridge National Laboratory included estimates on the benefit of using more geothermal heat pumps. Applying those national numbers to New Mexico shows the following benefits:[32]

- *Primary energy consumption reduction:* a 2.96 terawatt-hour (TWh) reduction in primary energy consumption annually by 2050.
- *Carbon emissions reduction:* 35 million metric tons of avoided CO_2 emissions by 2050.
- *Electricity generation savings:* approximate savings of 3 TWh annually in electricity generation by 2050.

HELPING NEW MEXICO'S NATURAL ENVIRONMENT

As its nickname—the Land of Enchantment—implies, New Mexico offers incredible beauty and sensitive landscapes. Ambitious renewable portfolio standards are in place, in part, to help protect the state's fragile ecosystems.[33] Achieving these goals will require balancing economic interests with environmental protection while also ensuring reliable and affordable energy access for all who live in the region.

On balance, having more geothermal in New Mexico would be a good thing for its environment. Because geothermal systems produce little to no carbon dioxide, methane, or pollutants, switching to geothermal energy would significantly reduce New Mexico's harmful emissions and air pollution. Compared to coal-fired power plants of a similar size, geothermal power plants can reduce the release of acid-rain-causing sulfur compounds by up to 97% and carbon dioxide by up to 99%.[34]

Geothermal power plants have a much smaller land footprint than any other energy source, so its use can support the conservation of natural landscapes and wildlife habitats. Geothermal energy also uses significantly less water—a precious resource in the southwestern United States—than oil, gas, or coal. New Mexico's subsurface also means it will have fewer issues with induced seismicity than other states.

When building a geothermal plant of any kind, there are environmental considerations to take into account. Chapter 9 outlines several recommendations for how to support responsible, ethical geothermal development given New Mexico's unique environment.

The data shows that across the board, geothermal is a good choice for safety, security, and the health of both people and the environment.

CONCLUSION

New Mexico clearly has the geology, heat, infrastructure, capacity, and political will to create a boom for geothermal energy. With these factors all taken together—significantly higher capacity factor, minuscule footprint, low emissions, applications across all industrial sectors, an existing skilled workforce—the benefits of geothermal couldn't be more obvious.

In recent years, New Mexico has taken steps along the geothermal path, including enhancements to the Lightning Dock Geothermal plant, the creation of a $15 million geothermal projects fund, the passage of a bill to make it easier to reuse capped and abandoned oil and gas wells for geothermal, and fiscal incentives. With the development of new technologies, and working on the recommendations offered in this report, New Mexico can tap into its vast heat resources, diversify the state's energy portfolio, and meet its climate targets while adding clean, stable energy to the grid.

In the years ahead, the successful integration of geothermal energy into New Mexico's energy mix will depend on continued collaboration among policymakers, researchers, industry leaders, and local communities—as well as investments in policy and regulatory streamlining. This report provides a road map to help make that happen, one that state leaders can use to continue New Mexico's role as an energy leader and help chart the course for the proliferation of geothermal around the globe.

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Part I

The Basics of Geothermal

Chapter 1

Geothermal 101: An Overview of Technologies and Applications

Project InnerSpace

Because it is hot everywhere underground, and thanks to technological developments from the oil and gas industry, we can access underground heat in significantly more locations than was historically possible. The potential for geothermal development across a variety of applications and use cases is now truly global.

Geothermal is a naturally occurring, ubiquitous, and clean energy source. About 4,000 miles from the planet's crust, the core of the Earth is roughly as hot as the surface of the sun. (See **Figure 1.1**). Geothermal heat is present across the entire planet—on dry land and on the ocean floor—and offers enough potential energy to power the whole world thousands of times over.

These resources have been exploited for centuries: In the 19th century, people started using heat from the Earth for industrial processes like heating and cooling buildings and generating electricity. The first documented instance of geothermal electricity generation was in Larderello, Italy, in 1904.[1]

But throughout history, these conventional hydrothermal systems have been geographically limited. They require specific subsurface conditions—sufficient heat, water, and rock permeability—which are typically found in tectonically active regions such as Iceland and the western United States.[2] Only when all three of these factors overlapped was there an exploitable geothermal resource. Even then, finding such a resource typically required a fourth natural phenomenon: an obvious surface manifestation such as a geyser or hot spring.[3] The need for these specific conditions severely restricted geothermal's broader global use, as few locations met these natural requirements.

Today, geothermal energy provides only 0.5% of global electricity.[4] Adoption of this energy is much higher in (primarily) volcanic regions, where geothermal resources—those conventional hydrothermal systems—are uniquely close to the surface. Conventional hydrothermal systems account for 46% of electricity in Kenya, 33% in Nicaragua, and 30% in Iceland.[5] New Mexico is one of seven states in the nation with a utility-scale hydrothermal power facility in operation,[6] the Lightning Dock Geothermal facility in Hidalgo County, in the southwest part of the state. (The plant's first customer was the state's public utility, Public Service Company of New Mexico [PNM].[7])

But now, geothermal energy can be produced from many more locations too. How?

Because it is hot everywhere underground, and thanks to technological developments from the oil and gas sector, we can now access that heat almost everywhere. Geothermal projects that use these technologies are referred to as *next-generation geothermal*. These new approaches—such as engineered geothermal systems and advanced geothermal systems—are expanding the future of geothermal energy beyond all previous geographical limitations. (See "The Evolution of Geothermal: From Constraints to Possibilities" for more on these approaches.) These technologies take many forms: directional drilling, deeper drilling, techniques that create additional pore space for fluid flow, more efficient drill bits, or the introduction of fluids into subsurface areas where they may not naturally be present.

Geothermal has the advantage of being a 24/7/365, clean baseload energy source. Unlike wind and solar, it is always on. Unlike natural gas and coal, it has no emissions or fuel costs. And unlike nuclear power, there is no need to dispose of radioactive material.

In general, the hotter the geothermal resource, the more efficient these next generation geothermal power plants will be at producing electricity. The more efficient the production, the lower the cost. As shown in **Figure 1.2**, geothermal electricity generation is possible with fluid temperatures as low as 200°F (approximately 93°C) using "binary" cycle power plants (in other words, two fluid cycles). Flash steam and dry steam electric turbines (see **Figure 1.3**) can be used when the fluid temperature rises above 350°F (approximately 180°C).[8] And some higher-temperature installations have started using novel binary-type configurations.

A report published in 2024 by the International Energy Agency (IEA) says "the potential for geothermal is now truly global," and next-generation geothermal systems have the technical potential "to meet global electricity demand 140-times over."[9] That analysis also notes that by 2035, geothermal could be highly competitive with solar photovoltaics and wind when paired with battery storage.

TEMPERATURE OF THE EARTH'S INTERIOR

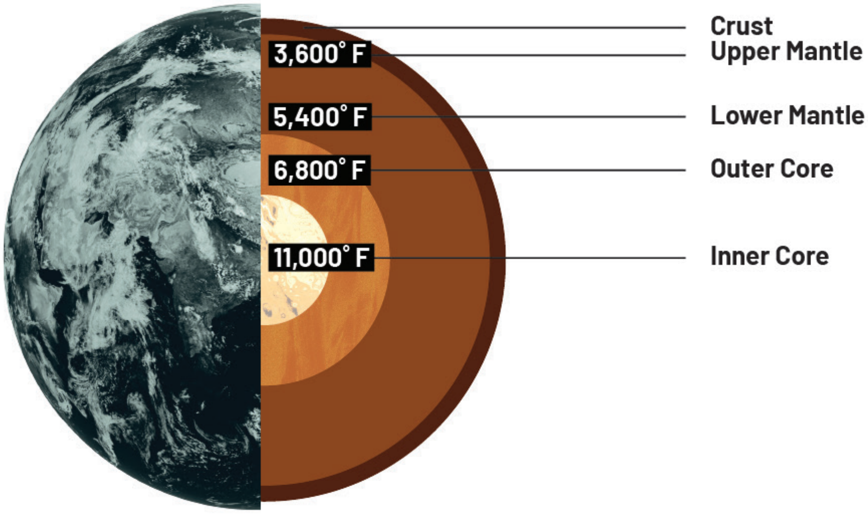

Figure 1.1: The core of the Earth exceeds the temperature of the surface of the sun. Because the crust of Earth is an excellent insulator, enough heat is trapped beneath us to power the world hundreds of times over. Source: Project Innerspace

GEOTHERMAL APPLICATIONS AND TEMPERATURE REQUIREMENTS

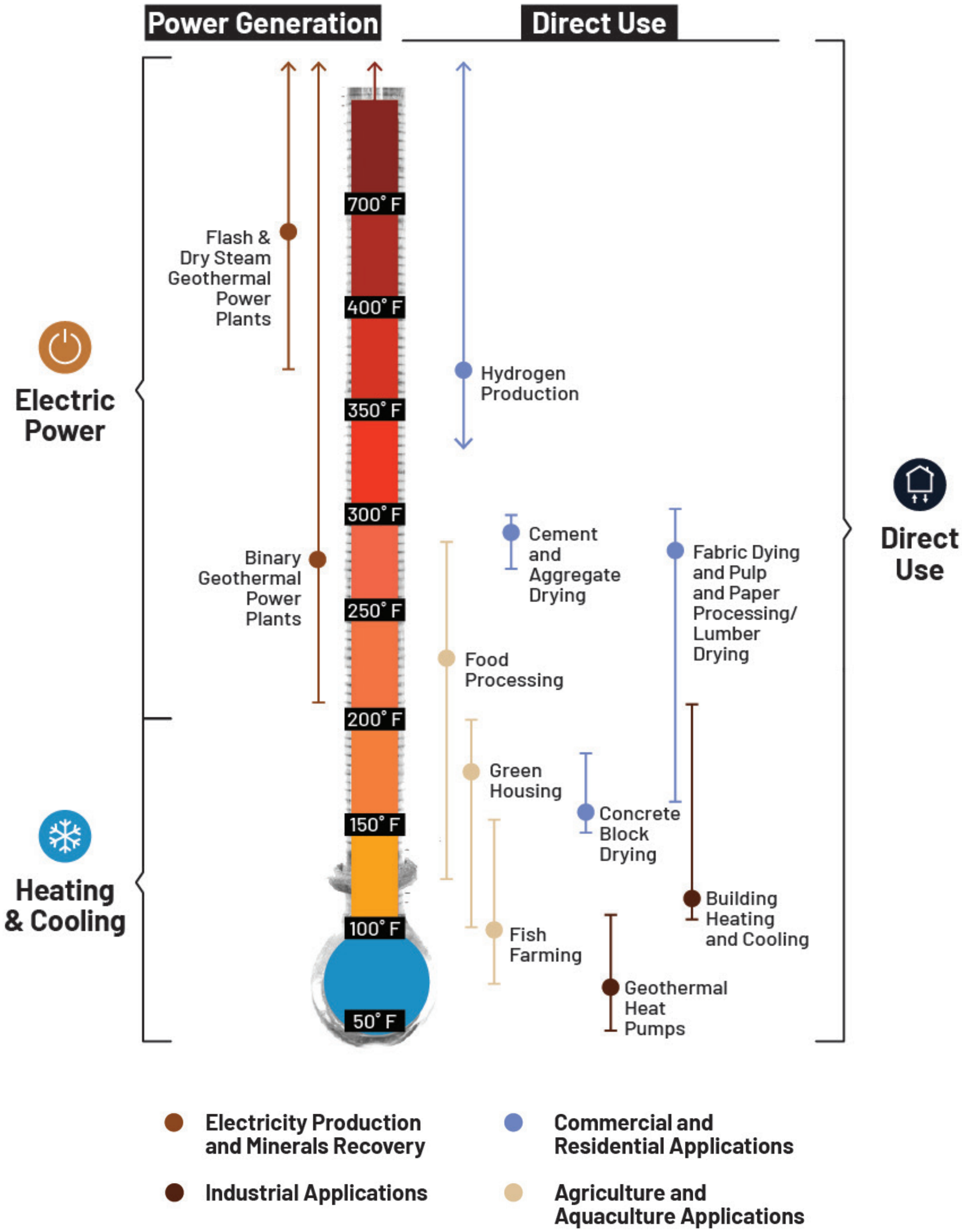

Figure 1.2: Geothermal energy can be used for generating electricity, heating and cooling homes, or manufacturing processes. There are also new and emerging applications such as geothermal energy storage, where the subsurface serves as an earthen battery, and geothermal critical minerals extraction for rare elements. Adapted from Porse, S. (2021, August 2-6). *Geothermal energy overview and opportunities for collaboration*. Energy Exchange, Georgia World Congress Center, Atlanta, GA, United States.

TYPES OF GEOTHERMAL ELECTRICITY GENERATION

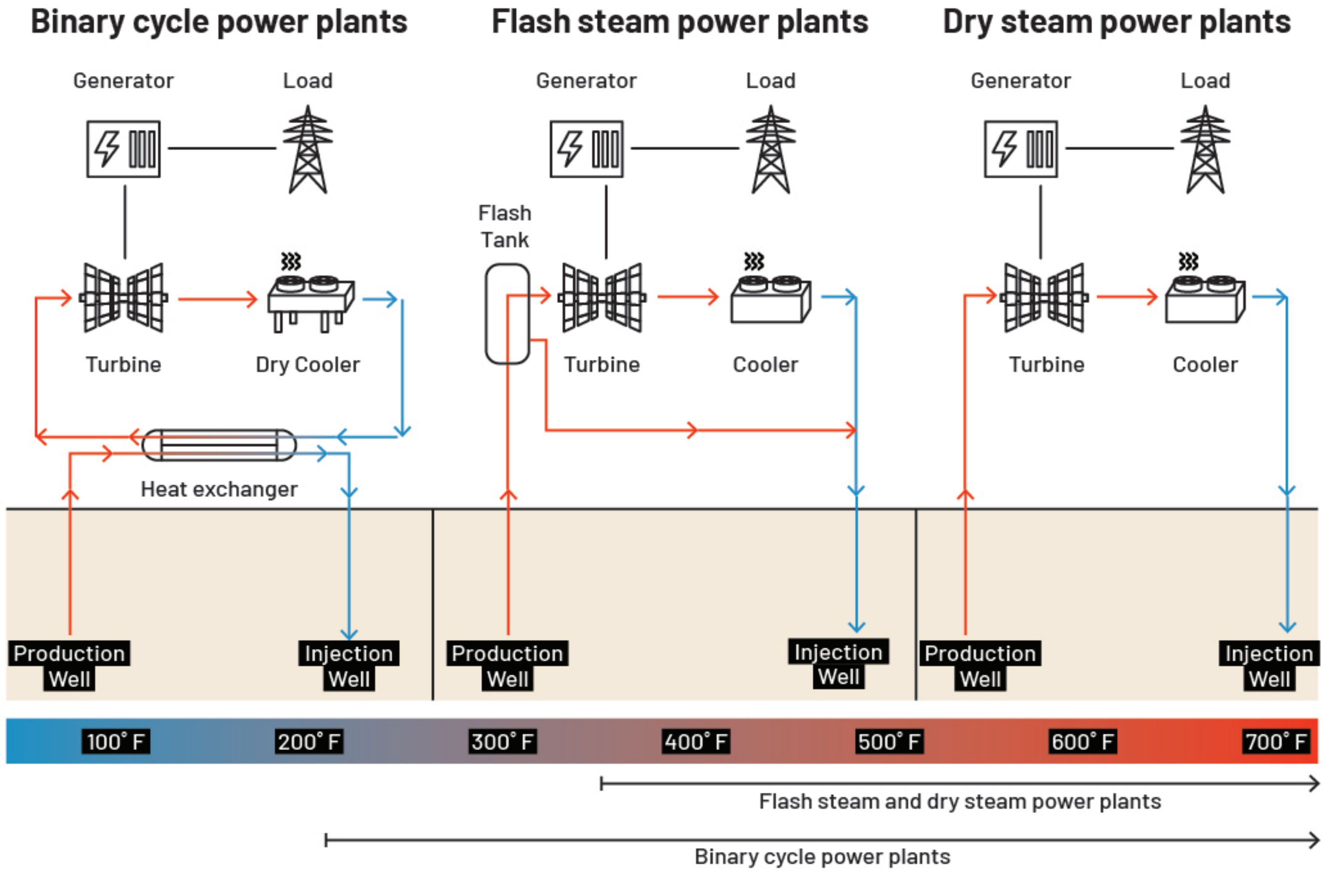

Figure 1.3: There are three primary configurations for generating electricity using geothermal: binary, flash steam, or dry steam. In general with these new technologies, the hotter the underground geothermal resource—whether conventional hydrothermal or next-generation geothermal—the more efficient the surface equipment will be at producing electricity. Binary geothermal electricity generation is possible with fluid temperatures as low as 200°F (about 95°C). Flash and dry steam geothermal electric turbines can be used when fluid temperature rises above ~360°F (182°C). Source: *The Future of Geothermal in Texas: The Coming Century of Growth and Prosperity in the Lone Star State.* https://energy.utexas.edu/research/geothermal-texas

Globally, heat energy makes up about half of all energy consumption and contributes to about 40% of energy-related emissions.[10] To put it another way: Clean geothermal can address almost half of the world's energy demand. Until recently, this opportunity has been almost entirely overlooked.

Direct Use: Geothermal Heating, Cooling, and Industrial Process Heat

Approximately three-quarters of all heat used by humans—from building heating and cooling to industrial processes—is produced by directly burning oil, gas, and coal.[11] The rest is produced from other sources, like burning biomass, or via the electrification of heat—meaning electricity that is produced using solar, wind, or other fuels and then converted back into heat. (For instance, electric strip heaters.)

INDUSTRIAL PROCESS TEMPERATURES AND HEAT PUMP TECHNOLOGIES

Sector	Process	Temperature °C
Paper	Drying	90-240 °C
Paper	Boiling	110-180 °C
Paper	Bleaching	40-150 °C
Paper	De-inking	50-70 °C
Food and Beverage	Drying	40-250 °C
Food and Beverage	Evaporation	40-170 °C
Food and Beverage	Pasteurization	60-150 °C
Food and Beverage	Sterilization	100-140 °C
Food and Beverage	Boiling	70-120 °C
Food and Beverage	Distillation	40-100 °C
Food and Beverage	Blanching	60-90 °C
Food and Beverage	Scalding	50-90 °C
Food and Beverage	Concentration	60-80 °C
Food and Beverage	Tempering	40-80 °C
Food and Beverage	Smoking	20-80 °C
Chemicals	Distillation	100-300 °C
Chemicals	Compression	110-170 °C
Chemicals	Thermoforming	130-160 °C
Chemicals	Concentration	120-140 °C
Chemicals	Boiling	80-110 °C
Chemicals	Bioreactions	20-60 °C
Automotive	Resin molding	70-130 °C
Metal	Drying	60-200 °C
Metal	Pickling	20-100 °C
Metal	Degreasing	20-100 °C
Metal	Electroplating	30-90 °C
Metal	Phosphating	30-90 °C
Metal	Chromating	20-80 °C
Metal	Purging	40-70 °C
Plastic	Injection molding	90-300 °C
Plastic	Pellets drying	40-150 °C
Plastic	Preheating	50-70 °C
Mechanical engineering	Surface treatment	20-120 °C
Mechanical engineering	Cleaning	40-90 °C
Textiles	Coloring	40-160 °C
Textiles	Drying	60-130 °C
Textiles	Washing	40-110 °C
Textiles	Bleaching	40-100 °C
Wood	Gluing	120-180 °C
Wood	Pressing	120-170 °C
Wood	Drying	40-150 °C
Wood	Steaming	70-100 °C
Wood	Cooking	80-90 °C
Wood	Staining	50-80 °C
Wood	Pickling	40-70 °C
Several sectors	Hot water	20-110 °C
Several sectors	Preheating	20-100 °C
Several sectors	Washing/Cleaning	30-90 °C
Several sectors	Space heating	20-80 °C

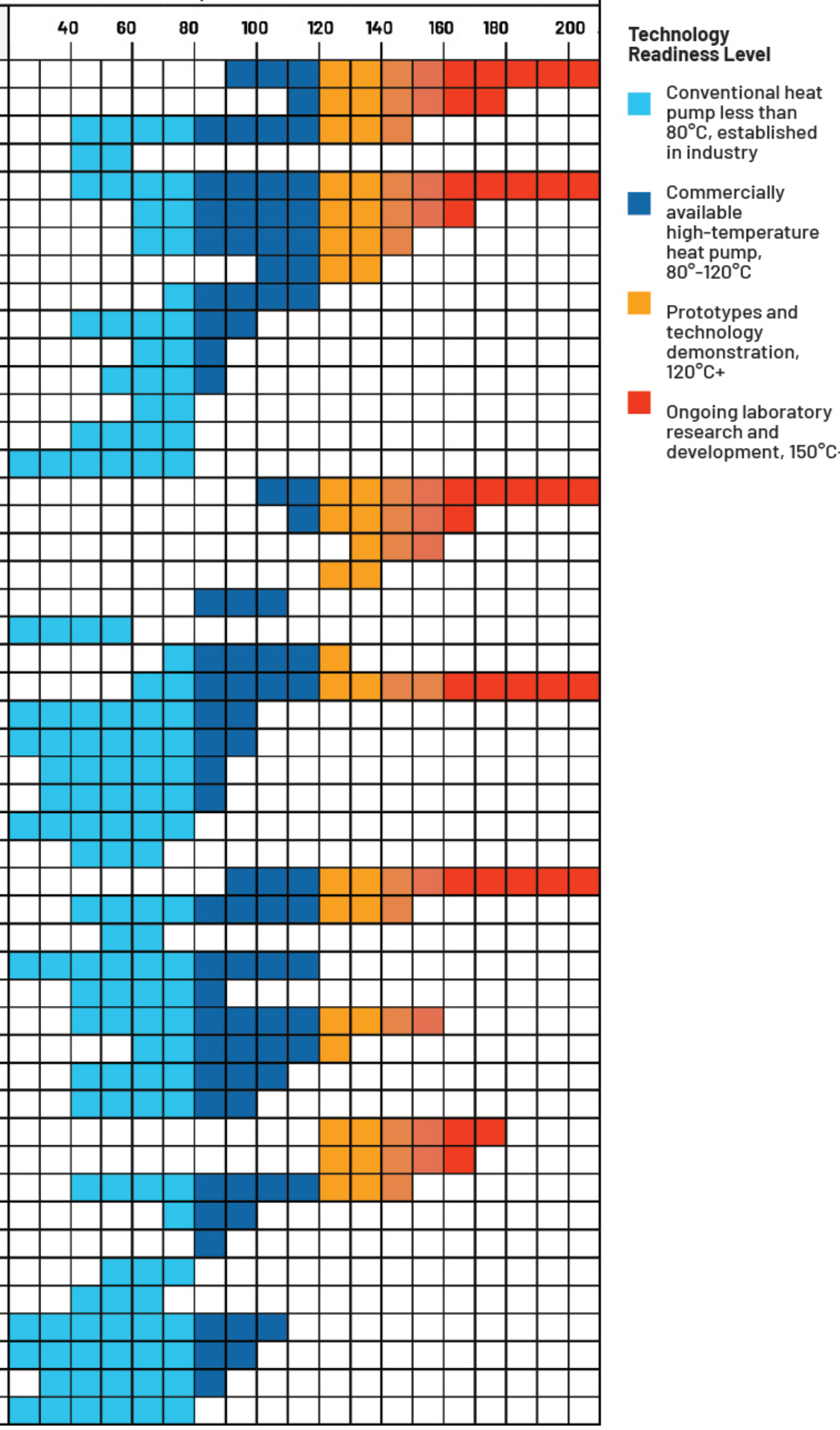

Figure 1.4: Rough technology readiness levels of high-temperature heat pumps as of mid-2023. Geothermal can enable industrial processes without heat pumps; however, combining the two technologies may prove even more useful. High-temperature industrial heat pumps above 100°C have seen significant advances in recent years. Source: Arpagus, C., et al. (2023). *Industrial heat pumps: Technology readiness, economic conditions, and sustainable refrigerants*. American Council for an Energy-Efficient Economy (ACEEE). https://www.aceee.org/sites/default/files/pdfs/IHP_Workshops_2023/Cordin_Arpagaus_-_OST.pdf

HEATING AND COOLING WITH GROUND SOURCE HEAT PUMPS

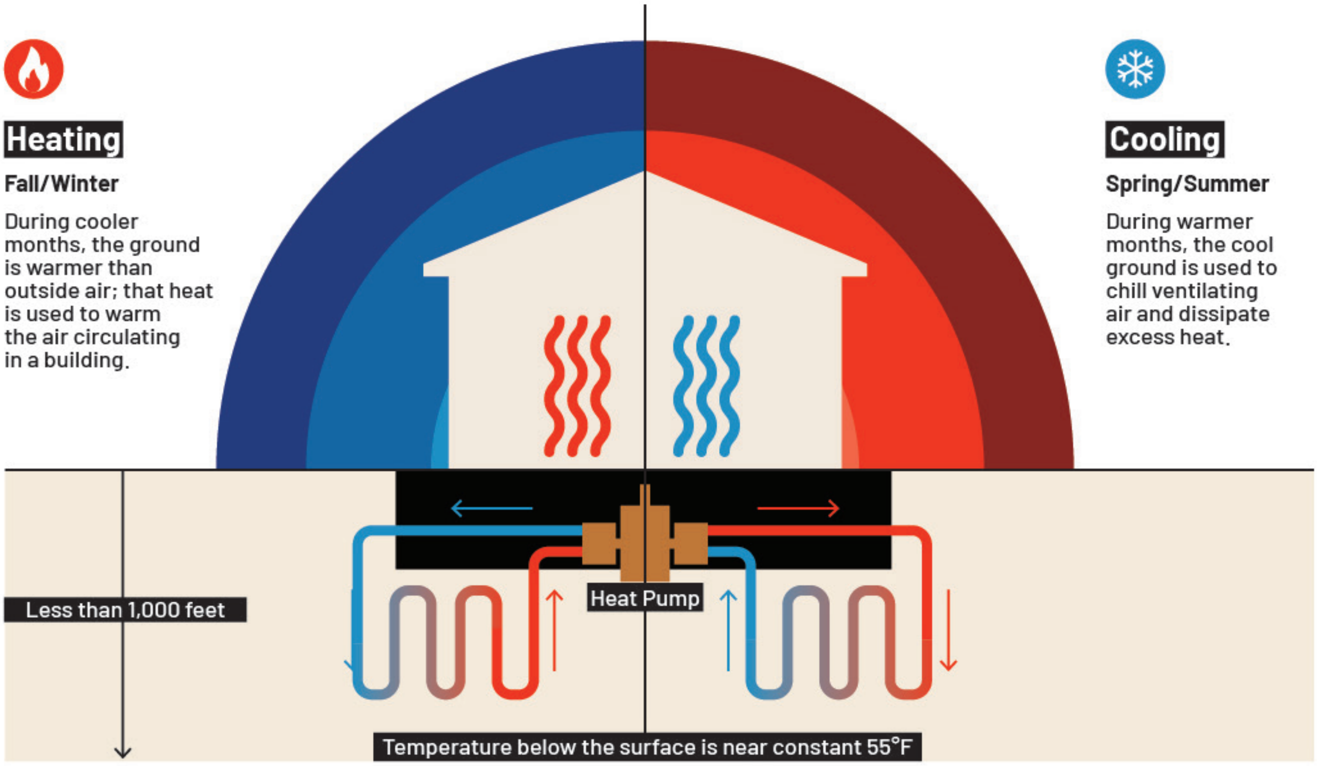

Figure 1.5: The constant temperature of the ground helps improve the efficiency of ground source heat pumps. Adapted from Beard, J. C. and Jones, B. A. (Eds.). (2023). Source: *The future of geothermal in Texas: The coming century of growth and prosperity in the Lone Star State*. Energy Institute, University of Texas at Austin. https://doi.org/10.26153/tsw/44084.

In the United States, the heating and cooling of buildings consumes about half of all energy use in both residential and commercial sectors.[12] That figure is higher in the residential sector in Europe.[13] The good news is that geothermal technologies that can help meet this demand already exist: ground-source heat pumps (geothermal heat pumps) and geothermal district heating. See Chapter 4, "Geothermal Heating and Cooling," for more information about these technologies and their deployment in New Mexico.

Industrial process heat is used to make everything from pens to paper, pasteurized milk to pharmaceuticals. Four of the most critical materials in the modern world—fertilizer, cement, steel, and plastics—all require significant amounts of heat to produce. In the industrial sector, thermal consumes more than half of total energy use and contributes the majority of the sector's emissions.[14]

All building heating and cooling (heating, ventilating, and air-conditioning; HVAC) and 30% of heat used for manufacturing processes worldwide use temperatures below 300°F (about 150°C).[15] In many parts of the world, geothermally derived heat at this temperature is currently comparable in cost with coal, biomass, solar, and wind. The IEA report estimates that next-generation geothermal could economically satisfy 35% of all global industrial thermal demand for processes requiring temperatures below 390°F (about 200°C). The use of next-generation geothermal could thus save about 750 megatons of carbon dioxide (CO_2) emissions—equivalent to the annual emissions of Canada, the world's 12th-largest emitter.[16]

Geothermal Energy Storage

The modern electricity grid is a delicate, vital system that requires constant monitoring to balance electricity production against electricity demands. With more

GEOTHERMAL DISTRICT HEATING SYSTEM

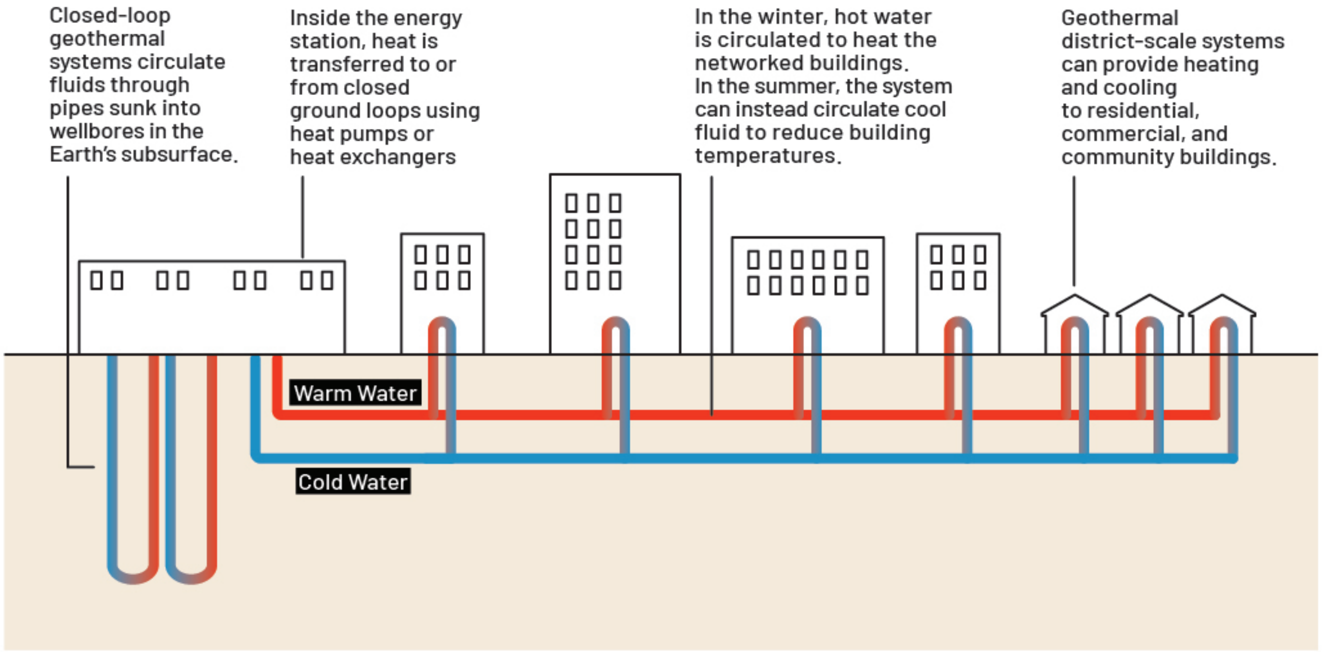

Figure 1.6: District heating system fluid is typically brought to the surface at a target temperature of around 70°F *(21°C). That fluid is then passed through a heat pump to provide hot water in the winter for heating and cold water in the summer for cooling. This style of heating and cooling can be more than twice as efficient as traditional HVAC systems because the thermal load is shared between buildings. Adapted from U.S. Department of Energy. *Geothermal district heating & cooling*. https://www.energy.gov/eere/geothermal/geothermal-district-heating-cooling

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COMPARING CAPACITY FACTOR

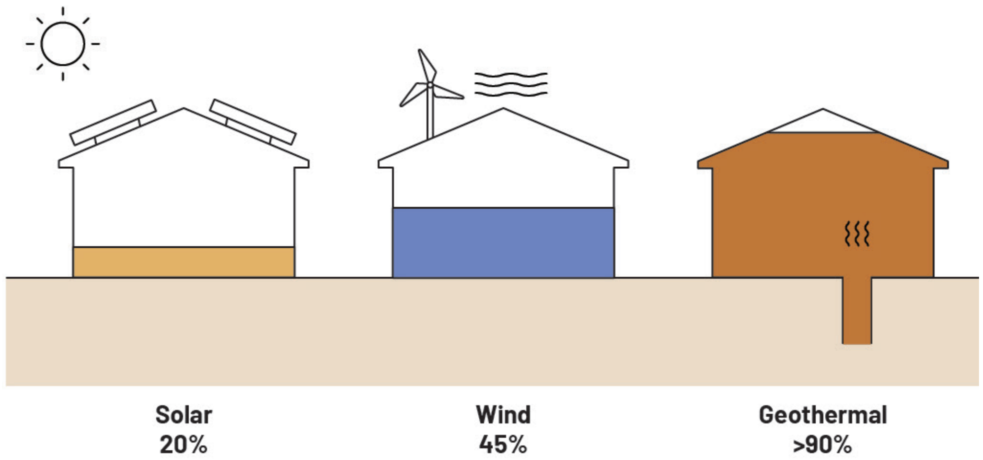

Figure 1.7: Capacity factor is the percentage of time that a power plant is generating electricity in a given day. Adapted from EIA, 2014.

electrons flowing onto the grid from intermittent energy sources such as wind and solar—which are only available when the sun shines or the wind blows—concerns about having power when it is needed have brought the need for energy storage to the forefront.[17] Today, hydroelectric storage provides most global energy storage capacity [18], and recent years have seen a significant expansion in the deployment of batteries for energy storage. A new approach—underground thermal energy storage, also known as *geothermal energy storage* (GES)—may offer an additional option.

GES systems capture and store waste heat or excess electricity by pumping fluids into natural and artificial subsurface storage spaces, from aquifers to boreholes to mines. GES can be primarily mechanical—with hydraulic fracturing techniques storing pressurized fluid in subsurface reservoirs—or mechanical and thermal—with both pressure and heat combined to return more energy than was required to pump the fluid underground.

Critical Minerals Extraction

Fluids, or brines, are often produced from geothermal systems. These brines are rich in dissolved minerals, including lithium, which can be harvested to meet the growing demand for lithium-ion batteries in electric vehicles and electric-grid storage solutions. This dual-purpose approach—providing clean energy and a domestic lithium source—could lower lithium extraction's environmental impact compared with traditional mining and improve the economics of a geothermal project.

At a conventional hydrothermal site in Southern California's Salton Sea, the brines are highly saline with high concentrations of minerals. Historically, salt and minerals were purely a nuisance, and significant work was required to keep pipes from scaling or developing mineral deposits that would restrict fluid flow. Today, direct lithium extraction offers the possibility that these critical minerals can instead be extracted and sold, providing power plant operators with an additional revenue stream. The California legislature has estimated that the Salton Sea contains enough battery-grade lithium to "satisfy more than one-third of the worldwide demand."[19]

COMPARING SURFACE FOOTPRINT

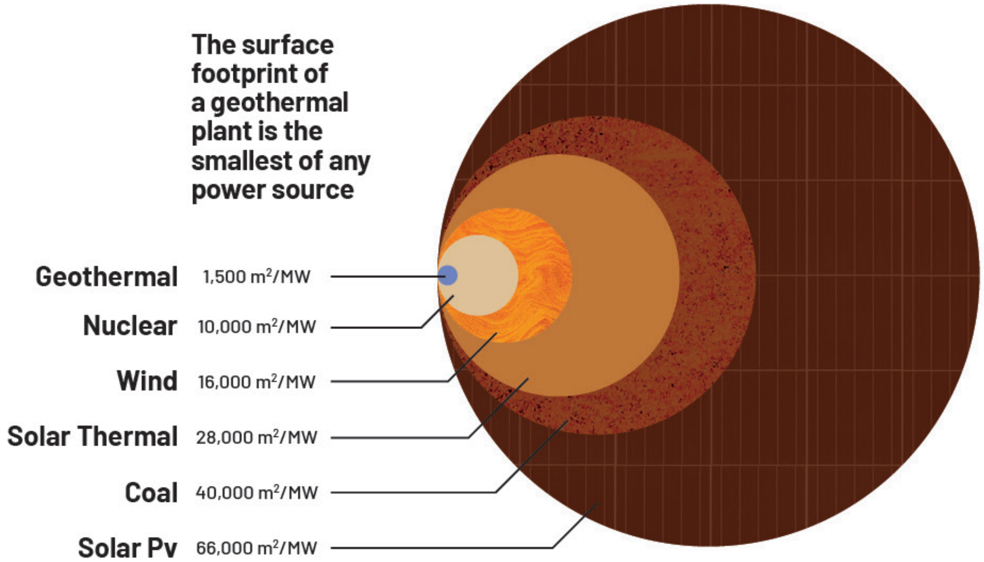

Figure 1.8: The project surface footprint, acre for acre for 1 gigawatt of generating capacity, is smallest for geothermal compared with other renewables and coal. Source: Adapted from Lovering et al., 2022 and NREL.

TRANSFERABLE SKILL SETS FROM THE OIL AND GAS INDUSTRY

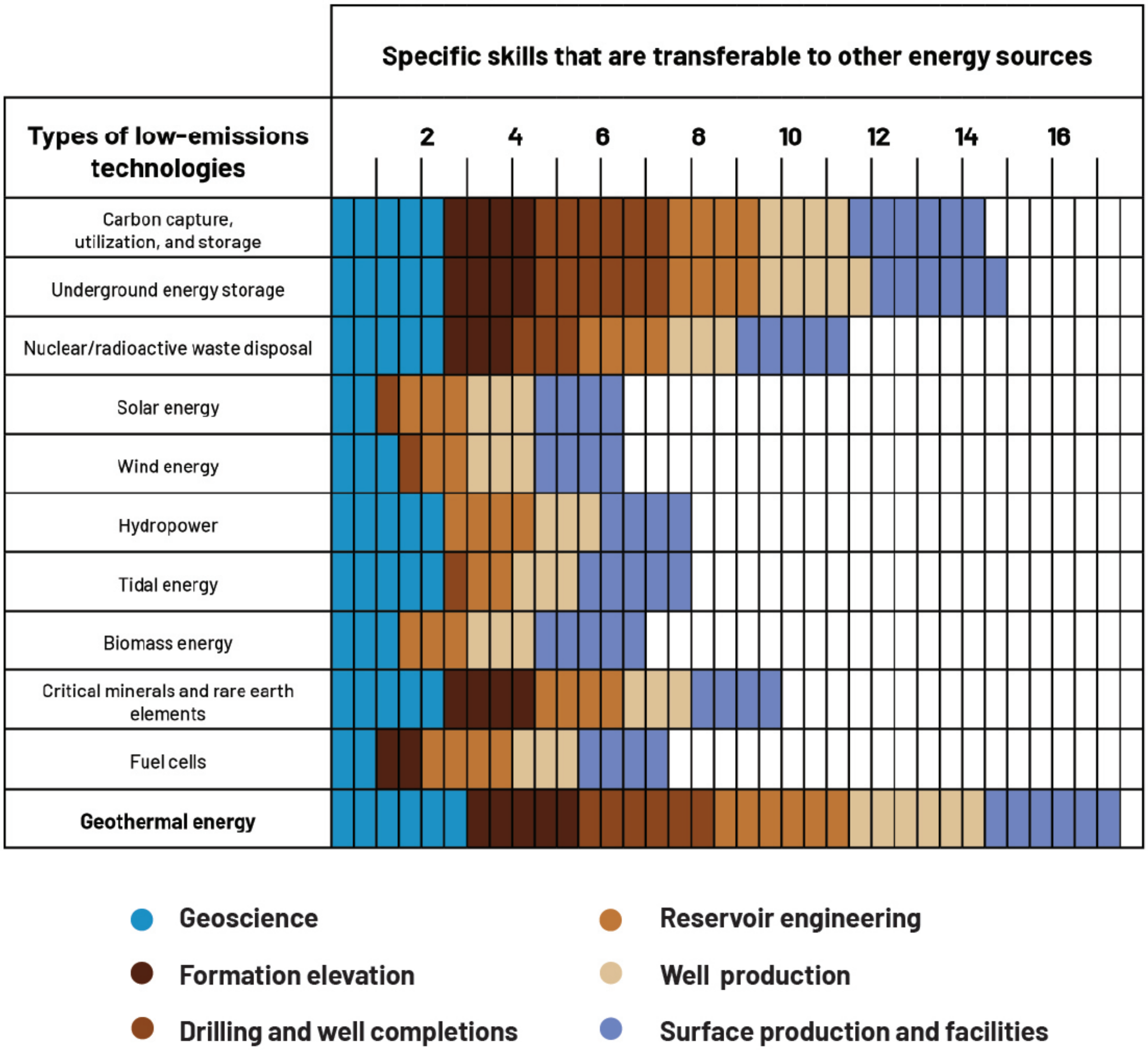

Figure 1.9: REE= rare earth elements. As shown, geothermal ranks highest when considering the potential impact of transferring oil and gas skills into other energy transition and low-carbon technologies. Source: Tayyib, D., Ekeoma, P. I., Offor, C. P., Adetula, O., Okoroafor, J., Egbe, T. I., and E. R. Okoroafor. *Oil and Gas Skills for Low-Carbon Energy Technologies*. Society of Petroleum Engineers Annual Technical Conference and Exhibition, San Antonio, Texas, United States, 2023: https://doi.org/10.2118/214815-MS

THE EVOLUTION OF GEOTHERMAL: FROM CONSTRAINTS TO POSSIBILITIES

As shown in **Figure 1.10**, the Earth's crust contains more potential thermal energy than is present in all fossil fuels and natural nuclear fissile materials combined. The challenge, then, is how to identify the areas and technologies that can tap into that potential energy most efficiently and economically.

Figure 1.11 summarizes the latest geothermal extraction technologies. The following sections describe these technologies in greater detail.

Engineered geothermal system (EGS): This kind of system uses both directional drilling and hydraulic fracturing to create artificial permeability, allowing for the use of geothermal energy far beyond regions with naturally occurring hydrothermal. EGS extracts heat by introducing fluids into the subsurface, breaking open fissures in relatively impermeable rock, and circulating fluid between one or more wells. The more fractures, the greater the surface area for the flowing fluid to conduct heat from rock.

Although EGS was conceived as early as the 1970s,[20] its scalability has only been possible because of cost reductions and technological advances in drilling and fracturing techniques commercialized by the oil and gas industry over the past few decades. However, unlike hydraulically fractured oil and gas wells—which are only intended for one-way extraction of oil and gas—EGS is designed to reuse fluids, so the same liquid flows continuously through hot rock in a convective loop.

EGS generally targets shallow hot-rock formations with few natural fractures and limited natural permeability to minimize uncontrolled fluid loss. Well depths can vary depending on where sufficient temperatures and appropriate stress conditions are found.[21]

Fracturing methods are subject to some uncertainty; even the most accurate engineering model cannot perfectly predict how a subsurface rock will crack or how fluids will flow. Nonetheless, as of this writing, EGS is seeing rapid technological advances, including at the U.S. Department of Energy's Frontier Observatory for Research in Geothermal Energy (FORGE) and from EGS startups such as Houston, Texas-based Fervo Energy and its Project

HOW ABUNDANT IS GEOTHERMAL ENERGY?

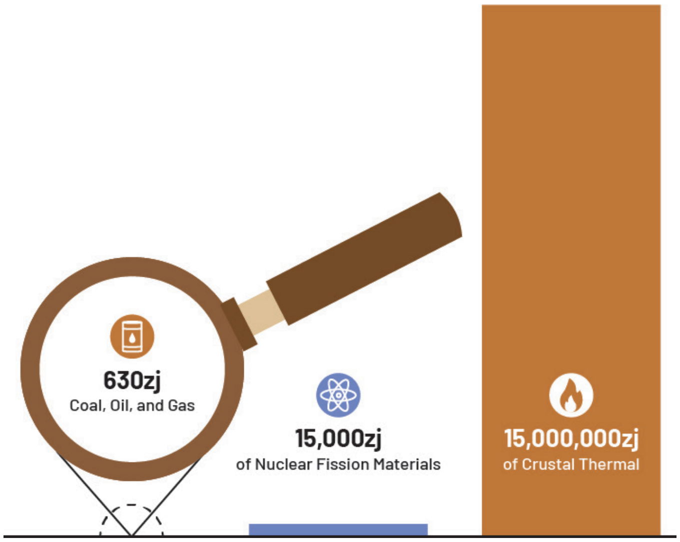

Figure 1.10: Comparison of total heat energy in Earth's crust, compared to fissionable materials and fossil fuels. Note that total fossil fuels, when compared with crustal thermal energy, is the equivalent of less than one pixel at the bottom of the graphic, shown magnified to illustrate scale. Measurements in zettajoules ("zj"). Source: Beard, J. C. and Jones, B. A. (Eds.). (2023). The future of geothermal in Texas: The coming century of growth and prosperity in the Lone Star State. Energy Institute, University of Texas at Austin. https://doi.org/10.26153/tsw/44084. Adapted from Dourado, 2021.

Red demonstration. Along with advances in tech, EGS is also being scaled for use in industrial-size projects. Fervo recently secured a 400 MW Power Purchase Agreement to construct a first-of-its-kind EGS power plant in Utah that will target approximately 350°F (about 175°C) hot rock.[22]

Advanced geothermal system (AGS): Like EGS, AGS eliminates the need for permeable subsurface rock. Instead, AGS creates and uses sealed networks of pipes and wellbores closed off from the subsurface, with fluids circulating entirely in a "closed loop."

Today, many AGS geothermal well designs are in development, including single well, U-shaped well "doublets" with injection and production wells and subsurface radiator designs. All of these designs use only their own drilled pathways; none require a conventional hydrothermal resource or hydraulic fracturing to create fluid pathways.

TYPES OF GEOTHERMAL ENERGY SYSTEMS

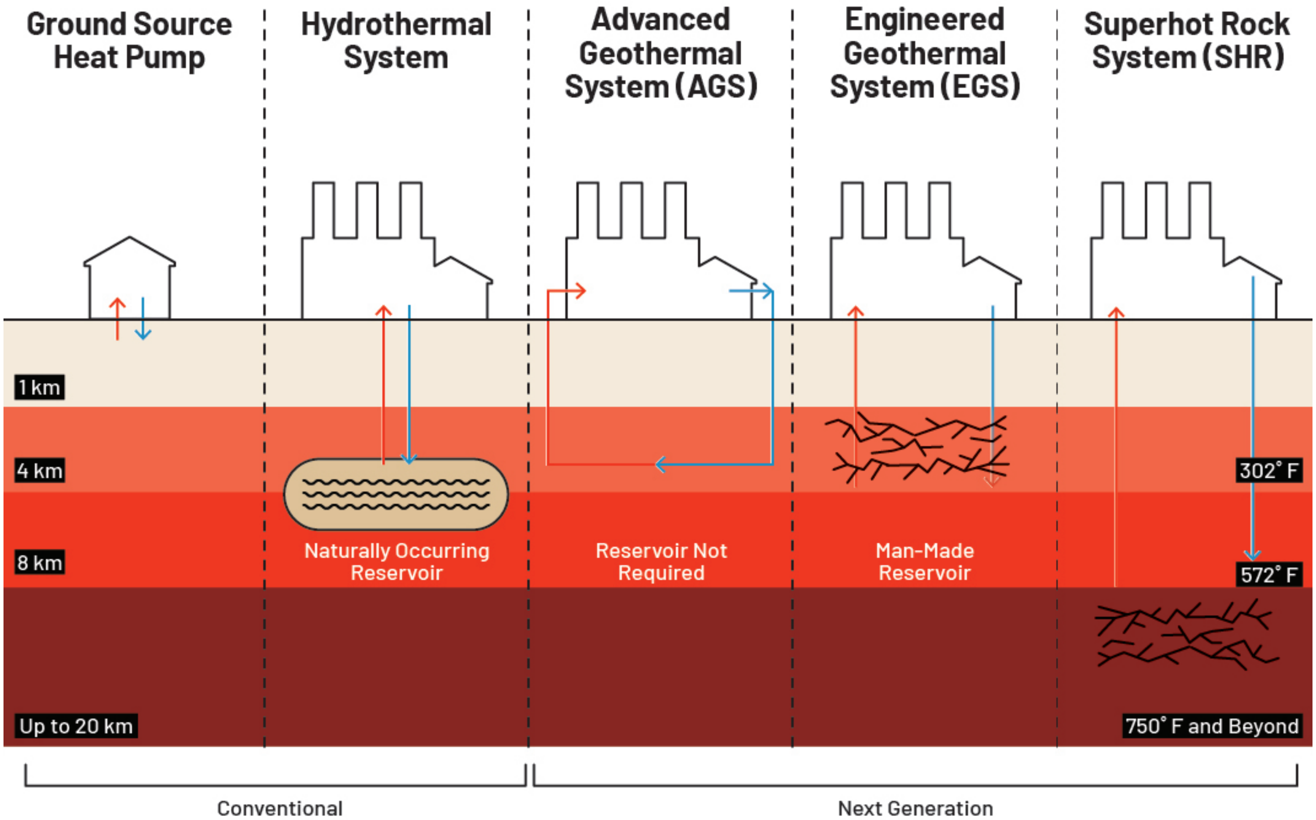

Figure 1.11: Geothermal electricity generation and industrial direct use. Ground source heat pumps shows building heating; the arrows and fluid flow would reverse for building cooling. Adapted from D'avack, F., & Omar, M. (2024, January 11). *Infographic: Next-generation technologies set the scene for accelerated geothermal growth*. S&P Global. https://www.spglobal.com/commodity-insights/en/news-research/latest-news/energy-transition/011124-infographic-next-generation-technologies-set-the-scene-for-accelerated-geothermal-growth-energy-transition

All geothermal energy extraction relies on conduction, the heat transfer from hot rock to fluid (see "Geothermal Geology and Heat Flow" for more details). Thus, unlike EGS, which benefits from the substantial surface area created by hydraulic fracturing, AGS have only the walls of their wells to conduct heat. As such, AGS must drill deeper, hotter, or longer well systems than EGS to conduct similar amounts of heat energy. Because an AGS doesn't exchange fluids with the subsurface, it can more easily use engineered, nonwater working fluids, such as supercritical carbon dioxide.

AGS can be developed in virtually any geological condition with sufficient subsurface heat. While an AGS guarantees a more definitive pathway for fluid flow in the subsurface relative to fracked EGS wells, drilling sufficiently long and deep AGS wells can be challenging and expensive.

Superhot rock (SHR): SHR is a type of next-generation geothermal that targets extremely deep, high-pressure rocks above approximately 703°F (373°C), the temperature at which water goes supercritical. SHR has the potential to revolutionize power production globally with superheated, supercritical geothermal steam capable of highly efficient heat transfer from the subsurface. Theoretically, SHR can employ either EGS or AGS well technologies, but no commercial SHR geothermal project has yet been developed because advances are needed in drilling technologies, rates, and costs to enable the economically competitive development of this next-generation concept.[23]

GEOTHERMAL GEOLOGY AND HEAT FLOW

The movement of heat from Earth's hot interior to the surface—what geologists call *heat flow*—is controlled by the geology of the planet. Heat from the core and mantle, as well as the decay of naturally occurring radioactive deposits in the Earth's crust, combine and emanate toward the surface of the planet.

Conduction, Advection, Convection, and Radiation

Heat flow in the Earth results from the following physical processes that contribute, to varying degrees, to the available heat in a geothermal resource.

- **Conduction**: The transfer of energy between objects in physical contact through molecular vibrations without the movement of matter. Conduction is efficient in some materials, like metals, and inefficient in others. Rock is a relatively poor conductor, but conduction is nonetheless considerable in the interior of the Earth.

- **Advection**: The transfer of heat due to the movement of liquids from one location to another. In geology, advection occurs in the movement of magma and groundwater, where the fluid carries heat as it moves through cracks, fractures, and porous rock formations. Advection is different from conductive heat transfer, which relies solely on direct contact between particles to transfer heat.

- **Convection:** A cycle of heat transfer involving conduction and advection that occurs when matter is heated, becomes less dense, rises, cools, increases in density, and sinks. Convection typically creates circulating loops of rising and sinking material. The Earth's mantle is almost entirely solid but behaves as a highly viscous fluid, thus allowing for convective heat transfer. The mantle's movement is extremely slow relative to human life but has a significant impact over geologic periods.

- **Radiation:** Energy that moves from one place to another as waves or particles. Certain areas in the Earth's crust have higher concentrations of elements with natural radiation, like uranium-238, uranium-235, thorium-232, and potassium-40.

Geology and Energy Extraction

The geological processes described interact to contribute to geothermal energy extraction under three common geological settings:

Convection-Dominated

1. Geologically open geothermal systems: In these systems, water circulates freely (e.g., the Great Basin in the United States). These systems are typically targeted for power generation and open-loop heat.

Conduction-Dominated

2. Geologically closed systems, with limited porosity/permeability: Water does not flow naturally in these systems, and geothermal energy extraction requires engineered "enhancements" (e.g., hydraulic fracturing).

3. Geologically closed systems, with natural porosity/permeability: These systems have natural pore spaces to a certain depth, allowing some fluid flow. This is beneficial when considering storage for heating and cooling.

Comparison of Existing and Emerging Geothermal Technologies and Concepts

	Geographies, Applications, and Technologies		
	Conventional Hydrothermal Geothermal	**District Heating**	**Ground Source Heat Pumps**
Basic Concept	Relies on natural hydrothermal systems with hot water and porous rock	Provides heating through interconnected building networks, using centralized geothermal systems	Uses shallow ground temperature stability to heat and cool buildings
Working Fluid	Naturally occurring fluids	Water or steam circulated through centralized pipes to buildings	Typically, water or antifreeze or refrigerant in a closed-loop system
Reservoir Type	Open to natural hydrothermal reservoir	Central reservoir supplying district buildings with hot water or steam	Closed-loop system buried at shallow depth
Geological Requirements	Natural hot aquifers in porous rock formations	Typically, sedimentary aquifers but can be used near conventional geothermal systems such as Iceland	No special geology; suitable for almost any location
Temperature Range	302°F-662°F (150°C - 350°C)	Generally, around 176°F-212°F (80°C-100°C)	All ranges
Drilling Depth	Shallow or deep, depending on hydrothermal location	Shallow to medium depth, depending on temperature requirements	Very shallow, typically 10 feet to 500 feet for residential to deeper for industrial heat pumps
Scalability	Limited to those few regions with natural hydrothermal conditions	Scalable anywhere concentrated clusters of buildings can share interconnected hot water or steam	Highly scalable; can be installed almost anywhere
Environmental Impact	Lower impact but dependent on natural resource conditions	Low impact; minimal drilling required and low emissions	Minimal impact; closed system without subsurface interaction
Examples of Use	Traditional geothermal power plants, direct-use heating in regions with hydrothermal conditions	Geothermal district heating in Iceland, Paris, and some U.S. cities	Commonly used for residential and commercial building heating and cooling but increasing in use for industrial heat when combined with industrial heat pumps
Primary Advantages	Established technology in areas with existing hydrothermal resources	Efficient and cost-effective heating for multiple buildings in urban or suburban networks	Proven, simple, reliable system for year-round building climate control and a key technology for data center cooling
Challenges	Limited to specific geographical areas with natural conditions	High initial setup cost, complex infrastructure needed to connect multiple buildings	Higher upfront cost relative to conventional HVAC

Figure 1.12

	New Geographies, Applications, and Technologies		
	Superhot Rock	**Sedimentary Geothermal System**	**Engineered Geothermal System**
Basic Concept	Exploits extremely high temperatures at great depths	Utilizes sedimentary rock formations that may contain hot water in pores; can involve low-porosity rocks	Uses hydraulic fracturing to create artificial permeability for heat extraction
Working Fluid	Water, potentially reaching supercritical state	Typically, water from aquifers in sedimentary rocks; may require pumped circulation	Recirculates same fluid (water or otherwise) through fractures in hot rock
Reservoir Type	Open, targeting superhot rock	Open, with naturally porous and permeable rock acting as the reservoir for fluid flow	Open to reservoir with engineered fractures
Geological Requirements	High temperatures (above 703°F/373°C)	Sedimentary rock formations with some porosity and permeability for water flow	Requires heat and engineered permeability; benefits from high rock surface area for heat transfer
Temperature Range	703°F/373°C + (targeting supercritical steam)	Can vary (from low ~ 68°F/20°C to > 392°F /200°C)	Typically, 302°F /150°C - 572 °F/300°C
Drilling Depth	Significant depth (potentially 10+ kilometers)	Variable depth range, from 500 meters to 8,000 meters	Typically < 3,000 meters, as high pressure and high drilling would incur additional costs
Scalability	Potentially scalable with improved deep-drilling technology	Scalable; 73% of continental land mass contains sedimentary basins	Scalable with advances in hydraulic fracturing and drilling but potentially limited to areas where hot dry rock is < 3,000 meters and does not contain natural fractures that will increase uncertainty and potential fluid losses
Environmental Impact	High-impact drilling; needs tech improvements for feasibility	Typically low	Possible induced seismicity, depending on geology; significant water use despite reuse of working fluid
Examples of Use	Experimental; no large-scale deployment yet	Residential and industrial heat applications: Southampton, United Kingdom; Paris	Department of Energy's FORGE project, Fervo's Project Red in Utah
Primary Advantages	High efficiency in power generation due to superheated steam	Cost-effective and scalable, particularly in well-explored basins. Stacked aquifer systems mean these basins could supply tiered geothermal, ranging from low-temp direct use to higher-temp electricity generation—and geothermal energy storage.	Unlocks geothermal potential in non-ideal rock formations with artificial permeability
Challenges	High-cost drilling; significant research and development required	Limited to areas with sufficient sedimentary rock in basins with moderate temperatures	Subsurface unpredictability in fracturing; possible seismic risks; high initial costs; high water use

	New Geographies, Applications, and Technologies		
	Advanced Geothermal System	**Geothermal Cooling**	**Thermal Storage**
Basic Concept	Closed-loop system with no fluid exchange with subsurface	Uses ground or subsurface temperatures to provide cooling in buildings or industrial processes	Stores thermal energy in subsurface reservoirs for later use in heating, cooling, or power generation
Working Fluid	Circulates fluid (water, supercritical CO_2, or otherwise) entirely within sealed, engineered system	Water or refrigerant circulated to transfer cool temperatures to buildings	Water or other heat-transfer fluid for thermal storage; optimal recovery in pressurized reservoirs
Reservoir Type	Closed to reservoir; uses sealed pipes and engineered pathways	Closed or open loop with pipes in shallow ground, utilizing ground cooling	Closed underground reservoirs or aquifers for energy storage, utilizing natural or engineered pathways
Geological Requirements	No permeability needed; functions anywhere with heat availability	Generally, no special requirements; suitable for most shallow grounds with stable temperatures	Requires subsurface space with adequate pressure retention for heat and energy storage
Temperature Range	Variable; typically requires hotter rock (> 212°F/100°C) to achieve competitive heat extraction	Utilizes both the shallow natural ground temperature (~55°F/13°C) for cooling purposes and the deep ground temperature with absorption cooling technology	Flexible; can be adapted for seasonal thermal storage or for high-temperature dispatch
Drilling Depth	Potentially deeper to access high heat, as system is inherently limited in the surface area available for conductive heat transfer	Both shallow, typically between 10 feet and 500 feet, as cooling requires lower temperatures, and deeper >100°C with absorption cooling technology	Depth varies; can be shallow for seasonal storage or deep for high-temperature storage
Scalability	Scalable, as system is independent of subsurface permeability	Scalable for residential, commercial, and industrial applications	Scalable; suitable for integration with renewable sources for energy balancing
Environmental Impact	Low impact; closed system with no interaction with surrounding rock fluids	Minimal impact; closed-loop systems ensure no ground contamination	Low impact; relies on pressure management for safe thermal storage
Examples of Use	Various closed-loop designs in development, technologies such as Eavor-Loop and GreenFire Energy's GreenLoop	ADNOC, in collaboration with the National Central Cooling Company PJSC (Tabreed), has initiated operations at G2COOL in Masdar City, Abu Dhabi.	Underground thermal energy storage, borehole thermal energy storage, and aquifer thermal energy storage
Primary Advantages	No fluid exchange with subsurface; suitable for areas lacking natural aquifers	Cost-effective cooling in regions with high air conditioning demand; reduces HVAC costs; could be used to optimize data center cooling	Provides energy storage to balance renewable power and support grid stability
Challenges	Expensive drilling costs; reduced heat transfer area compared with EGS; requires wells to touch more rock for heat exchange	Installation and initial costs; suitable ground area needed for installation	Requires specific geological settings for pressure control; drilling costs can be high

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Part II

Geothermal Resources and Applications in New Mexico

Chapter 2

The Geothermal Opportunity in New Mexico

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Olga Lavrova, New Mexico State University

New Mexico can position itself at the forfront of the global geothermal transition, ensuring a cleaner more secure energy future for generations to come.

As the first pages of this report make clear: New Mexico is abundant with the geothermal resources and technological expertise necessary to make the state a leader in the industry. All that geothermal potential, largely from the Rio Grande rift and the Jemez Lineament, blesses the Land of Enchantment with as much as 163.32 gigawatts of geothermal electricity potential, not to mention a vast amount of heat for heating and cooling and other direct-use applications.[1] In fact, there is sufficient heat at depth throughout nearly the *entire* state for geothermal energy use of one kind or another. (See Chapter 3, "Where is Geothermal in New Mexico?")

Also, although geothermal development has historically faced higher upfront costs than natural gas, recent advancements are narrowing the gap. Costs are already competitive with other always-on power generation sources. As the oil and gas industry continues to make improvements in drilling and other technology, costs will continue to come down.

Recognizing this potential—including a skilled oil and gas workforce—New Mexico created a $15 million Geothermal Projects Development Fund, as well as a production tax credit of 1.5 cents[2] and consumer incentives up to $9,000 for ground source heat pumps (GSHPs).[3] These incentives aim to reduce upfront costs and make geothermal projects more financially viable. This is a great start, but more can be done.

This report offers policy proposals (see Chapter 7) to accelerate geothermal in New Mexico; it dives into where to find the best heat for the best applications; it explores how to work closely with the state's strong oil and gas industry; and it examines the different people, organizations, and environmental considerations to

IN SHORT: THE BENEFITS OF GEOTHERMAL FOR NEW MEXICO

- **Untapped potential:** New Mexico ranks sixth in the country in estimated geothermal resources, according to one Department of Energy analysis, yet the resource remains largely underdeveloped.[4]
- **Workforce compatibility:** Geothermal development requires skills similar to those needed for oil and gas (e.g., drilling, reservoir management).
- **Existing infrastructure:** The state's oil and gas infrastructure, such as drilling rigs and service companies, could be adapted for geothermal development.
- **Economic diversification:** Expanding geothermal reduces the impact of oil and gas volatility by providing stable revenue streams for oil and gas companies that add geothermal to their business models.
- **Rural economic development**: Geothermal projects can bring investment, jobs, and infrastructure to rural communities that have geothermal potential but are located far from urban areas.
- **Baseload sustainable energy:** Unlike wind and solar, geothermal provides consistent, 24/7 power, improving grid reliability and energy security.
- **Low-carbon energy:** Whether it's deployed for electricity generation, or heating and cooling in the form of ground source heat pumps or direct-use systems, geothermal energy supports the state's climate goals and complies with New Mexico's regulations by delivering clean, sustainable energy with minimal greenhouse gas emissions.
- **Small footprint**: A typical geothermal energy power plant occupies just 3.7% of the land that a coal-fired power plant needs. Next-generation geothermal technologies require even less space. Additionally, geothermal facilities require far less infrastructure than most other energy sources, including less transmission build-out.
- **Energy independence and potential for energy export:** Developing local geothermal resources strengthens New Mexico's energy sovereignty, boosts its ability to remain a leader in energy production and exportation, and ultimately contributes to increased state revenues.

take into account. But, an important thing to establish is New Mexico's electricity landscape. That's because the ultimate goal is to use geothermal energy to deliver clean, always-on, secure energy at the source, and so much of that happens through the grid.

NEW MEXICO'S ELECTRICITY LANDSCAPE

Electricity Generation

New Mexico is a net energy exporter of raw energy commodities such as crude oil, natural gas, and coal, as well as electricity. Over the past decade, the state has harnessed advancements in technology to expand wind and solar resources.[5] As a result, the sourcing for electricity generation in New Mexico has shifted considerably. Wind now accounts for 41% of the state's total installed capacity[6] (**Figure 2.1**). Coal-fired electricity generation has declined significantly as the state has shuttered plants, including the San Juan Generating Station in 2022.[7,8] (Notably, battery capacity saw a substantial increase in 2023.[9]) And while New Mexico is one of only seven states with utility-scale geothermal electricity generation[10], geothermal provides a tiny fraction of the state's installed capacity, with one power plant, the Lightning Dock Geothermal facility.

As shown in **Figures 2.1** and **2.2**, since 2019, electric capacity and generation have increased by 22% and 12%, respectively. At the same time, the number of New Mexican electricity customers has grown by only 3% (see **Figure 2.4**). Some—but not all—of the increased generation has been exported, indicating an in-state increase in per-capita electricity consumption.

INSTALLED ELECTRICITY CAPACITY IN NEW MEXICO

Year	2019	2021	2023	2019–23 Change
Wind	2,036	4,266	4,409	117%
Natural gas	3,275	3,128	3,263	0%
Coal	2,640	2,387	1,540	-42%
Solar	672	739	1,132	69%
Hydroelectric	83	83	83	0%
Petroleum	48	187	46	-4%
Battery	2	2	239	11,850%
Geothermal	9	9	9	0%
Other biomass	5	5	3	-40%
Other	1	1	1	0%
Total electric industry	**8,771**	**10,807**	**10,725**	**22%**

Figure 2.1: New Mexico's primary installed electricity capacity (in megawatt-hours), 2019–23. Source: U.S. Energy Information Administration, 2024. https://www.eia.gov/state/analysis.php?sid=NM

ELECTRICITY GENERATION BY PRIMARY SOURCE

Year	2019	2021	2023	2019–23 Change
Coal	14,691,665	12,536,319	7,371,813	-50%
Natural gas	11,803,192	10,093,190	14,230,765	21%
Wind	6,892,087	10,580,735	14,914,473	116%
Solar	1,365,900	1,749,810	2,613,007	91%
Hydroelectric	158,180	122,862	107,792	-32%
Other biomass	22,582	25,683	13,081	-42%
Petroleum	183,601	33,178	1,411	-99%
Geothermal	58,102	50,934	35,858	-38%
Total electric industry	35,174,509	35,192,365	39,269,073	12%

Figure 2.2: New Mexico's electricity generation (in megawatt-hours) by primary energy source, 2019–23. Source: U.S. Energy Information Administration, 2024.

USE OF ELECTRICITY BY SECTOR

Year	2019	2020	2021	2022	2023	2019–23 Change
Residential	6,871,561	7,282,079	7,088,358	7,282,636	7,336,277	7%
Commercial	9,028,861	8,406,884	8,655,826	9,084,022	9,349,407	4%
Industrial	8,979,712	9,088,192	9,649,559	10,789,520	11,661,806	30%
Total electric industry sales	24,880,134	24,777,155	25,393,743	27,156,178	28,347,490	14%
Direct use	152,082	162,685	211,769	155,868	203,730	34%
Estimated losses	1,349,098	1,379,945	1,194,686	1,468,917	1,255,430	-7%
Unaccounted for	62,114	-37,222	162,183	-49,070	143,822	132%
Net interstate exports	8,731,082	7,793,020	8,229,984	12,157,142	9,318,601	7%
Total disposition	35,174,510	34,075,583	35,192,365	40,889,035	39,269,073	12%
Net trade index (ratio)	1.3	1.3	1.3	1.4	1.3	

Figure 2.3: Use of electricity by sector and end use (in megawatt-hours) 2019–2023. Source: U.S. Energy Information Administration, 2024.

Electricity Consumption

Figure 2.3 shows where and how the electricity generated in New Mexico is consumed. Electricity that isn't sold to the residential, commercial, or industrial sectors is either used directly by the producer without being sold to a customer, lost via transmission or parasitic load, unaccounted for, or exported to other states. Between 2019 and 2023, New Mexico's total electricity sales (in megawatt-hours) increased by 14%.

Figure 2.3 also shows that the industrial sector has been the largest user of electricity in the state, surpassing the commercial sector (which includes offices, retail, and other businesses). Industry is also the fastest-growing consumer of electricity, with a 30% increase between 2019 and 2023. Electricity exports have become a larger share of the state's electricity use, rising 7% between 2019 and 2023.

Figures 2.1 through **2.5** show the evolving electricity landscape in New Mexico. Oil and gas currently dominate New Mexico's industrial energy landscape, but the state has implemented initiatives such as the Renewable Energy Production Tax Credit,[11] the Geothermal Projects Development Fund,[12] and the Energy Transition Act[13] to promote renewable energy and encourage industries to explore power sources such as solar, wind, and geothermal. Today, there is a clear trend toward renewable energy sources, including significant investments in battery storage, which have also grown in recent years.[14]

As the share of intermittent power sources increases in the energy mix, more storage will be necessary to maintain grid stability. Not only is geothermal a non-intermittent renewable power source, but developers are also demonstrating that geothermal wells can provide energy *storage* capacity.[15] These storage benefits may enhance the attractiveness of geothermal energy investments in areas where solar and wind capacity are already high.

In addition to understanding the electricity generation landscape in New Mexico, it's also important to understand the power potential of geothermal; the capacity and reliability of the electrical grid; and the cost considerations of geothermal development, along with the benefits.

NUMBER OF ELECTRICITY CUSTOMERS BY SECTOR IN NEW MEXICO

Year	2019	2020	2021	2022	2023	2019-23 Change
Residential	895,086	905,885	914,495	921,109	928,216	4%
Commercial	144,960	145,459	146,312	147,142	147,632	2%
Industrial	9,456	9,436	9,271	9,278	9,339	-1%
Total	1,049,502	1,060,780	1,070,078	1,077,529	1,085,187	3%

Figure 2.4: Number of electricity customers by sector, 2019-23. Source: U.S. Energy Information Administration, 2024.

AVERAGE ELECTRICITY PRICE BY SECTOR IN NEW MEXICO

Year	2019	2020	2021	2022	2023	2019-23 Change
Residential	12.51	12.94	13.52	13.84	13.85	11%
Commercial	9.79	10.28	10.80	11.07	10.68	9%
Industrial	5.48	5.58	6.16	6.56	5.75	5%

Figure 2.5: Average electricity price (cents/kilowatt-hour) per sector, 2019-23. Source: U.S. Energy Information Administration, 2024.

GEOTHERMAL ELECTRICITY POTENTIAL IN NEW MEXICO

As noted, New Mexico ranks among the best states for geothermal potential.[16] Although some projections—like the National Renewable Energy Laboratory's (NREL) *Enhanced Geothermal Shot Analysis*—estimate New Mexico's potential to be only between 3 gigawatts and 5 gigawatts of generation capacity by 2050, this is a conservative estimate.[17]

At an average electricity generation capacity of between 3 megawatts and 10 megawatts per geothermal well, reaching New Mexico's full geothermal potential will require thousands of new wells. Given the state's 53,600 active oil and gas wells and 44,370 plugged or abandoned wells, and the demonstrated drilling capacity of the oil and gas sector (about 1,000 new wells per year), the state clearly has the resources and expertise to reach its full potential. And geothermal technology that uses existing oil and gas wells for energy production and storage can provide an another path to increased renewable energy generation.

With the advancements to drilling, turbine, and other technologies made in the oil and gas industry, it is feasible that we will see a 90% reduction in the cost of deploying an engineered geothermal system (EGS) by 2035.[18]

Grid Reliability Considerations and Geothermal Benefits

New Mexico's electric grid is a dynamic system undergoing significant changes to incorporate more renewable energy sources. Currently, the state's electric

GEOTHERMAL ENERGY STORAGE

As addressed in Chapter 1: The modern electricity grid is a delicate system that requires constant monitoring to balance electricity production against electricity demands. With more electrons flowing onto the grid from intermittent energy sources such as wind and solar—which are only available when the sun shines or the wind blows—concerns about having power when it is needed have brought the need for energy storage to the forefront. Today, hydroelectric storage provides most global energy storage capacity, and recent years have seen a significant expansion in the deployment of batteries for energy storage.

A new approach, underground thermal energy storage—also known as geothermal energy storage (GES)—may offer an additional option. GES systems capture and store waste heat or excess electricity by pumping fluids into natural and artificial subsurface storage spaces, from aquifers to boreholes to mines. GES can be primarily mechanical—with hydraulic fracturing techniques storing pressurized fluid in subsurface reservoirs—or mechanical and thermal—with both pressure and heat combined to return more energy than was required to pump the fluid underground.

Due to the passage of New Mexico's HB 361, which allows old wells to be converted to geothermal energy resources, and the significant production of wind and solar in the state, geothermal storage is an exciting opportunity in the Land of Enchantment.

grid transmits a blend of traditional and renewable energy sources. The state also has a renewable portfolio standard goal of 40% renewables by 2025; 80% by 2040; and 100% of electricity supplied by zero-carbon resources by 2045.[19]

Looking ahead, as New Mexico strives to meet those targets, growing the percentage of intermittent renewables will require adjustments to grid operations, while population growth and electrification trends will increase overall demand.

Important aspects of the current grid, and future needs, include the following:

- **Energy sources and generation:** New Mexico's electricity generation is diverse. A significant portion of energy on the grid comes from renewable sources.[20] Fossil fuels, particularly natural gas and coal, continue to play a significant role, with natural gas being a major component due to the state's extensive natural gas reserves.
- **Grid infrastructure and modernization:** The electric grid in New Mexico is undergoing significant modernization efforts to enhance its resilience and integrate renewable energy sources.[21] These efforts include investments in advanced metering infrastructure and smart-grid technologies that improve efficiency and enable better demand response capabilities (i.e., the managed reduction of electricity demand during peak times).
- **Transmission and distribution:** New Mexico's transmission infrastructure is extensive, with major utilities managing the grid. As noted earlier, the state is also a net exporter of electricity, helping meet the region's electricity demands.[22,23]
- **Stakeholder engagement and planning:** New Mexico has adopted an inclusive approach to energy planning, requiring that utilities provide opportunities for various stakeholders to comment on their plans for new generation. These initiatives ensure that the perspectives of different stakeholders—including utilities, consumers, and policymakers—are considered in resource planning.[24]
- **Challenges and future directions:** Despite the progress it has made, New Mexico faces challenges such as the costs associated with grid modernization and the need to balance energy affordability with environmental goals. The state is focusing on enhancing grid resilience, especially

in the face of climate change and increasing renewable energy integration.[25]

The Benefits of Geothermal Development for New Mexico's Grid

In addition to the benefits it provides to the state overall, geothermal also offers benefits for the grid in particular:

1. **Enhanced stability:** As a constant power source, baseload geothermal can provide stability and reduce reliance on fossil fuel–based peaker plants.

2. **Improved resilience:** Geothermal plants are less affected by weather conditions than solar and wind. Take the severe storm that struck New Mexico and Texas in February 2021 and caused widespread power outages. Numerous natural gas facilities, wind turbines, and other power plants were inadequately prepared for the extreme cold, leading to shutdowns for safety reasons.[26] Geothermal energy production remains largely unaffected by surface weather and can quickly return to operation after disruptions. By prioritizing investment in geothermal infrastructure, regions prone to severe weather could significantly enhance grid resilience, reducing the likelihood of future outages.

3. **Reduced transmission losses:** If developed close to demand centers, geothermal power can reduce transmission losses and alleviate some transmission constraints. Furthermore, electricity from steady, continuous baseload sources such as geothermal is transmitted more efficiently than electricity from sources that fluctuate with peak demand.

4. **Transmission line capacity:** Geothermal energy's high capacity factor reduces the need for extensive transmission infrastructure upgrades compared with more variable renewable sources. The consistent output of geothermal plants allows for more efficient use of existing transmission lines, reducing congestion and the need for additional capacity. As a matter of fact, no changes to grid architecture, operating principles, or controls would be needed to incorporate additional geothermal generation. Baseload geothermal can seamlessly integrate as a steady power source, while flexible geothermal requires more control systems (which already exist) to manage its variable output.

Additionally, flexible geothermal energy can adapt to changes in demand and supply. Its impact on grid reliability includes the following benefits:

1. **Increased flexibility:** The ability to ramp up or down helps balance supply and demand, especially with high penetration of intermittent renewables.

2. **Enhanced integration:** Flexible geothermal can facilitate the integration of more solar and wind power by providing backup power when renewable sources are not generating.

3. **Support for grid services:** Flexible geothermal can provide ancillary services such as frequency regulation and voltage support, which are crucial for grid stability.

By addressing current and projected reliability concerns, geothermal energy can play a pivotal role in strengthening New Mexico's grid and supporting its transition to a more sustainable energy future.

UNDERSTANDING GEOTHERMAL COSTS—PAST AND FUTURE

Historical Cost Structure (Before 2024)

Geothermal energy has historically been a capital-intensive industry; drilling and plant construction incur significant costs, and that's even before any energy production can occur. As mentioned, New Mexico has one operational utility-scale geothermal power plant, the Lightning Dock Geothermal site in Hidalgo County. Cyrq Energy began operations in 2013 with a 4 megawatt capacity. The initial geothermal plant developed by Cyrq had a total cost of $43 million,[27] translating to an overnight capital cost of $10,000 per kilowatt. In 2018, the plant was renovated to produce 14 megawatts with a novel topside Organic Rankine Cycle (ORC) system from Turboden.[28] Today, emerging technologies are driving down geothermal exploration and development costs, paving the way for significant growth in market potential.

Recent Technological Advances (2023–2025)

In 2024, Zanskar Geothermal & Minerals purchased the Lighting Dock facility, and in 2025, the company reported a major breakthrough with a newly directionally drilled large-diameter geothermal well achieving a productivity index of 50 gallons per minute/pounds per square inch (GPM/psi) and temperatures near 325°F (163°C).[29] The thermal capacity is estimated to exceed 200 megawatts per well, enough to feed the 14 megawatt electrical (MWe) power production plant, which would make the well one of the most productive pumped geothermal wells in the United States. Zanskar's approach highlights how data-driven and AI-assisted approaches can support target definition from large subsurface data sets and dramatically boost output without completely new field development. Geothermal development costs could be substantially reduced by adopting AI-assisted exploration techniques similar to those used in the oil and gas industry.

The Utah Frontier Observatory for Research in Geothermal Energy (FORGE) project, in operation since 2016, remains the leading U.S. field laboratory for advancing next-generation technologies.[30] Recent experiments successfully demonstrated circulation between well pairs and improved fracture control in hot, impermeable granite, significantly advancing EGS viability.[31]

The FORGE project has demonstrated the impact of the learning curve on drilling costs, as the project has significantly reduced both time and expense by applying a physics-based approach. The operational team was trained to understand the physical dynamics of bit dysfunction and other nonbit limitations. This understanding helped the team mitigate these issues in real time.[32] This methodology is now being widely applied to geothermal projects around the world.[33]

A number of companies are benefiting from the trailblazing activities undertaken by FORGE, including both the characterization of the granite basement in Utah and removing risks based on the team's findings and the demonstration of drilling, completion, and stimulation technologies. Between 2023 and 2025, Fervo Energy expanded its success from Project Red at new EGS deployments in Utah and Nevada. By refining horizontal drilling, real-time fiber-optic monitoring, and closed-loop reservoir management techniques, Fervo increased system efficiency and reduced drilling time by 70% compared with earlier projects,[34] leading to an overall cost of less than $400 per foot.

In 2023, Eavor Technologies, in partnership with Helmerich & Payne, Inc., ran a demonstration project near the Lightning Dock site that achieved depths of 18,000 feet true vertical depth (TVD).[35] The company successfully validated the use of insulated drill pipe, demonstrating both its thermodynamic and mechanical performance along with an increased rate of penetration enabled by shock cooling. It also achieved effective isolation of the upper fractured, permeable zone using casings, which facilitated the drilling of multilaterals into the deeper, low-permeability basement rock. This was followed by the application of the company's Rock-Pipe™ technology to seal the wellbore—a method designed to provide reliable isolation without the need for casings, which significantly reduces completion costs.

These advancements will also make next-generation geothermal competitive with other renewables for firm, dispatchable generation.

Policy Support and Cost-Reduction Incentives

As explained in other chapters of this report, in recognition of geothermal's potential, New Mexico established a $15 million Geothermal Projects Development Fund in 2024 to reduce upfront project costs. This incentive, combined with advancing technologies, positions geothermal projects for lower overall capital expenditures and operational and maintenance expenses moving forward.

As these technologies scale and financing mechanisms mature, geothermal development is projected to become more cost competitive, which will in turn support broader deployment of clean energy across the state.

Royalty Cost Considerations in Land Leasing for Geothermal

The economic potential of geothermal development for property owners is an important part of the economic benefits to New Mexico overall. As Chapter 6, "Who Owns the Heat?" explains, geothermal resources are typically handled similarly to oil and gas leases.

Leases for resources such as oil and gas in New Mexico include several key components: (i) lease duration and terms for extension or renewal; (ii) bonus payments, usually an upfront payment to the mineral right owner stated in per-acre terms; (iii) royalty rate, meaning the percentage of revenue generated from the extracted resource; and (iv) annual rentals of a per-acre fee paid whether production occurs or not. There may also be requirements for development during a specific time frame and land restoration required as a result of damage during the extraction process.[36]

Of course, the biggest upside for a geothermal rights owner is usually the royalty if valuable resources are extracted. For related surface and subsurface leases, royalty rates have varied by land type. Royalty rates for onshore oil and gas leases on federal lands recently increased from 12.5% to 16.67%.[37] Royalty rates for oil and gas leases on land owned by the state are capped at 20%. Attempts have been made to increase this cap to 25%, which would equal the oil and gas lease royalty rate for Texas lands.[38,39] Royalty rates for oil and gas on private lands are negotiable, and nationwide these rates generally range from 12% to 25%.[40] The rates are influenced by state rates as well as the region. Royalty rates of between 18% and 20% are typical in the Permian Basin in New Mexico.[41]

For revenues from geothermal resources, royalties are typically charged on revenues generated, either from electricity sales or direct-use applications. Royalties from geothermal resources on state lands, per New Mexico statute, range from 2% to 10%.[42] Royalties from geothermal resources on federal lands range from 1.75% to 10%.[43] The most recent competitive federal geothermal lease sale took place in November 2021, when 3,987 acres in Sierra County and Hidalgo County were auctioned with a high per-acre bid of $6.00.[44] In general, geothermal royalty rates are lower than oil and gas royalty rates.

Other mechanisms also provide a minimum level of compensation to a rights holder and align incentives for the extraction or development of the mineral resources.

PROJECTIONS OF NEW MEXICO'S GEOTHERMAL CAPACITY

Researchers have done numerous projects studying the state's heat potential. Here are some summaries:

International Energy Agency's (IEA's) *The Future of Geothermal*: In late 2024, IEA published an analysis of the technical heat energy provided by geothermal resources around the world. The analysis relied on subsurface data calculations from Project InnerSpace's GeoMap tool to detail the resource potential. The report calculated the recoverable quantities of geothermal energy at various price points given today's technology.[45] Project InnerSpace's data shows that if New Mexico were to develop all available geothermal resources within the first 16,400 feet of subsurface, the state would have a geothermal potential of 163.32 gigawatts, or more than 15 times its 2023 installed capacity. If costs come down with improved technologies, Project InnerSpace estimates that almost 300 gigawatts of geothermal could be available at or below a levelized cost of electricity of $100.

NREL's *Enhanced Geothermal Shot Analysis* for the Geothermal Techonologies Office: This 2023 analysis outlines ambitious targets for the advancement of EGS. The initiative aims to reduce the cost of EGS by 90%, with a target of $45 per megawatt-hour (MWh) by 2035. Achieving this cost reduction could unlock substantial geothermal capacity across the United States. The analysis projects that geothermal capacity in New Mexico could reach between 1 gigawatt and 1.5 gigawatts by 2030, with further increases to between 3 gigawatts and 5 gigawatts by 2050. These milestones depend on technological advancements, supportive policies, and investment in geothermal infrastructure. Although specific figures for New Mexico are not detailed, the state's significant geothermal resources mean it's in a good position to benefit from these advancements. The successful implementation of EGS technologies could enable New Mexico to develop a considerable portion of the projected national geothermal capacity by 2050. These developments underscore the transformative potential of EGS for enhancing geothermal energy deployment, particularly in resource-rich states such as New Mexico.[46]

***Nature Energy* article "The Role of Flexible Geothermal Power in Decarbonized Electricity Systems":** In this 2024 study, the authors examined the impact of operational flexibility in EGS within the western United States. The research highlights that EGS plants capable of load-following generation and in-reservoir energy storage can significantly enhance their role in cost-effective, decarbonized electricity systems. Specifically, flexible EGS operations can increase optimal geothermal deployment and reduce overall electricity supply costs compared with an inflexible EGS or systems without an EGS. In scenarios where flexibility is incorporated, two categories of capacity are defined: baseload capacity, which reflects the steady-state output aligned with the sustainable flow rate of the wellfield, and flexible capacity, which captures additional generation enabled by temporarily elevated flow rates. Baseload capacity represents the total developed subsurface resource and includes full wellfield and reservoir development costs, while flexible capacity can be added at substantially lower marginal cost. According to the author's data, 2.85 gigawatts of EGS can be realized as baseload capacity, with an additional 1.74 gigawatts achievable through flexible operation under optimized conditions in New Mexico by 2045. The study also notes that flexible geothermal plants can shift their generation on diurnal and seasonal timescales, achieving round-trip energy storage efficiencies of between 59% and 93%. These findings suggest that implementing flexible EGS could substantially increase geothermal capacity beyond current levels, contributing to grid stability and reliability in regions like New Mexico.[47]

Oak Ridge National Laboratory's *Grid Cost and Total Emissions Reductions Through Mass Deployment of Geothermal Heat Pumps for Building Heating and Cooling in the United States:* This 2023 study provided national-scale data on the impacts of geothermal heat pump deployment. The following are estimates for New Mexico, using proportional scaling:

- *Primary energy consumption reduction*: New Mexico accounts for approximately 0.5% of the U.S. population. Assuming similar energy-use patterns, the state could see a 2.96 terawatt-hour (TWh) reduction in primary energy consumption annually by 2050, proportional to the national savings of 593 terawatt-hours.

- *Carbon emissions reduction:* Based on New Mexico's energy usage profile and Oak Ridge's projected 7 gigatons CO_2-equivalent national reduction, the state could avoid 35 million metric tons of CO_2 emissions by 2050 with the adoption of geothermal heat pumps.
- *Electricity generation savings:* Extrapolating from Oak Ridge's 593 terawatt-hours savings, New Mexico could save approximately 3 terawatt-hours annually in electricity generation by 2050, particularly in residential and commercial cooling applications.
- *Peak demand mitigation:* Geothermal heat pump deployment in New Mexico's high-temperature zones could contribute to reducing peak summer electricity demand by between 5% and 10%, which would help alleviate grid stress during heat waves.

These estimates highlight the potential benefits of scaling geothermal heat pump deployment in New Mexico, particularly in reducing energy consumption, emissions, and peak grid loads. This extrapolation is based on Oak Ridge's national findings and adjusted for New Mexico's size and energy usage patterns.[48]

Caveat: Differences in Model Assumptions and Their Impact

The reviewed studies vary in their treatment of geothermal expansion. Models such as NREL's Enhanced Geothermal Shot Analysis and the U.S. Energy Information Administration's Annual Energy Outlook emphasize EGS, while others may not fully account for this technology. Some models, such as IEA's Net Zero by 2050, consider geothermal conversions for industrial processes, which can significantly impact the energy mix and emissions profiles. Other studies consider the dual role of geothermal power in providing both baseload and flexible power.[49,50] This distinction is crucial to ensure grid stability and to integrate variable renewable energy sources. These differences impact New Mexico–specific analyses by influencing projections of geothermal capacity, cost, and emissions reductions. For instance, a model that includes flexible geothermal deployment in New Mexico may show higher potential for grid integration and reliability benefits than one that focuses solely on baseload capacity.

CONCLUSION

As this chapter shows, by combining New Mexico's electricity demand, its high subsurface temperatures, the legislative goals to further diversify the energy mix, the state's expertise in the robust oil and gas industry, and opportunities from next-generation geothermal, the Land of Enchantment is poised to vastly expand its position as a leader in geothermal energy.

In the years ahead, the successful acceleration of geothermal energy in New Mexico will depend on continued collaboration among policymakers, researchers, industry leaders, and local communities. Investments in research, transmission infrastructure, and regulatory streamlining will be essential to unlocking geothermal's full potential.

With the right policies and a sustained commitment, New Mexico can make geothermal energy a cornerstone of its clean energy economy—one that not only powers homes and industries but also sets a precedent for other states seeking sustainable and resilient energy solutions. By embracing this opportunity, New Mexico can position itself at the forefront of the global geothermal transition, ensuring a cleaner, more secure energy future for generations to come.

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Chapter 3

Where Is Geothermal in New Mexico? Exploring Our Underground Heat Abundance

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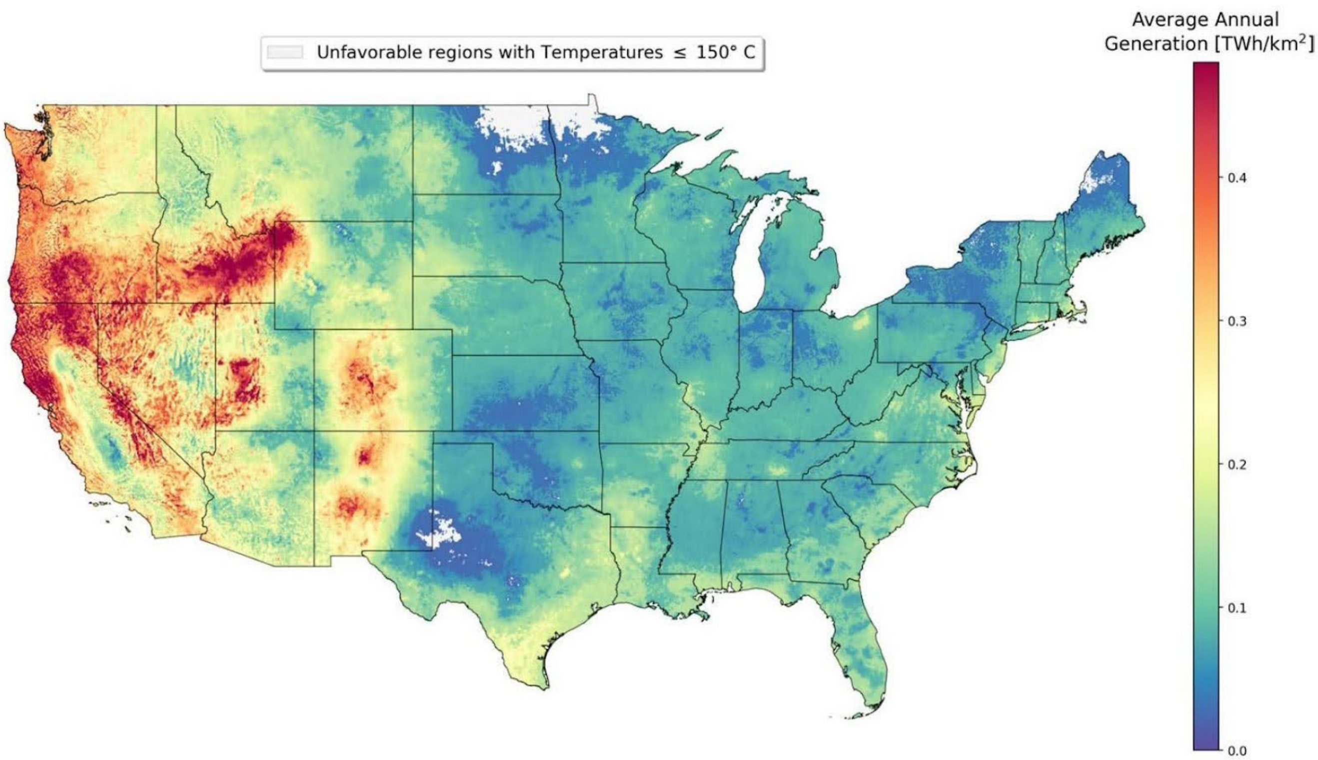
An important note: As mentioned in the Executive Summary and elsewhere in this report, New Mexico was a target for extensive geothermal exploration of hydrothermal—or conventional—resources during the 1970s and 1980s. This first section of this chapter describes geologic and conceptual models used to identify and develop a few of the key hydrothermal resources in the state. At the end of this chapter, you'll find a summary of the extensive subsurface possibilities, with a focus on next-generation geothermal development in New Mexico.

New Mexico is ranked sixth in the nation in geothermal potential (**Figure 3.1**).[1,2] That is, in part, due to an important north-trending geologic feature that bisects the state—the Rio Grande rift, a place where the Earth's crust is stretched and thinned, bringing elevated temperatures closer to the surface (**Figure 3.2**). Seismic profiles across the rift show that the crust is 40 to 50 kilometers thick to the east and west of the rift, but the crust thins to 30 to 40 kilometers beneath the rift.[3,4] More recent seismic studies document a 150-kilometer-wide, low-velocity zone in the mantle beneath the rift, indicative of hot mantle.[5,6]

In addition to the Rio Grande rift, another significant geologic feature, the northeast-trending Jemez Lineament, influences geothermal potential (**Figure 3.2**). The Jemez Lineament intersects the Rio Grande rift in the vicinity of the Valles Caldera. Passive seismic and more recently magnetotelluric data[7,8] indicates the presence of a moribund (slowly cooling) magma body under the Valles Caldera. The Jemez Lineament is an alignment of 10 volcanic fields that are generally less than 10 million years old; the aligned fields stretch from eastern Arizona to southeastern Colorado (**Figure 3.2**).[9,10] The volcanic fields have no spatial or temporal or chemical progression along the Jemez Lineament. Late Cenozoic volcanism along the Jemez and in the Rio Grande rift in New Mexico is predominantly basaltic. Holocene basalt flows include the Bandera flow (11,000 years old) and the McCartys flow (3,900 years old) in the Zuni-Bandera volcanic field and the 5,200-year-old Carrizozo flow in the Tularosa Basin in central New Mexico. Although several hot springs are associated with the volcanic fields along the lineament, the only volcanic field with a significant high-temperature geothermal system is the Jemez Mountains volcanic field, which culminated with the eruption of the 0.07 million to 1.23 million-year-old Valles Caldera.

GEOTHERMAL POTENTIAL IN THE UNITED STATES



Disclaimer: While the maps and analyses in this chapter and insert highlight areas of geothermal potential, additional site-specific analyses, including economic, engineering, and fluid production rate analyses, are required to identify potential uses and drill-ready prospects.

Figure 3.1. *Map illustrating why New Mexico is ranked sixth in the nation for geothermal potential. This map shows the average annual engineered geothermal system (EGS) power generation per unit area (TWh/km^2) for geothermal projects spanning depths of 1 km–7 km. High EGS capacity follows a north-south trend that bisects New Mexico. White areas indicate techno-economically infeasible locations, with temperatures of less than 150°C (302°F) at a depth of 7 kilometers.* Source: Aljubran, M. J., & Horne, R. N. (2024). Thermal Earth model for the conterminous United States using an interpolative physics-informed graph neural network. *Geothermal Energy, 12*(1), 25. https://doi.org/10.1186/s40517-024-00304-7

TECTONIC FEATURES IN NEW MEXICO

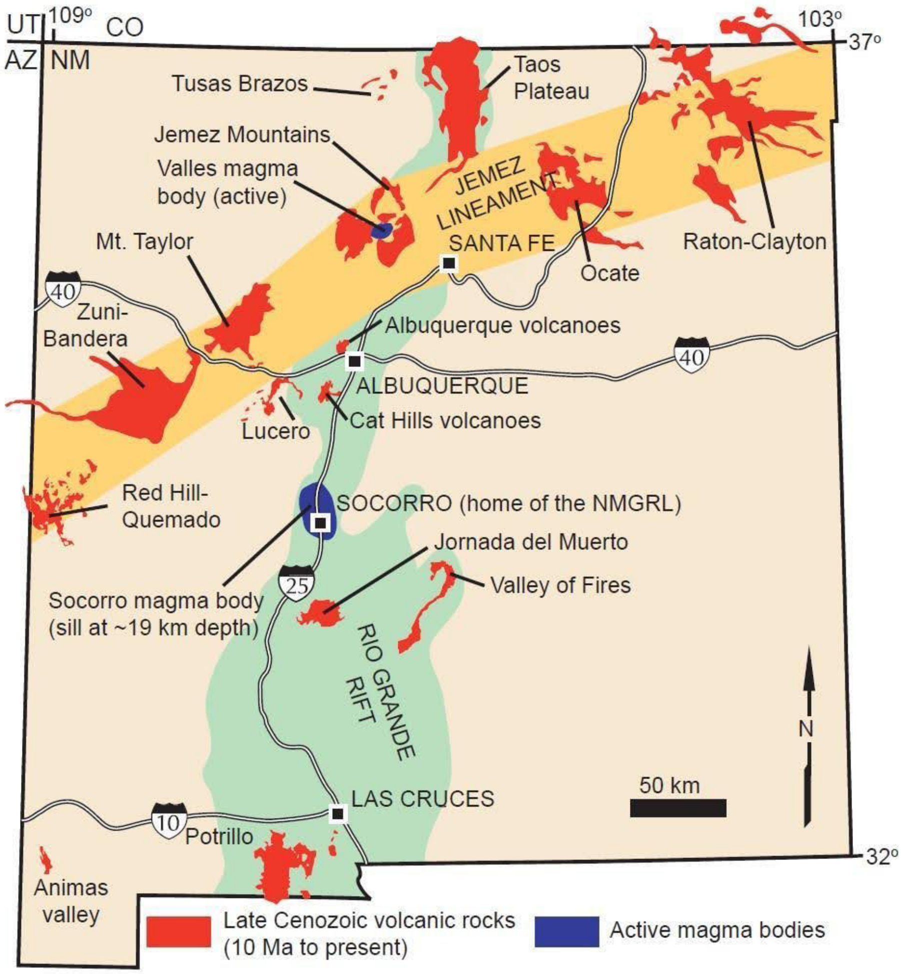


Figure 3.2. *Map of the Rio Grande rift (green) and the young volcanic rocks (red areas) in New Mexico.* Source: Zimmerer, M. J. (2024). A temporal dissection of late Quaternary volcanism and related hazards within the Rio Grande rift and along the Jemez lineament of New Mexico, USA. *Geosphere, 20*(2), 505–546. https://doi.org/10.1130/GES02576.1

The concept of extracting heat from the Earth using a hot dry rock system was originally developed in Los Alamos (the Los Alamos Scientific Laboratory at the time) by Burnham and Stewart,[11] who used nuclear explosives to create a fractured cavity surrounding well-penetrating crystalline basement rocks. Because of technical and environmental concerns about using nuclear material, hydraulic fracturing—a different design using a technology already in use by the oil and gas industry—was investigated starting in 1970 and was implemented at a site on the west side of the Valles Caldera starting in spring 1972.[12] The Los Alamos developments and the 1973 oil crisis triggered extensive exploration for geothermal resources in New Mexico in the 1970s and 1980s. Many companies—including Unocal, Hunt Oil Company, Phillips, Sunedco, and Geothermix—drilled hundreds of shallow exploration holes across the state; the well records from these companies are archived in the Geologic Information Center at the New Mexico Bureau of Geology and Mineral Resources. During this same time frame, New Mexico State University in Las Cruces,[13,14,15,16] the University of New Mexico in Albuquerque,[17] and the New Mexico Institute of Mining and Technology in Socorro[18,19,20,21] developed geothermal research programs that instilled interest in geothermal research for a generation of students.

Figure 3.3 shows the locations of hot springs and wells in New Mexico. The use of geothermal heat in the Land of Enchantment during the 1970s and 1980s focused on direct-use projects in the Rio Grande rift, particularly in southern New Mexico (**Figure 3.3**). As mentioned, New Mexico has one geothermal power plant located near Lordsburg in southwestern New Mexico (**Figure 3.4**). The original 4 megawatt electric power plant Lighting Dock

HOT SPRINGS AND WELLS WITH TEMPERATURES ABOVE 30°C (86°F)

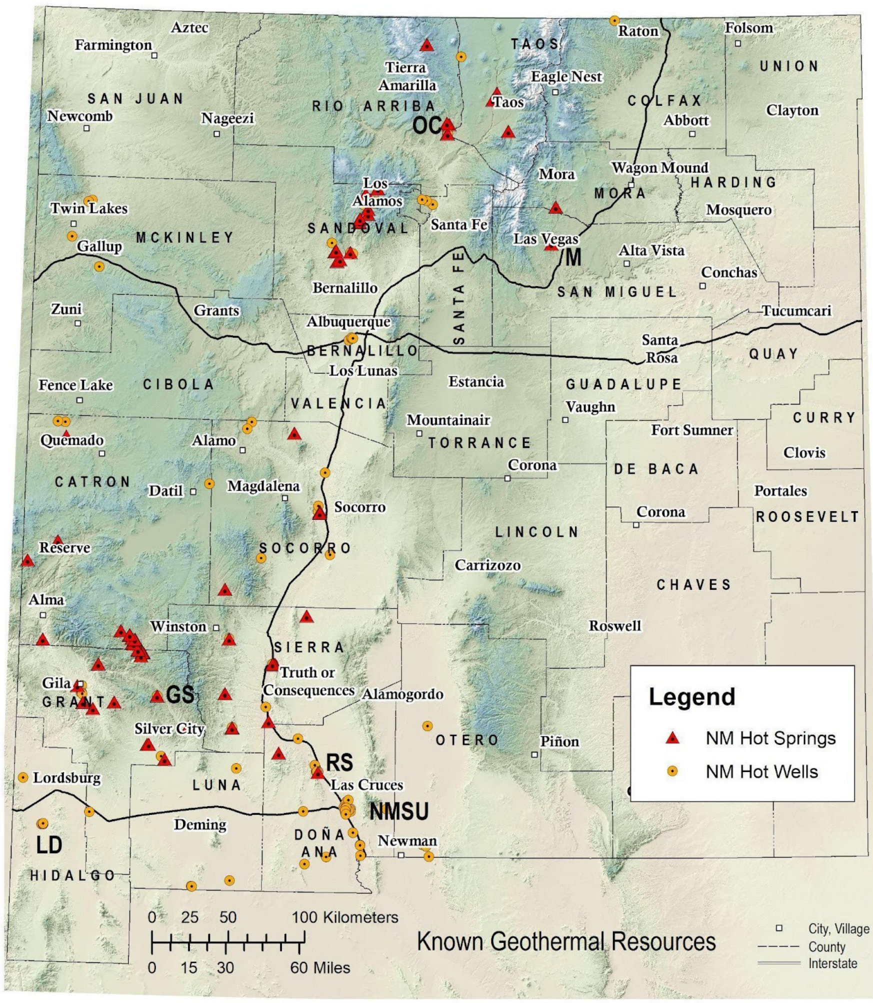


Figure 3.3. *Locations of hot springs and wells with temperatures above 30°C (86°F) in New Mexico. M = Montezuma Hot Springs. OC = Ojo Caliente. RS = Radium Springs. GS = Gila Hot Springs. LD = Lightning Dock. NMSU = New Mexico State University. Source: Shari Kelley.*

was built by Cyrq in 2013. The original plant was replaced with a new, more efficient 10 megawatt electric power plant that went online in 2018. Zanskar purchased the property from Cyrq in 2024 and drilled a successful new step-out well in 2025. The geologic setting for Lightning Dock is described in more detail later in the report.

Now, with the expansion of modern horizontal drilling technologies into geothermal fields that use concepts derived from the shale revolution in the oil and gas industry, **the entire spectrum of Earth's heat—from low temperatures needed for heating and cooling buildings via ground source heat pumps to intermediate temperatures for direct-use applications to higher temperatures for producing electricity from hydrothermal systems (also called conventional systems), engineered systems, and advanced systems—is available in New Mexico.**

As discussed later in this chapter, hydrothermal geothermal systems in New Mexico are commonly associated with fractured basement rocks, faults, and juxtaposition of aquitards and aquifers across faults. Conceptual models for these systems are fairly well established (see "Geothermal Resources in New Mexico" section). Proterozoic rocks in parts of the state have been intensely fractured by mountain-building events during late Pennsylvanian compression (Ancestral Rocky Mountains), late Jurassic to early Cretaceous extension (Bisbee Basin), late Cretaceous to Paleogene compression (Laramide), and middle to late Cenozoic extension (Rio Grande rift and Basin and Range). The Proterozoic metavolcanic, metasedimentary, and plutonic rocks that form the basement of New Mexico have variable capacities to fracture. For example, brittle rocks such as plutonic rocks and quartzite fracture more readily than metamorphic schist. Part of the reason that recent engineered geothermal system (EGS) development in Utah at the Frontier Observatory for Research in Geothermal Energy (FORGE) and Fervo sites has been so successful is because new horizontal wells are penetrating uniform rocks with sealed natural fractures that are not faulted, which improves drilling speed and reduces induced seismic risk.[22,23]

Nw exploration in New Mexico should focus on finding Proterozoic rocks like those in Utah that are ideal for next-generation geothermal technology development.

Figure 3.5 shows estimated depths to temperatures across the state. Across New Mexico, as explored in Chapter 4, "Geothermal Heating and Cooling," there are depths to temperatures that are good for uses such as heating of greenhouses and other direct-use applications (**Figure 3.5A**).

Yellow to red areas in **Figure 3.5B** indicate that favorable temperatures for electricity production can be reached at depths greater than or equal to 3,500 meters (close to 11,500 feet) in the southwestern corner of New Mexico. This depth is commonly reached via wells drilled by the

HISTORY OF LIGHTNING DOCK GEOTHERMAL RESOURCE AREA

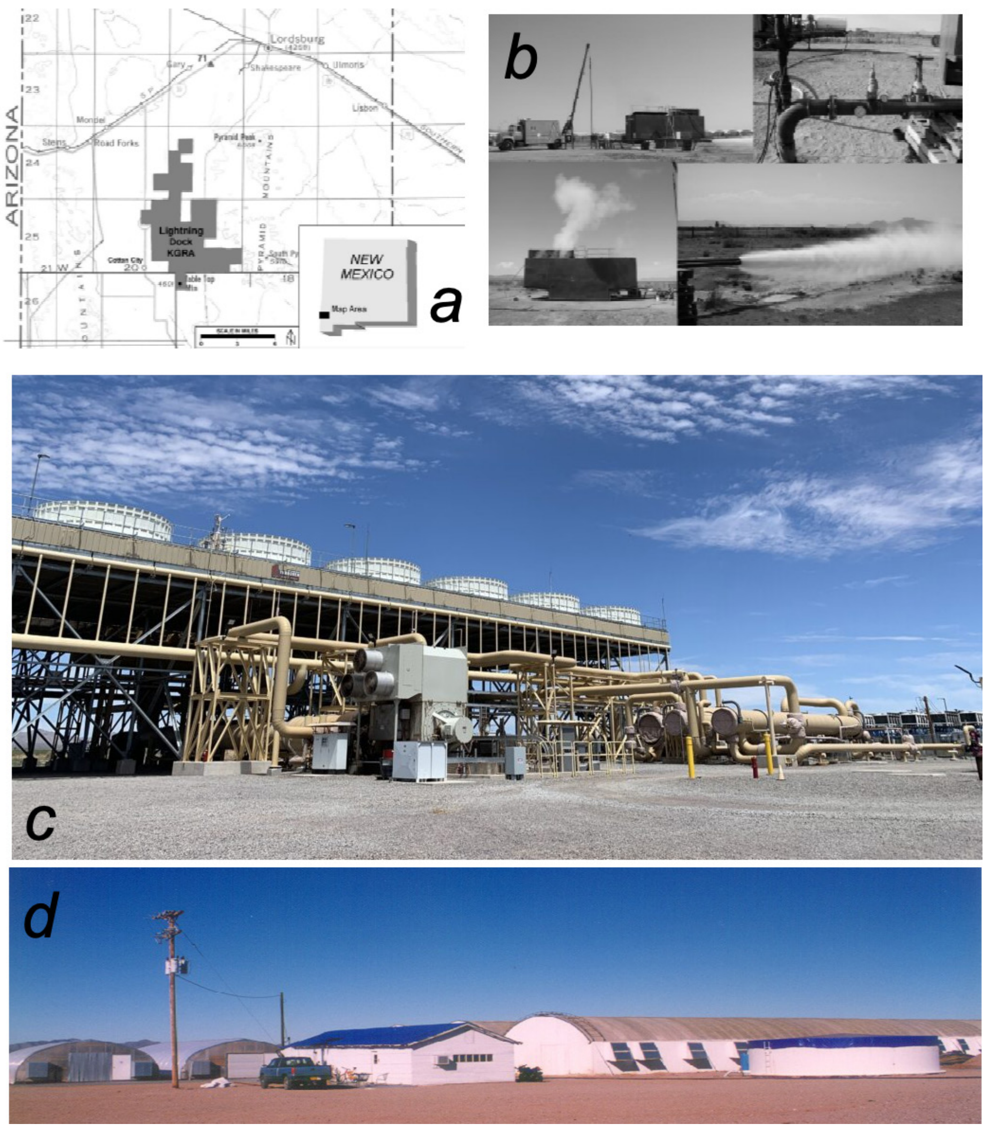


Figure 3.4. *(a) Location of the Lightning Dock geothermal area in southwestern New Mexico. (b) Images of early geothermal production test (1948) in which boiling conditions were encountered at depths of less than 30 meters. (c) The current binary geothermal power plant that became operational in 2018 and is now operated by Zanskar, Inc. (d) The Americulture tilapia geothermal heated aquaculture facility opened in 1995. Photos courtesy of Jim Witcher and from Elston et al. (1983).*

ESTIMATED DEPTHS AT TEMPERATURES

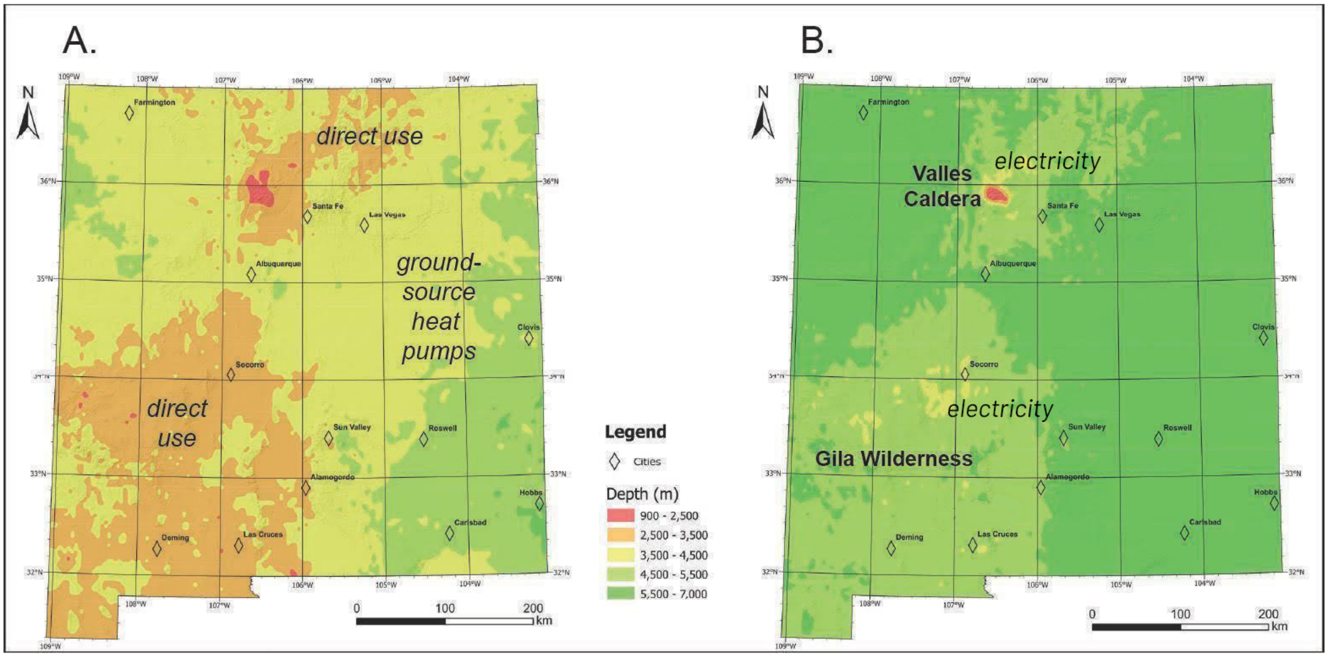


Figure 3.5. *(A) Estimated depth to at least 100°C (212°F), a temperature favorable for direct-use applications like heating a greenhouse. The red and orange areas are favorable for direct use. Ground source heat pumps are currently being installed statewide, particularly in new public schools and other public buildings. (B) Estimated depth to at least 150°C (302°F), a favorable temperature for producing electric power using a binary power plant. The red to yellow areas are favorable for electricity development, and the darker green areas are less favorable.* Source: Aljubran, M. J., & Horne, R. N. (2024). Thermal Earth model for the conterminous United States using an interpolative physics-informed graph neural network. *Geothermal Energy, 12*(1), 25. https://doi.org/10.1186/s40517-024-00304-7

oil and gas community. Southwestern, south-central, and north-central New Mexico and the Raton Basin in the northeastern part of the state have high electricity potential. The red areas on **Figure 3.5B** suggest favorable temperatures can be reached at depths of about 2,500 meters (about 8,000 feet). However, factors other than temperatures must be considered when evaluating geothermal potential (permeability of basement, proximity to tectonic provinces, etc.). Additionally, two of the state's highest-potential geothermal sites are currently off-limits to development due to their federally protected status (Gila Wilderness and the Valles Caldera National Preserve).

GEOLOGIC OVERVIEW

The complex geologic evolution of New Mexico has influenced the location of shallow geothermal reservoirs that have been used in the past. Understanding that history will guide future exploration and development of geothermal resources in the state. In this chapter, we consider the state as divided into six physiographic provinces with distinctive yet common geologic histories and geothermal resource potential (**Figure 3.6**): the Colorado Plateau, which includes the San Juan Basin in northwestern New Mexico; the Southern Rocky Mountains in north-central New Mexico; the extensional Rio Grande rift basins and adjacent mountains that occupy most of the central part of New Mexico; the Southern High Plains region that includes the Raton Basin in the northeast and the Permian and Delaware Basins in the southeastern parts of the state; the Southern Basin and Range, an extensional province in southwestern New Mexico; and the Eocene to Oligocene Mogollon-Datil volcanic field. The San Juan, Raton, and Delaware Basins are important oil- and gas-producing regions in New Mexico. The San Juan and Raton Basins and the Southern Rocky Mountains

SIX PHYSIOGRAPHIC PROVINCES IN NEW MEXICO

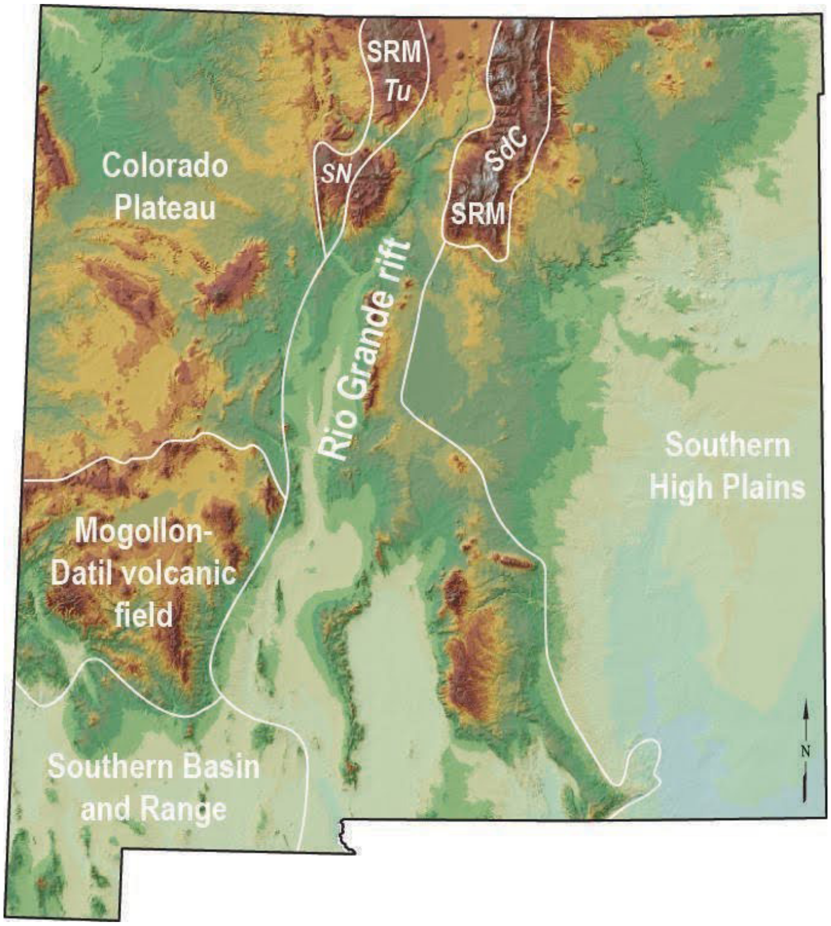


Figure 3.6. *Six physiographic provinces in New Mexico. SRM = Southern Rocky Mountains; SdC = Sangre de Cristo Mountains; Tu = Tusas Mountains; SN = Sierra Nacimiento. Source: Shari Kelley.*

formed starting about 75 million years ago during compressional Laramide deformation. The Delaware Basin formed during Permian time.

The Colorado Plateau is a relatively undeformed region that is occasionally interrupted by sharp monoclines and gentle folds. The Southern Rocky Mountains include the Sangre de Cristo and Tusas Mountains and the Sierra Nacimiento (**see Figure 3.6**); these three high-elevation ranges are cored by Proterozoic basement and serve as important sources of groundwater recharge in northern New Mexico. The High Plains occupy the region between tectonically active areas to the west and the tectonically quiescent mid-continent to the east. Narrow ranges bounded by normal faults that are separated by basins filled with sedimentary deposits derived from the adjacent highlands characterize both the Rio Grande rift and the Southern Basin and Range provinces. The basins between the ranges tend to be deeper in the Rio Grande rift than in the Southern Basin and Range, and the number of Quaternary faults and youthful volcanic fields (<1 million years old) is higher within the rift. The Mogollon-Datil volcanic field is an erosional remnant of an extensive volcanic highland formed by multiple andesitic volcanic and rhyolitic caldera eruptions 40 to 25 million years ago that was subsequently faulted during basin and range extension.[24] Extension in the rift began 30 to 25 million years ago, with activity generally waning at 10 million years ago. Local extension has continued into the Pleistocene and Holocene.[25] GPS measurements indicate that the rift is still extending at a very slow rate of between 1 millimeter and 2 millimeters per year.[26] Extension in the Southern Basin and Range peaked in the Miocene, with minor extension continuing into the Quaternary. Most previous geothermal exploration efforts in New Mexico have focused on the extensional terrains of the Rio Grande rift and Southern Basin and Range provinces.

GENERALIZED MAP OF RIFT AND PETROLEUM BASINS

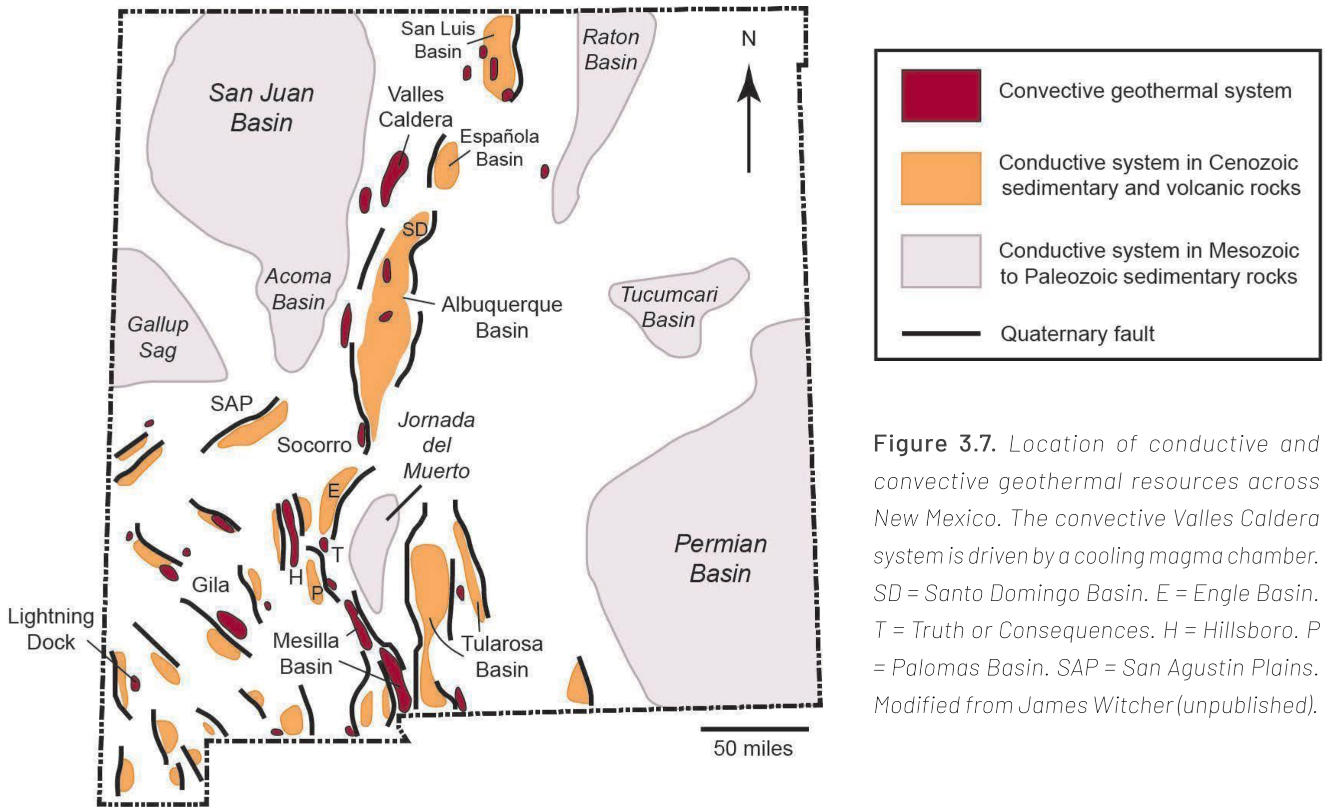


Figure 3.7. *Location of conductive and convective geothermal resources across New Mexico. The convective Valles Caldera system is driven by a cooling magma chamber. SD = Santo Domingo Basin. E = Engle Basin. T = Truth or Consequences. H = Hillsboro. P = Palomas Basin. SAP = San Agustin Plains. Modified from James Witcher (unpublished).*

GEOTHERMAL RESOURCES IN NEW MEXICO

New Mexico hosts three types of geothermal resources: magmatic, conductive, and convective (**Figure 3.7**). Chapter 1 explains the differences in each of these resources. Geothermal heat is concentrated near the Earth's surface in places where volcanic activity has recently occurred or is actively happening. Active faulting enhances geothermal potential by convectively bringing hot water toward the surface.

The only magmatically heated geothermal system in New Mexico is underneath the Valles Caldera in the Jemez Mountains volcanic field in north-central New Mexico. This volcanic field has been active since about 14 million years ago, culminating with two massive caldera-forming eruptions at 1.6 million (Toledo Caldera) and 1.2 million years ago (Valles Caldera). Immediately after the formation of the Valles Caldera, remaining magma pushed up the floor of the caldera, creating a dense fracture network on the resurgent dome, which hosts the modern geothermal system. Post-caldera ring-fracture rhyolite domes were emplaced between 1.23 million and 0.5 million years ago. The two most recent ring-fracture eruptions occurred at 74,000 and 69,000 years ago along the southwestern margin of the ring-fracture system.[27]

Numerous deep-drilling projects that accompanied geothermal exploration in the Jemez Mountains in the 1970s to mid-1990s illuminate subsurface stratigraphic relationships and thermal conditions beneath the western and central caldera (**Figure 3.8**). Unocal drilled 24 deep exploration wells into the resurgent dome, encountering temperatures of between 250°C and 300°C (482°F-572°F). The deepest industry well was 3.2 kilometers deep and was in the Proterozoic basement at total depth.[28] Three deep research boreholes (up to 1762 meters deep; maximum temperatures of 200°C [392°F]) drilled on the west side of the caldera that were supported by the

GEOLOGIC MAP AND EAST-WEST CROSS-SECTION OF THE VALLES CALDERA

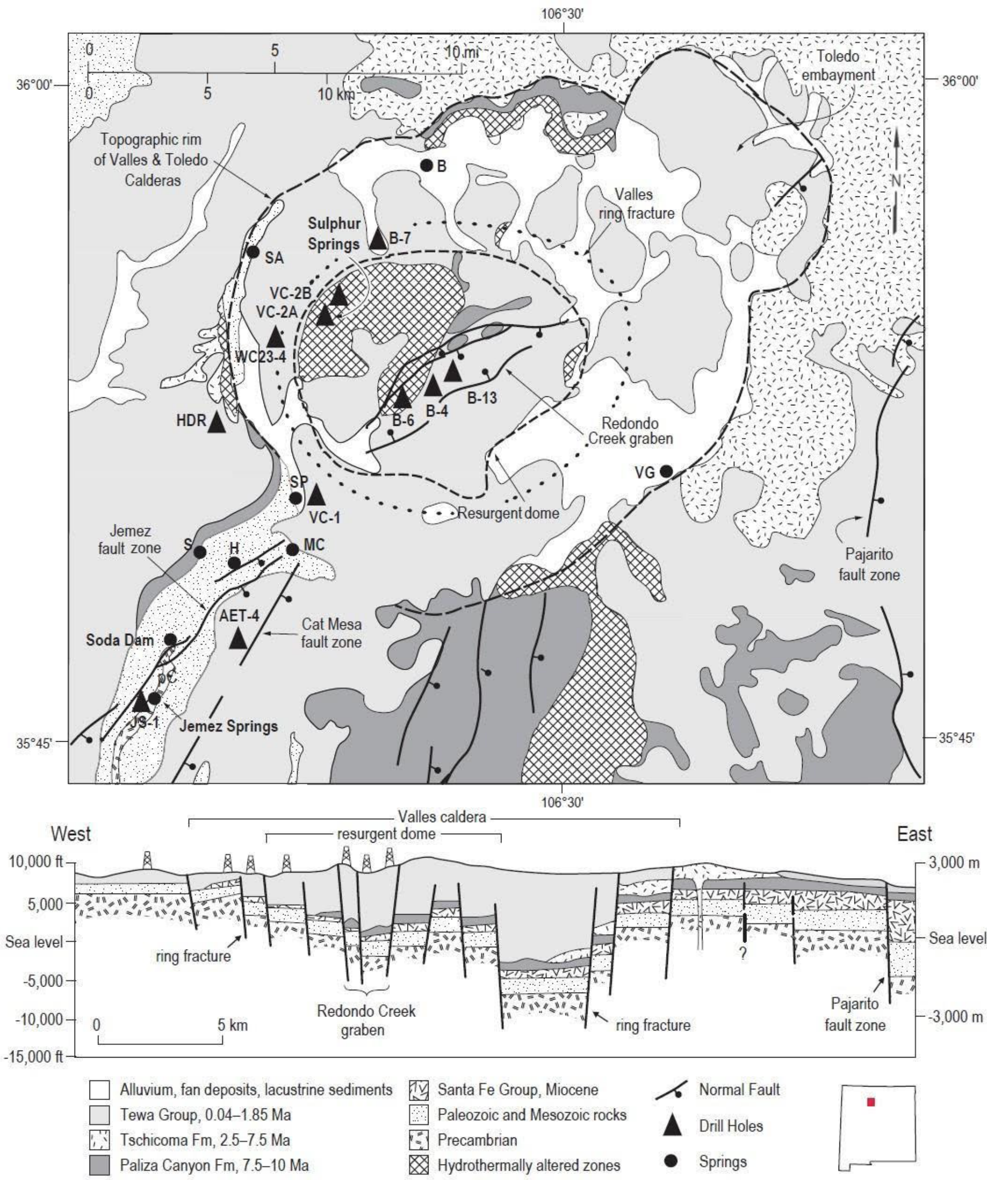


Figure 3.8. *Geologic map and east-west cross-section of the Valles Caldera.* Source: Goff, F., & Goff, C.J. (2017). *Energy and mineral resources of New Mexico: Overview of the Valles caldera (Baca) geothermal system.* New Mexico Bureau of Geology and Mineral Resources. https://doi.org/10.58799/M-50F

U.S. Continental Scientific Drilling Program provided important insights into intracaldera stratigraphy and the temperatures, alteration, and mineralization associated with the hydrothermal system.[29,30,31,32]

Several hot and warm springs (89°F–165°F, or 74°C–32°C)[33] in Cañon de San Diego southwest of the margin of the caldera are associated with an outflow plume from the caldera (**Figure 3.9**). In addition, the stratigraphy and structure of the southwestern topographic rim of the caldera were characterized to depths of 4.5 kilometers during the hot dry rock experiment.[34,35] Learnings from that experiment have guided the vast improvements in developing EGS in recent years at FORGE in Utah.[36,37,38] Because this system is within the Valles Caldera National Preserve, this resource has been retired from development since 2006.

Conductive resources are typically located in Laramide and Permian oil-producing sedimentary basins that have undergone little tectonic upheaval since the formation of the basins (**Figure 3.7**). These basins include the San Juan, Permian/Delaware, and Raton basins. In these settings, the average geothermal gradient (typically 16°C–37°C/kilometer [0.9°F–2.0°F/100 feet]) shows the increasing temperatures with depth (**Figure 3.10**). **Figure 3.10** illustrates the uncorrected bottom-hole temperature measurements in petroleum wells in the three major conductive basins in New Mexico. The Raton Basin in northeast New Mexico lies in proximity to the Jemez Lineament and thus is the warmest basin at relatively shallow depths in the state. At three kilometers deep, the temperature within sandstone and limestone reservoirs in the Raton Basin can reach 212°F (100°C). The groundwater in these basins is typically saline (three times the salinity of seawater; greater than 100 parts per thousand). Provided that these sandstone and limestones are permeable, "dry" petroleum wells could potentially be repurposed to be geothermal wells. However, sedimentary formations with a temperature of about 302°F (150°C) would need to be pumped at a rate of at least 4,000 cubic meters per day (about 800 of gallons per minute) to generate about 1.3 megawatts of electricity using a binary power plant.[39] Few oil wells have the capacity or the permeability to accommodate such flow rates.

Amagmatic geothermal systems are common in New Mexico along the Rio Grande rift, where the Earth's crust is extending and thinning and the hot mantle rocks move closer to the surface as the crust thins. These systems are also widespread in the Southern Basin and Range. The multiple tectonic events that have affected New Mexico (discussed in the previous section) have fractured the crystalline basement rocks beneath the Paleozoic-Mesozoic and rift-fill sedimentary strata, promoting groundwater circulation to depths of 6–8

VALLES CALDERA MAGMATIC GEOTHERMAL SYSTEM

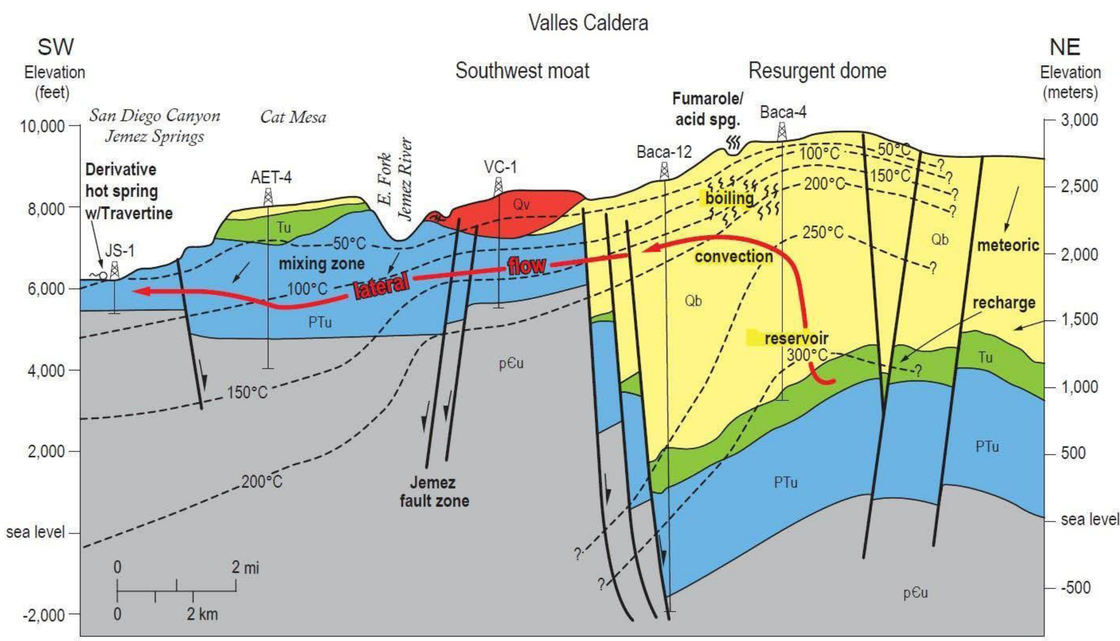


Figure 3.9. *The Valles Caldera is the only example of a magmatic geothermal system in New Mexico. pCu = Proterozoic basement. PTu = Paleozoic and Triassic sedimentary rocks. Tu = Tertiary sedimentary and volcanic rocks. Qb = Bandelier Tuff. Qv = ring fracture rhyolite and associated sedimentary rocks. Fluids in the caldera are heated by a moribund magma chamber in the southwest corner of the caldera. The water then flows southwest along northeast-striking faults (Jemez fault zone; Figure 3.8), paralleling Cañon de San Diego, and traveling primarily in fractured Pennsylvanian limestone.* Source: Goff, F., & Goff, C.J. (2017). *Energy and mineral resources of New Mexico: Overview of the Valles caldera (Baca) geothermal system.* New Mexico Bureau of Geology and Mineral Resources. https://doi.org/10.58799/M-50F

BOTTOM-HOLE TEMPERATURES IN NEW MEXICO BASINS

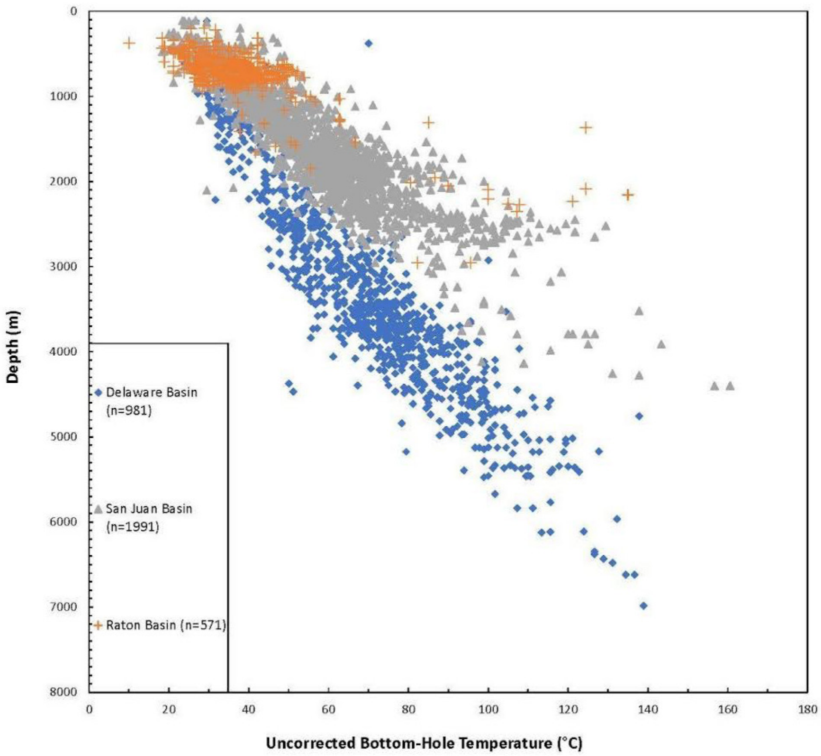


Figure 3.10. *Uncorrected bottom-hole temperature measurements for the conductive, oil-producing Raton, San Juan, and Permian Basins in New Mexico (New Mexico Bureau of Geology and Mineral Resources Geothermal Database). The gradients were calculated using the surface intercept of mean annual surface temperature from the NOAA 2006–2020 data set. Raton Basin: 2°F/100 ft (37°C/km) with 48.2°F (9°C) surface temperature intercept (9 stations); San Juan Basin: 1.6°F/100 ft (29°C/km) with 50°F (10°C) surface temperature intercept (16 stations); Delaware Basin: 0.9°F/100 ft (16°C/km) with 60°F (16°C) surface temperature intercept (10 stations).* Source: Palecki, M., Durre, I., Applequist, S., Arguez, A., & Lawrimore, J. (2021). *U.S. climate normals 2020: U.S. hourly climate normals (1991–2020).* NOAA National Centers for Environmental Information. Retrieved March 6, 2025, from https://www.ncei.noaa.gov/metadata/geoportal/rest/metadata/item/gov.noaa.ncdc:C01622/html

kilometers.[40,41] Convective amagmatic geothermal systems form as a consequence of two conditions: (i) There is significant (greater than 0.5 meters per year)[42] groundwater recharge in mountainous terrains; and (ii) the permeability of fractured crystalline basement rocks is high enough to result in flow rates on the order of meters per year. Permeability is typically represented in units of square meters by hydrogeologists and milliDarcies (mD) by the petroleum industry. Fractured bedrock or sandstone with a permeability of 1,000 mD (equivalent to 10^{-12} m^2) is considered by petroleum engineers to be an excellent oil reservoir.[43] Assuming that Snow's law[44] is valid, a permeability of this magnitude can result from a distributed fracture network with a spacing of 100 millimeters. A pumping test carried out in the crystalline basement beneath the Truth or Consequences hot springs district at a depth of about 70 meters below the land surface had a permeability of 3.6×10^{-10} m^2 (36,000 mD) (Unpublished data collected by the second author.). Calibrated hydrothermal models suggest that the average crystalline basement rocks at 6 kilometers have a permeability of about 10^{-14} m^2 to 10^{-13} m^2.[45,46]

Figure 3.11 illustrates a gravity-driven hydrothermal system that redistributes heat across a regional groundwater flow system in the vicinity of Socorro (**Figures 3.2** and **3.3**). Groundwater flow within a gravity-driven geothermal system is controlled by water table topographic gradients between the mountains and lowlands. The water table elevation drop between the Magdalena Mountains located west of Socorro and the Rio Grande in **Figure 3.11** is about 500 meters. As groundwater flows to depths of 5 kilometers or more, groundwater temperatures increase. Concentrations of dissolved silica and other cations suggest that fluid temperatures exceed 120°C (248°F) at these depths. The distribution of temperatures shown in **Figure 3.11** is based on temperature profiles from Barroll and Reiter[47] at shallow levels and from a hydrothermal model of the area west of Socorro at depth.[48] Due to vigorous downward circulation of cold meteoric water proximal to the Magdalena Mountains, which are in the groundwater recharge zone, temperature isotherms are deflected downward, reducing thermal gradients in wells at high elevations (see temperature profiles for Wells #17 and #48 in **Figure 3.11**). In the lowlands,

CONCEPTUAL MODEL OF AN AMAGMATIC GEOTHERMAL SYSTEM

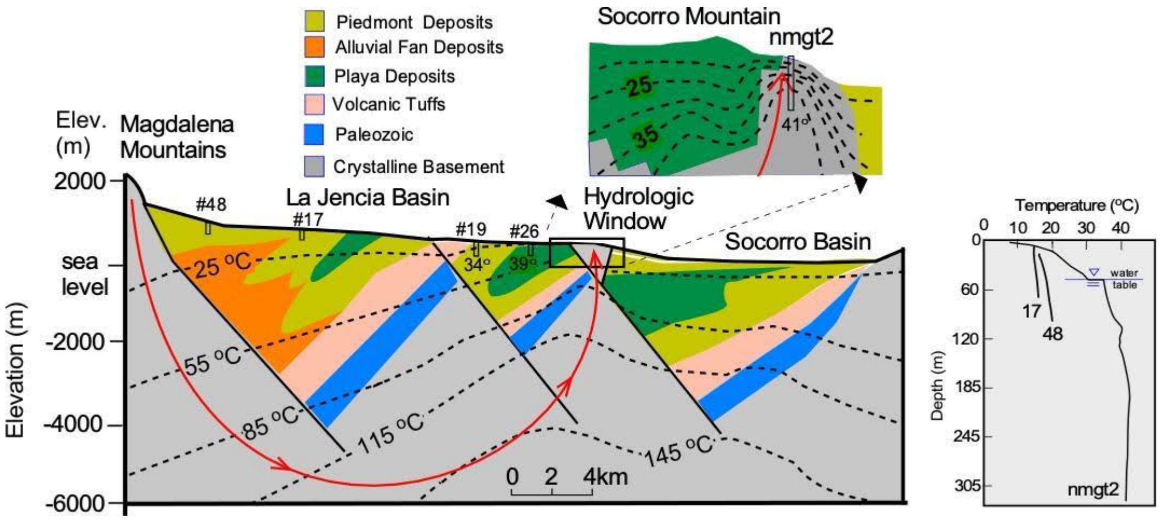


Figure 3.11. *Conceptual model of an amagmatic geothermal system. New Mexico has abundant convective geothermal resources along the Rio Grande Valley. This figure illustrates a gravity-driven convective geothermal model in a rift-flank setting with possible flow paths shown as red arrows.* Adapted from Barroll, M. W., & Reiter, M. (1990). Analysis of the Socorro hydrogeothermal system: Central New Mexico. *Journal of Geophysical Research, 95*, 21949–21964. https://doi.org/10.1029/JB095iB13p21949; Mailloux, B. J., Person, M., Kelley, S., Dunbar, N., Cather, S., Strayer, L., & Hudleston, P. (1999). Tectonic controls on the hydrogeology of the Rio Grande Rift, New Mexico. *Water Resources Research, 35*(9), 2641–2659. https://doi.org/10.1029/1999WR900110

EXAMPLES OF HYDROGEOLOGIC WINDOWS

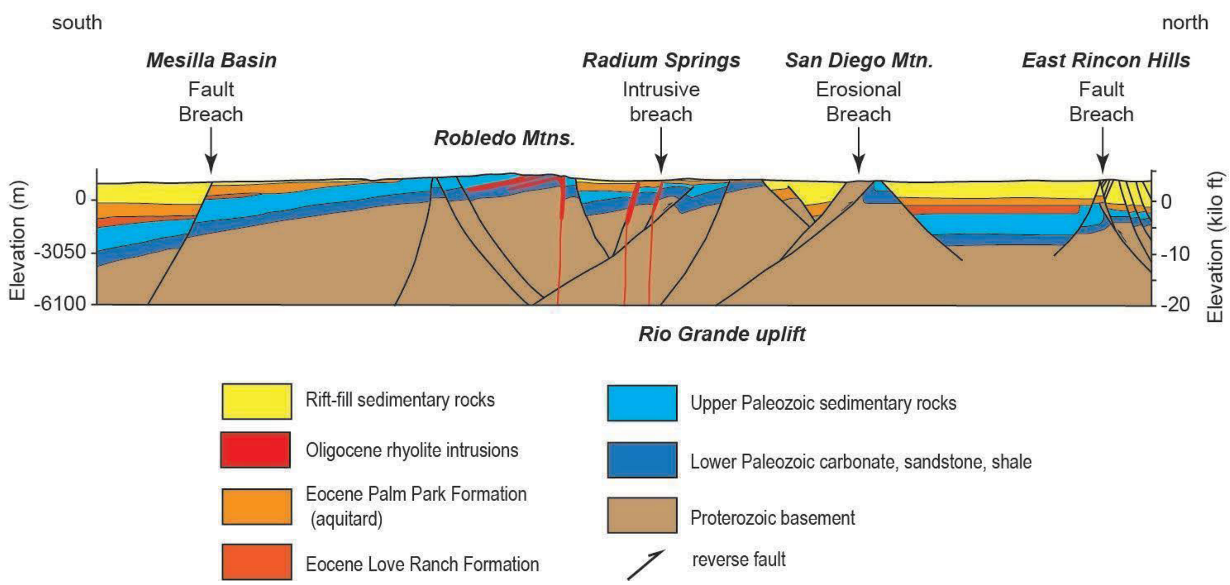


Figure 3.12. *Different types of hydrologic windows through the volcaniclastic Palm Park Formation aquitard in southern New Mexico, including fault, erosional, and intrusive windows.* Adapted from Seager, W. R., Hawley, J. W., Kottlowski, F. E., & Kelley, S. A. (1987). *Geology of east half of the Las Cruces and northeast El Paso 1 degree by 2 degree sheets* (GM-57: 1:250,000). New Mexico Bureau of Mines and Mineral Resources.

SUBCROP MAP AND MACHINE LEARNING RESULTS

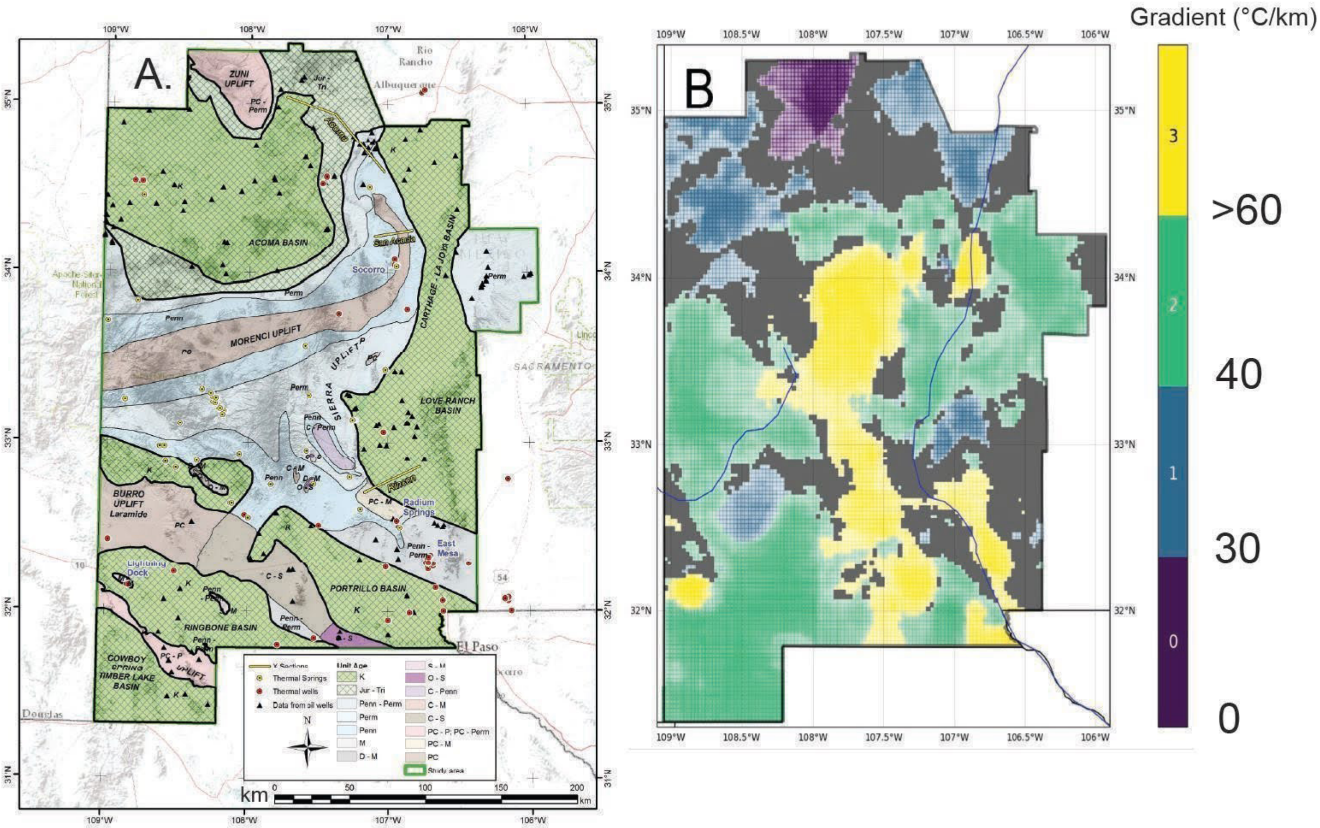


Figure 3.13. *(A) subcrop map of southwestern New Mexico depicting the landscape at the end of Laramide deformation, just prior to deposition of Eocene to Oligocene volcanic and volcaniclastic rocks from the Mogollon-Datil volcanic field. (Bielicki et al., 2015). The various colors represent the rock unit or units that lie below the unconformity. The northwest-striking fabric of southwestern New Mexico is inherited in part from Jurassic rifting associated with the formation of the Bisbee Basin (Lawton, 2000). (B) ensemble prediction map of geothermal gradients produced by supervised machine learning (Holmes and Fournier, 2022). The gray areas highlight areas of high uncertainty.* Sources: Bielicki, J., Blackwell, D., Harp, D., Karra, S., Kelley, R., Kelley, S., Middleton, R., Pepin, J., Person, M., Sutula, G., & Witcher, J. (2015). *Hydrogeologic windows: Regional signature detection for blind and traditional geothermal Play Fairways applied to Southwestern New Mexico* [Data set]. Geothermal Data Repository. Los Alamos National Laboratory. https://gdr.openei.org/submissions/611; Lawton, T. F. (2000). Inversion of late Jurassic-early Cretaceous extensional faults of the Bisbee Basin, southeastern Arizona and southwestern New Mexico. *New Mexico Geological Society Guidebook, 51*, 95–102. https://doi.org/10.56577/FFC-51.95; Holmes, R. C., & Fournier, A. (2022). Machine learning-enhanced Play Fairway analysis for uncertainty characterization and decision support in geothermal exploration. *Energies, 15*(5), 1929. https://doi.org/10.3390/en15051929

heated groundwater flows upward before discharging at the surface or to the water table. Within the Socorro Basin, this is facilitated by the absence of confining units such as playa deposits (**Figure 3.11**). Upward flow of groundwater in the discharge area transports heat toward the surface, resulting in an amagmatic convective geothermal resource. Well nmgt2 has a temperature of about 41°C (106°F) near the water table.

The Socorro system is an excellent example of how the juxtaposition of aquitards and aquifers across faults and disruption of aquitards by erosion and faulting can control discharge in hydrothermal systems. The concept of hydrogeologic windows was first described by Witcher et al.[49] The hydrologic window within the Socorro Basin, as exemplified in **Figure 3.11**, formed as a result of faulting and erosional processes occurring over millions of years.[50] The window provides a pathway of least resistance for groundwater discharge. Although the sediments overlying the crystalline basement can host permeable aquifers, the overlying deposits also contain regionally extensive clay or shale formations that can block upward flow. A breach related to faulting and erosion is only one type of a hydrologic window (**Figure 3.12**).[51] In southern New Mexico, a regionally extensive andesite debris-flow deposit called the Palm Park Formation acts as an aquitard that covers potential blind geothermal resources developed in fractured basement rocks and Paleozoic limestone.[52,53] Hot springs and shallow geothermal systems occur in fractured volcanic dikes that act as hydrologic windows, as well as in other areas where the Palm Park aquitard is breached (**Figure 3.12**).

An exploration map created as part of a Department of Energy–funded Play Fairway project[54] depicting regions where hydrologic windows may exist below aquitards in the subsurface is shown in **Figure 3.13A** for southwestern New Mexico. This map was first presented by Witcher et al. and many of the concepts used in the 2015 Play Fairway analysis are described in the 1988 paper.[55] Rock units below the Eocene-Oligocene volcaniclastic debris flows and lahars (aquitards) mentioned earlier were identified, and the landscape developed on Laramide structures preserved beneath the unconformity in southwestern New Mexico was mapped. Cretaceous basins filled with intercalated shales (e.g., Mancos Shale) or fine-grained tight sandstones that act as aquitards are shown in the green-cross hatched pattern in **Figure 3.13A**. These areas are not likely to have post-Laramide windows, but deeper windows related to earlier Ancestral Rocky Mountain deformation may exist beneath the Cretaceous rocks. Possible hydrogeologic windows in the northwest-striking Proterozoic- to Paleozoic-cored Laramide highlands are shown in shades of brown, pink, and blue. Areas where a Devonian shale aquitard has been stripped from Ordovician to Silurian karstic carbonate aquifers are among the best targets for geothermal exploration in the state.

Data collected as part of the 2015 Play Fairway project were analyzed with machine-learning algorithms to better understand which geologic, geochemical, and geophysical parameters have high correlation in known geothermal systems, as well as to quantify parameter uncertainty.[56,57] These studies consider 18 to 25 independent parameters related to geothermal prospectivity. The unsupervised machine-learning algorithm used by Vesselinov and colleagues identified five geographic areas that have a unique set of dominant data attributes.[58] The key data attribute used to distinguish between low-temperature (less than 194°F, or 90°C) and medium-temperature (194°F–302°F, or 90°C–150°C) hydrothermal systems was the silica geothermometer, a geochemical proxy for reservoir temperature. The two medium-temperature systems are in the northern part of the Mogollon-Datil volcanic field and in the Rio Grande rift near Las Cruces. Interestingly, Swanberg came to similar conclusions primarily using silica geothermometry.[59] Holmes and Fournier used four different types of machine-learning supervised algorithms to evaluate three types of data uncertainty related to the choice of model, errors in the parameters estimated by the models, and input data preparation.[60] The results from the four models were combined to form a weighted-average ensemble model (**Figure 3.13B**). Holmes and Fournier note that the analysis of uncertainty can be used to find areas where the four models do not agree, which can be used to target additional data collection.[61]

The effects of convective heat transfer are illustrated in the heat flow map of New Mexico (**Figure 3.14**). In the northern part of New Mexico, the Valles Caldera (VC) stands out as a geothermal anomaly. In the Albuquerque Basin (A), heat flow is lowest along the eastern flanks of the rift due to convective anomalies associated with meteoric "cold" groundwater recharge. In the center and along the western flank of the rift, heat flow is elevated. This is likely due to convective warming. Within the Socorro-La Jencia basin (S), a classic pattern of low heat flow (17 milliwatts per square meter) in the La Jencia Basin adjacent to the Magdalena Mountains in the region of groundwater recharge occurs. At the base of the Socorro Mountain block, heat flow reaches 490 milliwatts per square meter in a hydrologic window, where the crystalline basement crops out at the land surface. The high heat-flow values such as those observed in the Socorro geothermal system are deceiving. High and low shallow temperature gradients beneath the land surface are due to convective upwelling and downwelling.

NEW MEXICO HEAT FLOW MAP IN MILLIWATTS PER SQUARE METER

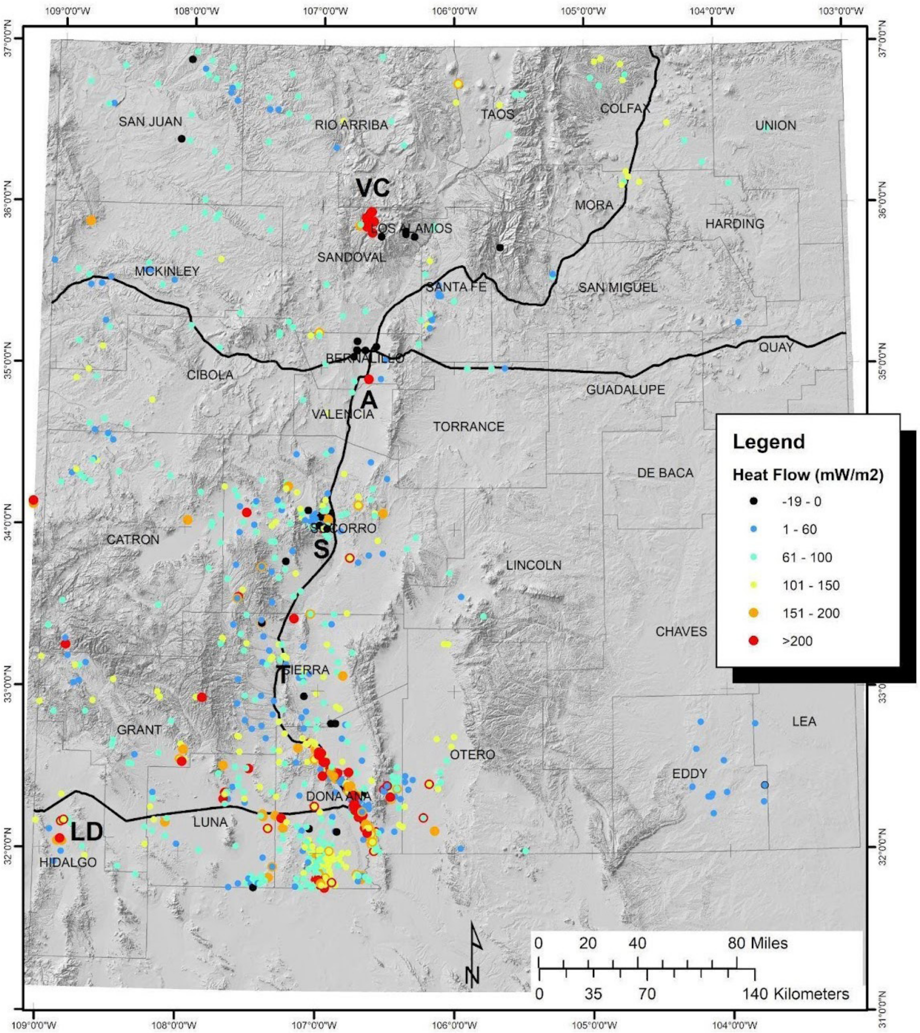


Figure 3.14. *New Mexico heat flow map in mW/m²; data compiled from published and industry data sources. VC = Valles Caldera, A = Albuquerque Basin, S = Socorro Basin, T = Truth or Consequences, LD = Lightning Dock. Source: Shari Kelley.*

Temperatures within the discharge area do not exceed 41°C (106°F). Beneath this area, isothermal conditions exist. The same is true for the Truth or Consequences geothermal system. The crystalline basement is exposed just below the land surface. Measured temperatures do not exceed 109°F (43°C). Further to the southwest in the "bootheel" region of New Mexico at Lightning Dock, temperatures approach boiling conditions. Here, discharge occurs along a fault zone. Lightning Dock discharge is likely focused in a narrow outflow zone associated with the fault, allowing for higher temperatures. Within the Truth or Consequences and Socorro geothermal systems, upflow is more diffuse because flow is less restricted to a narrow zone.

DETAILED ANALYSIS

Due to page constraints, only a few geothermal areas are discussed in detail in this chapter. Many areas in New Mexico do not have the thermal and geophysical data needed for rigorous analysis of geothermal potential. The examples described here are areas with significant, but not complete, quantities of useful data. The geothermal potential of the Socorro magma body at the intersection of the southern Albuquerque and northern Socorro Basins; the San Agustin, Engle, and Mesilla Basins; and the Rincon system is discussed. Lightning Dock in the southern Basin and Range is briefly described. We close with a discussion of the geothermal potential of the three conductive petroleum basins with large amounts of stratigraphic and bottom-hole temperature data.

Socorro Magma Body

The Socorro magma body is considered to be the largest active magma chamber in the U.S. continental crust (**Figure 3.15**).[62,63] This unique feature is located between the southern terminus of the Albuquerque Basin and northern Socorro Basin (**Figure 3.2**). Seismic data suggests that the intrusion is at a depth of about 19 kilometers.[64,65] The footprint of the body is about 3,400 square kilometers. The sill has a thickness of only 100 to 150 meters.[66,67] Williams and colleagues report evidence of mantle-derived helium associated with a saline spring near the town of San Acacia, located about 20 kilometers north of Socorro.[68] The magma body is associated with a region of dome-like uplift detected by Interferometric Synthetic Aperture Radar (InSAR) that is presently rising at a rate of between 2 millimeters and 3 millimeters per year.[69] The uplift is interpreted to be the result of thermal expansion and magma injection into the sill.[70] Studies of the deformation of terrace deposits, the deformation of the railroad grade near the Rio Grande detected in the 1970s, and InSAR studies in the Socorro area indicate two episodes of inflation between 26,000 to 3,000 years ago and more modern inflation detected during the 1970s and continuing to the present day.[71] Swarms of earthquakes are common, and studies of the swarms can be used to distinguish between fluid-related swarms and fault-related swarms.[72,73] The largest event in the 2005 swarm studied by Stankova and colleagues[74] had a magnitude of 2.4 and the largest event in the 2009 swarm studied by Ruhl and colleagues[75] had a magnitude of 2.5.

Because there is no clear regional temperature anomaly at the surface, magma injection appears to occur episodically. Reiter and colleagues hypothesized that episodic magma injection with associated pressure increases could result in the observed seismic anomalies.[76] The regional heat flow above the Socorro magma body is about 90 milliwatts per square meter, indicating that the thermal regime related to sill emplacement at 19 kilometers at 1–3 million years ago has yet to reach the surface.[77,78] The only hint of hydrothermal fluid flow related to a possible geothermal upflow zone is a discharge temperature of 83.4°F (28.8°C) that was recorded at the San Acacia municipal well about 22 kilometers north of Socorro, near the southern Albuquerque Basin boundary;[79] the well is 164 meters deep.

SOCORRO MAGMA BODY AND SOCORRO SEISMIC ANOMALY

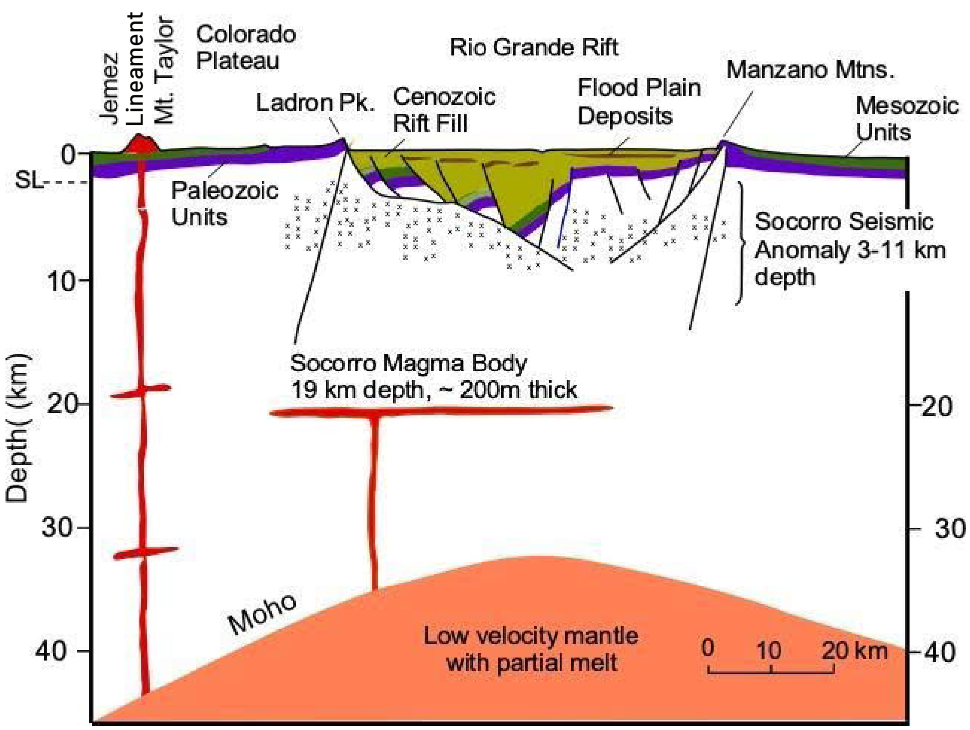


Figure 3.15. *General east-west cross-section across the Rio Grande rift showing the Socorro magma body and Socorro seismic anomaly near the southern Albuquerque Basin terminus. X=earthquakes.* Adapted from Williams, A. J., Crossey, L. J., Karlstrom, K. E., Newell, D., Person, M., & Woolsey, E. (2013). Hydrogeochemistry of the Middle Rio Grande aquifer system—Fluid mixing and salinization of the Rio Grande due to fault inputs. *Chemical Geology, 351,* 281–298. https://doi.org/10.1016/j.chemgeo.2013.05.029

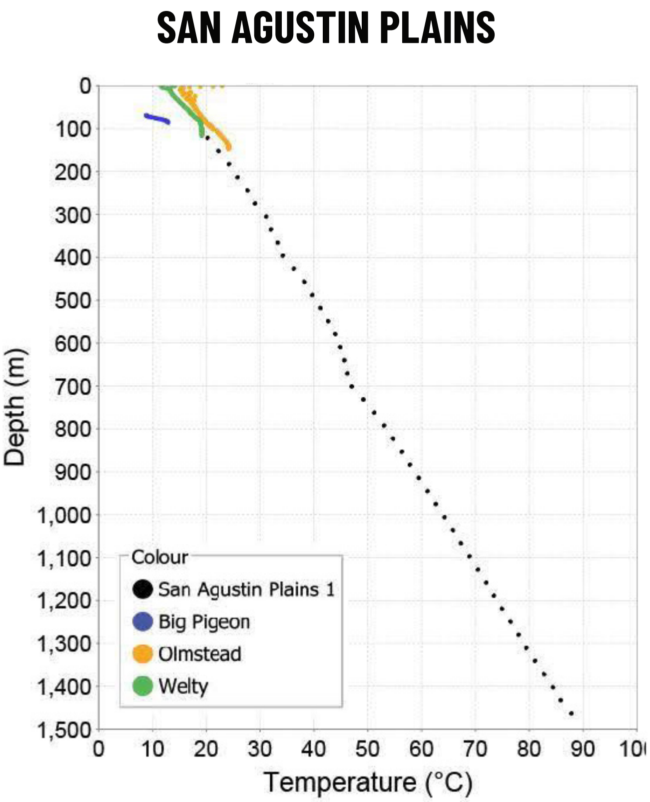


Figure 3.16. *Measured temperature-depth profiles from four wells from the San Agustin Plains. Source: Shari Kelley.*

San Agustin Plains

Reiter and colleagues[80] present the results of repeat temperature measurements in the upper part of Sun Oil Co. 1 San Agustin Plains (API 30-003-05002; SAP); the most recent log measured in December 1975 is shown by dotted line in **Figure 3.16.** This well encountered temperatures of 194°F (90°C) at 1500 meters. Geothermal gradient was calculated in three intervals in the well. The gradients range from 48.9°C/km (2.7°F/100 ft) to 59.9°C/km (3.3°F/100 ft). The average calculated heat flow is 73.2 milliwatts per square meter. This well penetrated Cenozoic tuff and volcaniclastic sediments to a depth of 2,016 meters, then penetrated Cretaceous, Triassic, Permian, and Pennsylvanian sections before bottoming in Proterozoic gneiss at 3,744 meters.

Several middle Cenozoic rhyolite intrusions were encountered during the drilling of this well; according to the driller's log, the thickest interval is 463 meters. The equilibrium temperature log of Reiter and colleagues[81] is in the Cenozoic section. The uncorrected bottom-hole temperature readings for the oil well are 280°F–309°F (138°C–154°C). Given the conductive nature of the geothermal gradient shown in **Figure 3.16**, this site might be attractive for the development of engineered geothermal systems, advanced geothermal systems, and other options.

Temperature logs in three shallow water wells (**Figure 3.16**) were measured and analyzed as part of the current investigation. Two of the wells have geothermal gradients that are similar to those encountered in the top of the deep oil well. The geothermal gradient in the Olmstead well is 67.4°C/km (3.7°F/100 ft) below the water table. The Welty log is located just north of the divide that separates the San Agustin Plains from the Alamosa Creek, a tributary of the Rio Grande. The geothermal gradient measured above the water table is about 3.3°F/100 ft (60°C/km), but the gradient is much lower below the water table due to influx of cold groundwater. The Big Pigeon well is in a recharge zone in the San Mateo Mountains, and thus the log records cold temperatures.

Engle Basin

The Engle Basin hosts the Truth or Consequences geothermal system.[82] A geologic cross-section extending from the recharge area in the San Mateo Mountains and Sierra Cuchillo eastward to the Rio Grande in the Truth or Consequences hot spring district is shown in **Figure 3.17.** The location of this cross-section is shown in **Figure 3.17A** (black line a to a') and is perpendicular to the regional water table elevation contours. The large fault in the middle of the cross-section is the Mud Springs fault, and the portion of the Engle Basin to the west of the fault is the Monticello graben. The broad Cuchillo Negro fault zone, which has Quaternary offset, lies to the west of the Mud Springs fault; Pepin reports a warm well (86°F, or 30°C) that is 262 meters deep along Alamosa Creek near the Cuchillo Negro fault zone.[83]

Mark Person and colleagues, with the support of town officials in Truth or Consequences, conducted a study to assess the sustainability of the geothermal system in light of increased development in the area.[84] Person and associates[85] and Pepin and colleagues[86] collected temperature-depth profiles in wells less than or equal to 25 meters deep in and around the Truth or

THERMAL MODEL AND MAGNETOTELLURIC DATA INTERPRETATION FOR THE TRUTH OR CONSEQUENCES GEOTHERMAL SYSTEM

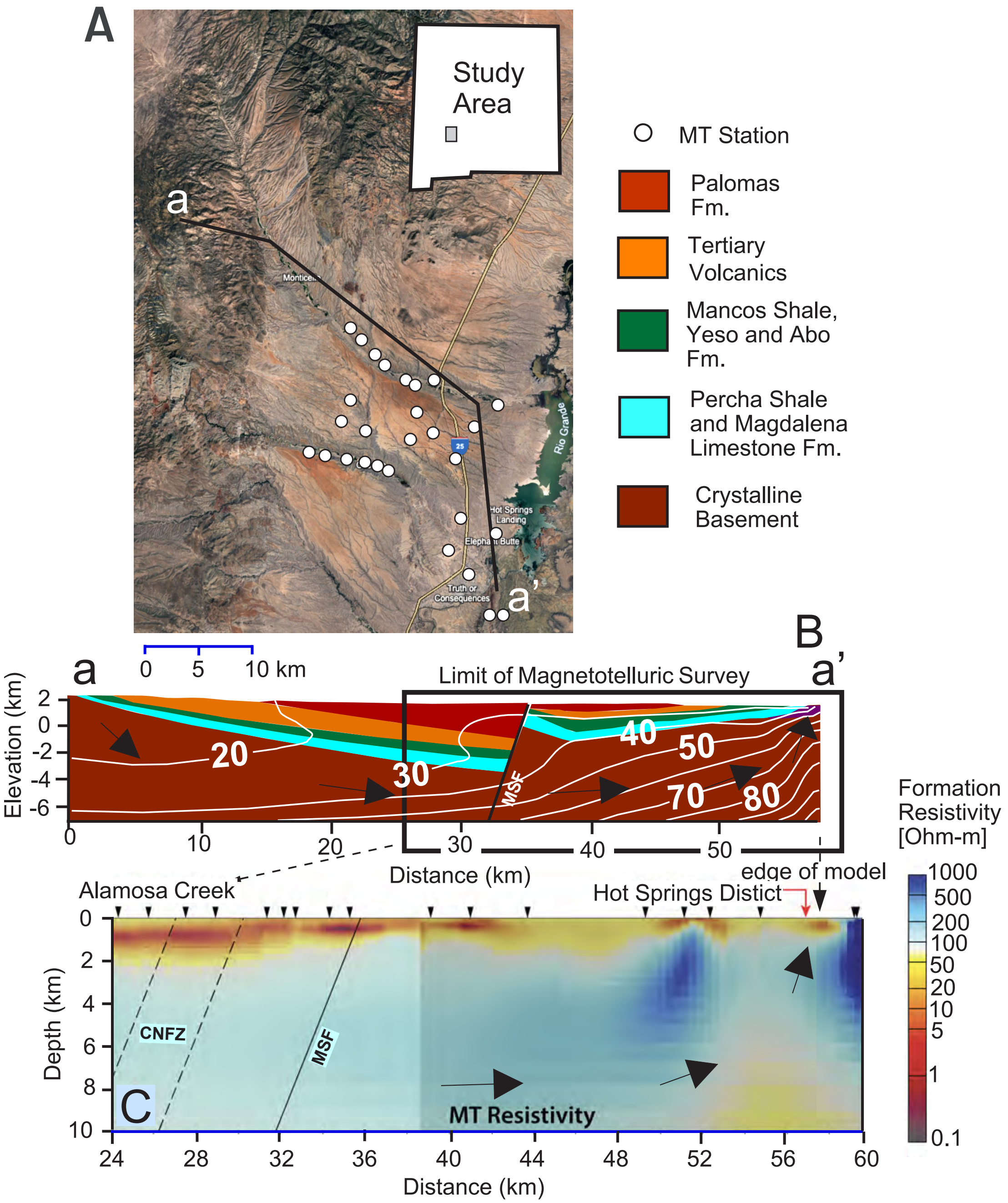


Figure 3.17. *(A) Location of magnetotelluric (MT) soundings and hydrothermal model within the Engle Basin and the northernmost Palomas Basin. (B) Simplified geologic cross-section. Solid black line shows location of MT survey and inversion (from Person et al., 2013). Temperature-depth contours calculated from the hydrothermal model are shown as white lines (°C). (C) MT inversion showing formation resistivity map. CNFZ = Cuchillo Negro fault zone. MSF = Mud Springs fault.* Sources: Pepin, J. (2018). *New approaches to geothermal resource exploration and characterization* [Doctoral dissertation]. New Mexico Institute of Mining and Technology; Person, M., Phillips, F., Kelley, S., Timmons, S., Pepin, J., Blom, L., Haar, K., & Murphy, M. (2013). *Assessment of the sustainability of geothermal development within the Truth or Consequences Hot-Springs District, New Mexico* (Open-file Report 551). New Mexico Bureau of Geology and Mineral Resources. https://doi.org/10.58799/OFR-551 *(from Pepin, 2018).*

Consequences hot springs district. Temperature-depth profiles were isothermal at depth with significant curvature near the water table, indicative of groundwater upflow. The maximum temperatures range from 30°C to 45°C (86°F–113°F). Pepin collected three-dimensional magnetotelluric data in portions of the Engle Basin and the northernmost Palomas Basin in Sierra County (**Figure 3.17C**).[87] The station spacing was between 2 kilometers and 5 kilometers (**Figure 3.17C**). A fence diagram showing the results of the three-dimensional MT inversion is presented in **Figure 3.17C**. At shallow depths, the Palomas Formation, within the Santa Fe Group, is conductive (less than 1 Ohm-meter) to depths of around 1.5 kilometers. The rift-fill sediments were deposited when the Engle Basin was hydrologically closed and include playa deposits, which likely accounts for the low formation resistivity at the top of the model. The subsurface becomes more resistive with depth, and at the base of the Paleozoic units, the resistivity has increased to about 200 Ohm-meters. Pepin interprets this region as containing relatively fresh groundwater (less than 0.5 parts per thousand total dissolved solids).[88] The transition between the crystalline basement and the lower Paleozoic units is not apparent, suggesting that the crystalline basement is highly fractured. The Paleozoic rocks include the basal Pennsylvanian limestone aquifer system. Below 2.5 kilometers, the subsurface beneath the Truth or Consequences hot spring district becomes more conductive with depth and commonly has resistivity values that are less than 100 Ohm-meters. Pepin interprets these values to indicate salinity buildup along the flow path through the crystalline basement.[89]

Person and colleagues[90] and Pepin[91] conclude that upward groundwater flow in the hot spring district has diminished since the study by Theis and associates,[92] that many of the wells drilled in the 1940s no longer exist or are in poor repair, and that buried faults compartmentalize the reservoirs beneath Truth or Consequences. The district has been closed to further development to ensure the system's sustainability.

TOPOGRAPHIC MAP OF JORNADA DEL MUERTO BASIN, HYDROGEOLOGIC CROSS-SECTION, AND SIMULATED TEMPERATURES

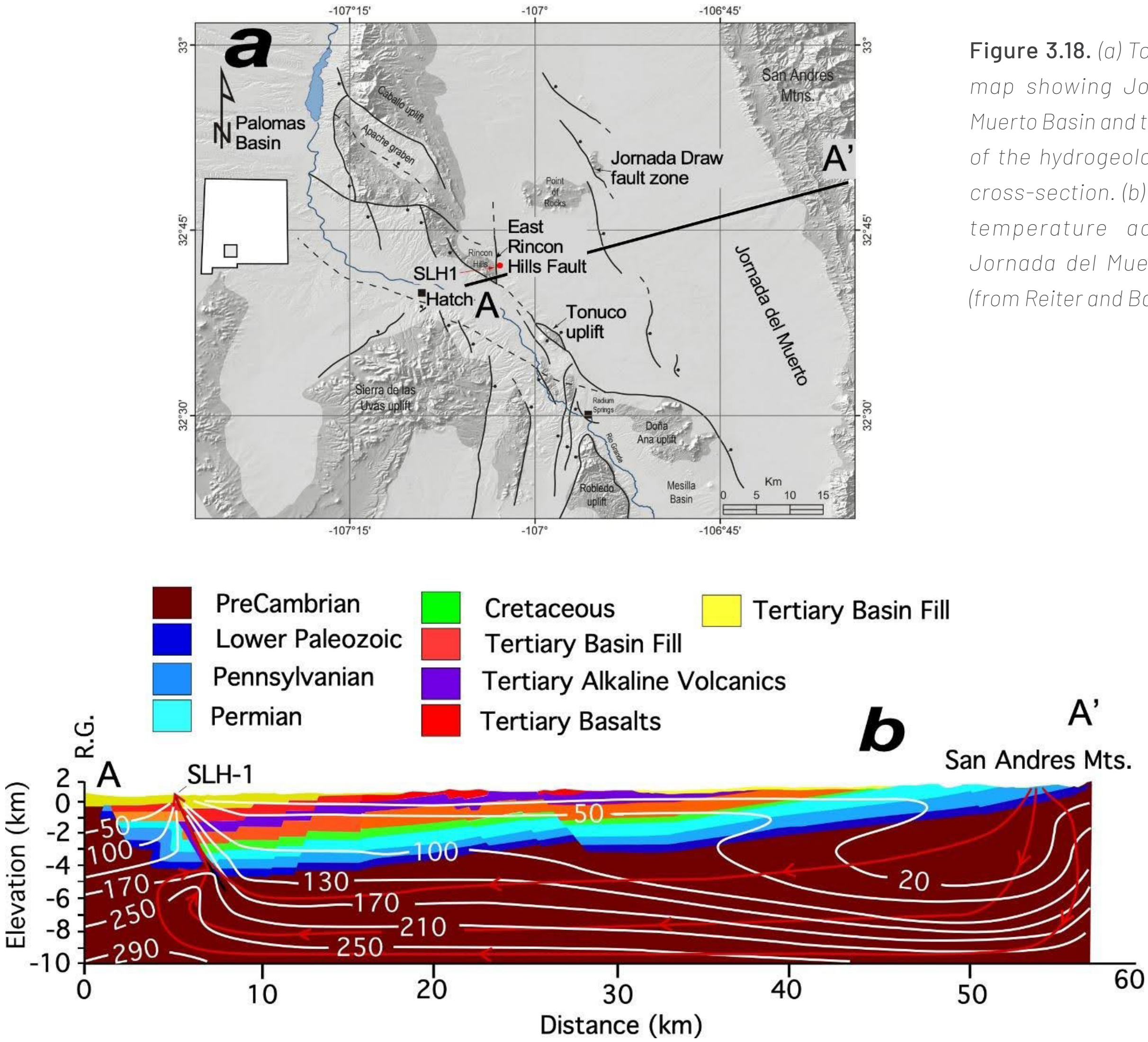


Figure 3.18. *(a) Topographic map showing Jornada del Muerto Basin and the location of the hydrogeologic model cross-section. (b) Simulated temperature across the Jornada del Muerto Basin. (from Reiter and Barroll, 1990)*

Jornada del Muerto and Hatch-Rincon Basins

The southern Jornada del Muerto and Hatch-Rincon Basins host the Rincon geothermal system, which is located at the intersection of the two basins (**Figure 3.18**). The geothermal system is located just to the northeast of the Rio Grande. The southern Jornada del Muerto is bounded to the east by the San Andres Mountains (maximum elevation 2,755 meters) and to the west by the Caballo Mountains (maximum elevation 3,194 meters).

Reiter and Barroll analyzed bottom-hole temperature data from oil wells in the northern and central Jornada del Muerto (not shown on **Figure 3.18a**).[93] The heat flow is high (95 milliwatts per square meter), which is unusual in this area that has few extensional features. These authors pose several ideas to explain the elevated heat flow in this little-deformed area. High crustal radioactivity in buried Proterozoic plutons and intrusions into the middle to lower crust were among the ideas proposed. Identifying the cause of the elevated heat flow in this area warrants additional research.

REGIONAL WATER TABLE CONTOUR MAP ACROSS THE JORNADA DEL MUERTO BASIN

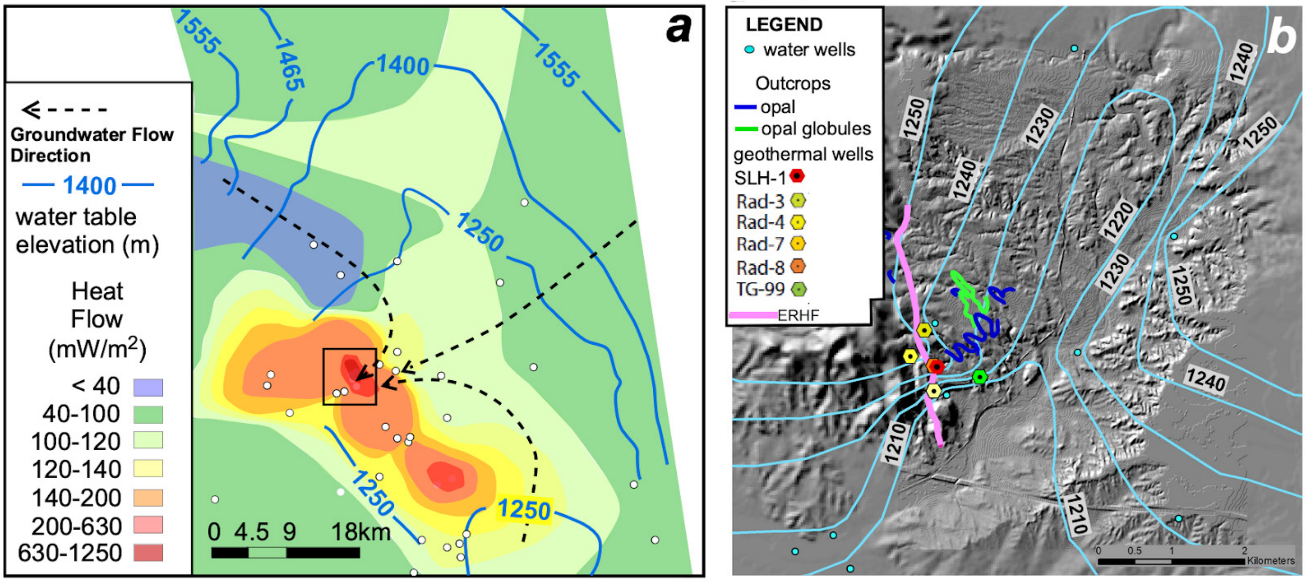


Figure 3.19. (*a) Regional water table contour map (blue lines) across the Jornada del Muerto Basin. Green to red shaded patterns denote temperature gradients contours (°C/km). White circles denote location of temperature gradient drill holes. (b) Expanded water table contours near the East Rincon Hills Fault (purple line) near the southwest edge of the basin. Temperature gradient drill holes and water wells are indicated by the blue dots (data source James Witcher, personal communication). Outcrops of opal deposits are also shown as a green line.* Source: Mack, G. H., Jones, M. C., Tabor, N. J., Ramos, F. C., Scott, S. R., & Witcher, J.C. (2012). Mixed geothermal and shallow meteoric origin of opal and calcite beds in Pliocene-Lower Pleistocene axial-fluvial strata, Southern Río Grande Rift, Rincon Hills, New Mexico, USA. *Journal of Sedimentary Research, 82, 616–631. https://doi.org/10.2110/jsr.2012.55*

The Rincon geothermal prospect is a blind geothermal system (in other words, no geothermal features are present on the surface). The system was initially identified by the presence of opal deposits (**Figure 3.19b, green lines**).[94] Witcher found anomalous radon soil-gas levels (up to 322 picocuries per liter) in the Rincon Hills, and he mapped potential upflow zones in the vicinity of the East Rincon Hills fault using radon soil-gas surveys.[95] Subsequent drilling of thermal gradient boreholes in the Rincon area showed very high geothermal gradients within the vadose zone (> 400°C/km; 219°F/100 ft) (**Figure 3.20**). The gradients in RAD-8 and RAD-4 are conductive, whereas the thermal gradients in RAD-3 and RAD-7 (**Figures 3.19b and 3.20c**) decrease below the water table, indicative of an outflow plume. Self-potential surveying by Ross and Witcher further refined the shape and extent of the shallow upflow and outflow zones of the system.[96]

RAD-7, northeast of SHL-1 (**Figure 3.20**), was sampled for water chemistry via airlifting.[97] RAD-7 intersects the water table at around 90 meters deep and has a water table temperature of 60°C, or 140°F (**Figure 3.19.c**). The water is predominantly a sodium-chloride fluid with a total dissolved solids of 1924 milligrams per liter. A suite of geothermometry calculations yielded potential reservoir temperatures ranging from 94°C to 177°C (201°F–351°F). The 120°C (248°F) chalcedony geothermometer yields results similar to the sodium-lithium geothermometer (**Figure 3.21**). The sodium/potassium/calcium geothermometer may be unreliable because these waters have flowed through carbonate rocks.[98] Using this information, SLH-1 was drilled in 1992 (**Figure 3.20**).

A second temperature log was obtained in SHL-1 in 2018 (**Figure 3.20c**), and the results are presented in an article by Person and colleagues, who concluded that the temperature overturn observed in SLH-1 had to be due to a three-dimensional hydrologic flow system with components of flow of cold water from the northwest in addition to upflow along the East Rincon Hills fault.[99]

WELLS NEAR THE SAN ANDRES MOUNTAINS AND THE RIO GRANDE

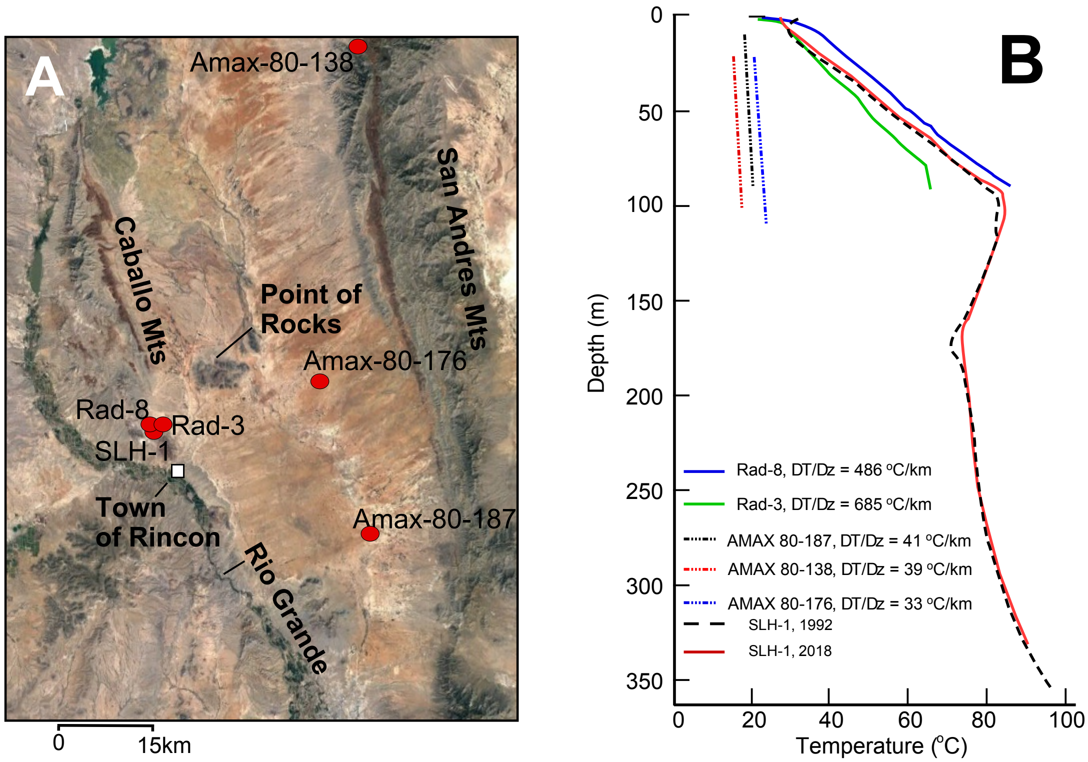


Figure 3.20. *(A) Map showing wells to the west of the recharge area in the San Andres Mountains and in the discharge area near the Rio Grande. (B) Upland temperature profiles on the east side of the Jornada del Muerto Basin to the west of the recharge area. Lowland wells RAD-8, RAD-3, and SLH-1 are located near a geothermal upflow zone east of the East Rincon Hills fault. Repeat temperature profiles were collected for SLH-1 in 1993 and 2018.* Sources: Witcher, J.C. (1998). The Rincon SLH1 geothermal well. *New Mexico Geological Society Guidebook*, (35–38). https://doi.org/10.56577/FFC-49; Person, M., Stone, W. D., Horne, M., Witcher, J., Kelley, S., Lucero, D., Gomez-Velez, J., & Gonzalez-Duque, D. (2023). Analysis of convective temperature overturns near the East Rincon Hills Fault Zone using semi-analytical models. *Geothermal Resources Council Transactions, 47,* 3093–3117.

RINCON GEOTHERMOMETER RESULTS

Na/K/Ca	Na/Li	Mg/Li	quartz	chalcedony	alpha-cristobalite
177°C	117°C	94°C	146°C	120°C	96°C

Figure 3.21 *Estimated reservoir temperatures (in oC) for fluids from well SLH-1 using chemical geothermometers. Source:* Horne, M. (2019). *Assessing the Rincon geothermal system using transient electromagnetic surveys and hydrothermal modeling* [Master's thesis]. New Mexico Institute of Mining and Technology.

MAP OF THE MESILLA BASIN

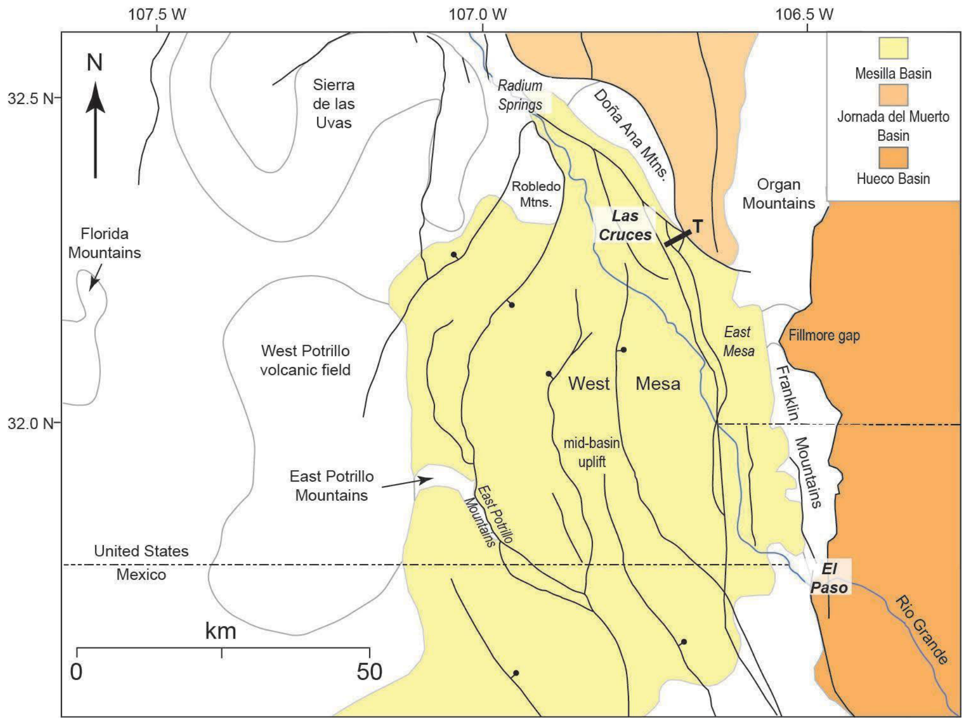


Figure 3.22. *Map of the Mesilla Basin showing the locations of geographic features, major faults (bar and ball on downthrown side), and known geothermal systems (names in italics). The cross-section shown in Figure 3.22 is the bold line labeled T (Tortugas Mountain) in this figure.*

They used semi-analytical mathematical models to evaluate flow rates up the fault and within the water table aquifer. The vertical and horizontal flow rates had to be of the same order of magnitude. Vertical flow up the East Rincon Hills fault was estimated to be about 22 meters per year. This rate is an order of magnitude higher than the estimated upflow based on measurements in the Truth or Consequences upflow zone.[100]

Mesilla Basin

The Mesilla Basin has been the target of extensive geothermal exploration since the early 1970s. Pepin and colleagues recently reported on the analysis of 397 temperature-depth profiles collected between 1972 and 2018 from the basin.[101,102] Known geothermal systems discovered in the basin during this time frame include the East Mesa, Radium Springs, and East Potrillo Mountains fields (**Figure 3.22**).[103,104]

The East Mesa geothermal system is associated with the Mesilla Valley fault zone and a horst located just east of the fault. The developed part of the system in the vicinity of Tortugas Mountain was originally found when the Clary and Ruther State 1 oil test produced steam[105] and hot water in 1949 and when warm salty water in shallow wells was noted during the construction of the Las Alturas neighborhood.[106] New Mexico State University decided to develop the geothermal system from the mid-1970s to early 1980s to save on heating costs. A direct-use heating system was built in 1981 and 1982 to heat athletic buildings and other facilities on the east side of campus. Greenhouse and aquaculture business incubators were added to the system in 1985. This was one of the first attempts to use a geothermal resource to directly heat large facilities on a university campus. Because this was a groundbreaking use of this resource, several mistakes in the initial design led to maintenance problems in later years,[107] and the system was taken offline in 2001. Numerous geophysical surveys, shallow thermal gradient holes, two deep test wells, and four deep production wells were used to define the resource.[108,109,110,111] The resource is associated with a structural bench that is cut by the 3- to 4-mile-wide Mesilla Valley fault zone that generally steps up and down across a series of faults (**Figure 3.23**). All of the wells, except PG-4, are completed in the middle to lower Santa Fe Group. The deepest 12 meters of PG-4 are in breccia in Permian limestone that may represent a fault zone or a karst feature (**Figure 3.23**).[112]

CROSS-SECTION THROUGH THE EAST MESA GEOTHERMAL SYSTEM

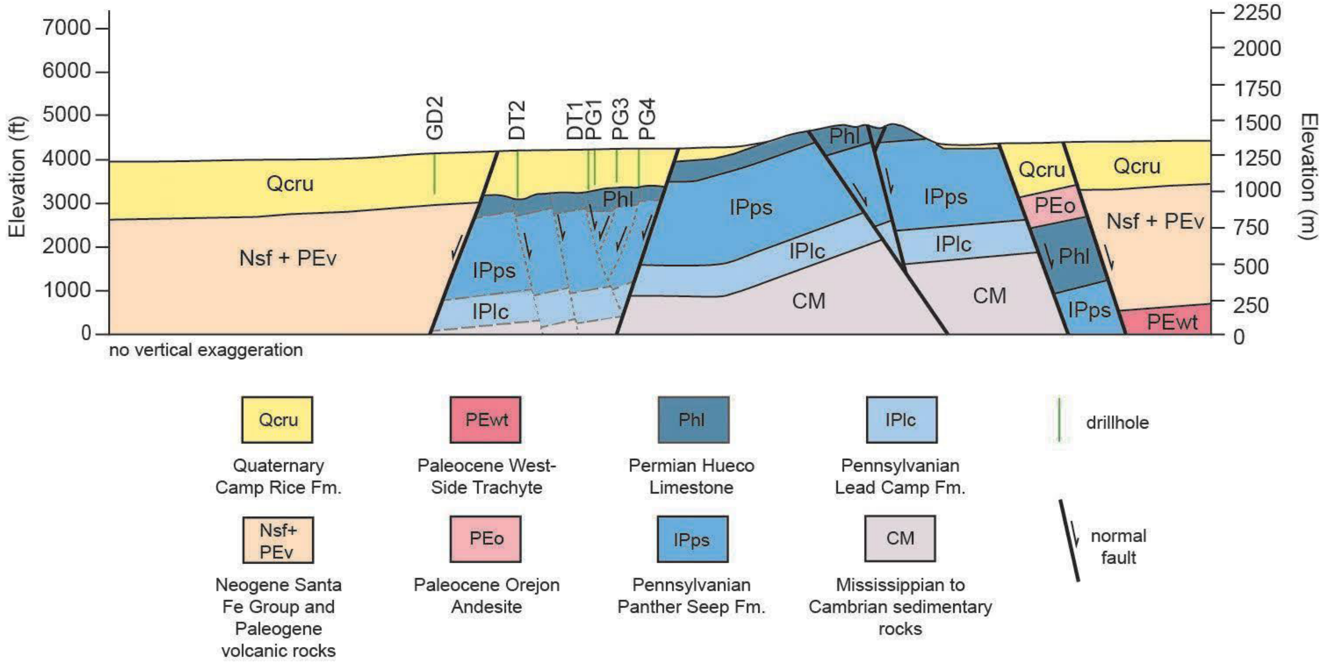


Figure 3.23. *Cross-section through the East Mesa geothermal system. The dashed gray lines show the geometry of faults and layering of rock units imaged by a seismic reflection line.* Sources: Witcher, J. C., Schoenmackers, R., Polka, R., & Cunniff, R. A. (2002). Geothermal energy at New Mexico State University in Las Cruces. *Geo-Heat Center Bulletin, 23*, 30–36; Jochems, A. P., Kelley, S. A., & Seager, W. R. (2020). *Geologic map of the Tortugas Mountain 7.5-minute quadrangle, Doña Ana County, New Mexico* (Open-file Geologic Map 282: scale 1:24,000). New Mexico Bureau of Geology and Mineral Resources.

CROSS-SECTION OF THE RADIUM SPRINGS GEOTHERMAL SYSTEM

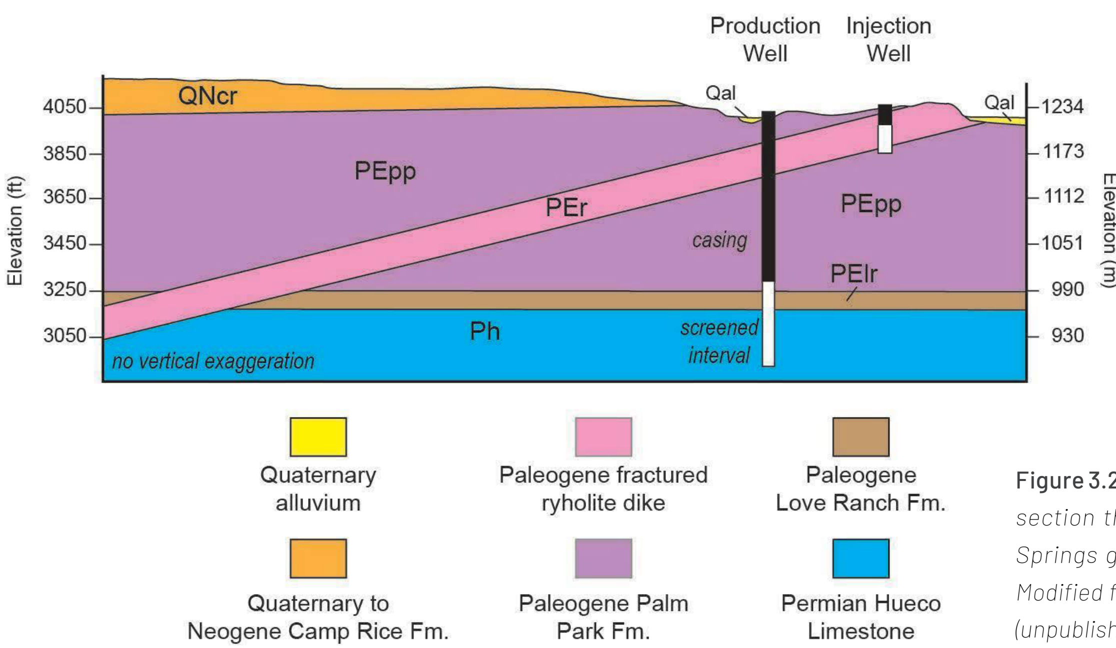


Figure 3.24. *Schematic cross-section through the Radium Springs geothermal system. Modified from James Witcher (unpublished).*

The Radium Springs system is at the very northern edge of the Mesilla Basin; this system is used to heat the greenhouse at the Masson Radium Springs Farm. The reservoir for this system is in fractured Permian limestone (**Figure 3.24**). The limestone is overlain by less than 30 meters of sand and gravel of the Paleocene to Eocene Love Ranch Formation and more than 216 meters of Eocene Palm Park Formation (**Figure 3.24**).[113] The Palm Park Formation in this area is a low-permeability andesitic lahar that acts as an aquitard. The aforementioned rock units at Radium Springs are cut by a rhyolite dike that is intensely fractured. Geothermal fluids in the limestone move to the surface through the fractured dike to form the natural springs in this area. The 30 meter to 46 meter dike is a hydrogeologic window through the Palm Park aquitard. The production well that heats the greenhouse is 244 meters deep and has a discharge temperature of 92.7°C (198.9°F).[114]

Geologic structures in the East Potrillo Mountains include Laramide thrust, low-angle normal and high-angle normal faults.[115] An oil well (Pure 1 Fed H) was drilled in 1962 about halfway along the eastern side of the range. The well was spudded in middle Permian limestone and penetrated a normal Permian, Mississippian, Devonian, and Silurian section to a depth of 1,343 meters. A repeat of the Permian and Mississippian section was then encountered, suggesting the presence of a fault at this depth. Marble and Cenozoic diorite were penetrated between 1902 and the total depth at 2,239 meters. The bottom-hole temperature for this well is 70°C (158°F). The undeveloped geothermal system along the east side of the southern East Potrillo Mountains is located in fractured carbonate rocks along the East Potrillo fault zone, a major basin boundary fault in the southwest part of the basin. Snyder used temperature-depth data from more than 140 geothermal industry shallow- and intermediate-depth wells to identify a heat flow anomaly within the carbonates that extends from the south end of the Eastern Potrillo Mountains southward toward the Mexican border.[116] Thermal logs from three wells that are close together at the south end of the East Potrillo uplift indicate strong upflow of fluids in the carbonates along the fault.[117,118] A possible reservoir in the form of thick eolian deposits may occur in the early Santa Fe Group deposits east of the East Potrillo fault zone.[119] Pepin and colleagues also note a single well to the north of the East Potrillo Mountains that indicates upflow along the projected trend of the East Potrillo fault zone;[120] elevated temperatures were noted to the northeast, suggesting the presence of an outflow plume.

Lightning Dock

The Lightning Dock known geothermal resource area was established in 1974. In 1995, Damon Seawright developed a geothermally heated aquaculture facility (AmeriCulture Inc., **Figure 3.4**). Americulture currently provides tilapia fry to aquaculture facilities across the USA. Since the initial discovery in 1948, a variety of greenhouses have utilized the resource, and a 15 MWe binary electrical plant was built by Cyrq Energy in 2013. Today, a step-out well drilled by Zanskar in late 2024 produces 163°C (325°F) water from more than 2,287 meters with a flow rate of roughly 19,000 liters per minute. Zanskar believes this new well can power the existing power plant without use of the earlier wells.[121]

The origin of the hot water is a matter of some discussion. Elston and colleagues proposed that the hot water was associated with upwelling along a Quaternary fault, which might coincide with a ring fracture of the Muir caldera preserved in the Pyramid Mountains to the east of Lightning Dock.[122] Geophysical data defined the extent of thermal anomaly, which overlies a buried horst.[123,124] In addition, the geophysical data shows that the mapped late Pleistocene fault has very little displacement and that larger faults delineate a graben between the thermal anomaly and the Pyramid Mountains to the east. Witcher used volcanic and sedimentary stratigraphic data from three wells in the Lightning Dock region to document Jurassic rift extension, Laramide compression, caldera collapse, and basin and range extension, which caused intense fracturing of rocks in this area, creating the wide fault zone discovered by Zanskar.[125]

Petroleum Basins

Bottom-hole temperatures and circulation information from geophysical well logs measured in the New Mexico portions of the Raton, San Juan, and Delaware Basins were compiled in the New Mexico Bureau of Geology and Mineral Resources Geothermal Database by Shari Kelley and her students starting in 2010. Colorado data for the San Juan Basin were sourced from Dixon.[126] Morgan compiled bottom-hole temperature data for the Colorado portion of the Raton Basin.[127] More than 800 bottom-hole temperature records were integrated

PETROLEUM WELLS WITH BOTTOM-HOLE TEMPERATURE DATA

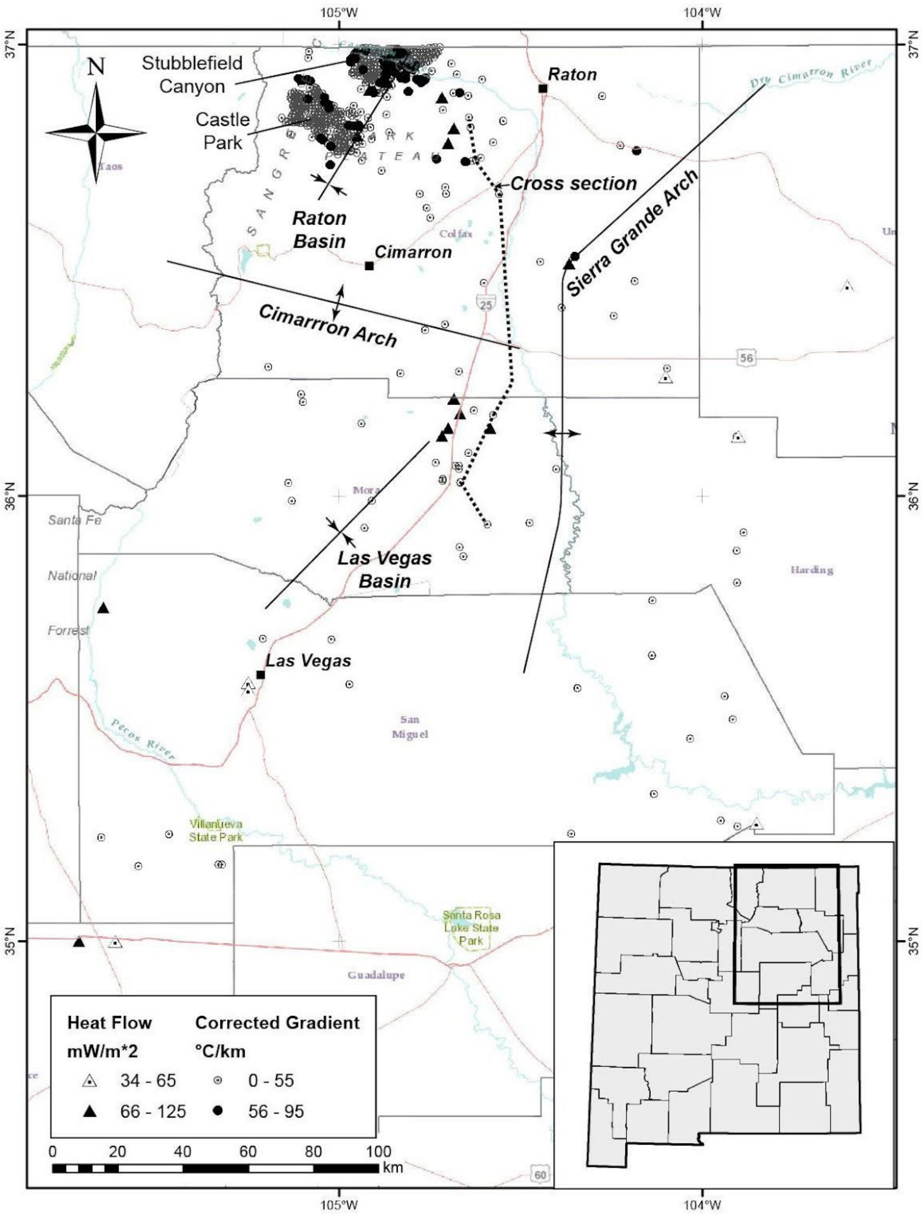


Figure 3.25. *Location of petroleum wells with bottom-hole temperature data (circles) and heat flow (triangle) data measured by Reiter and colleagues, and Edwards and colleagues in and near the Raton and Las Vegas Basins in northeastern New Mexico. The location of the cross-section in Figure 3.23 and Pennsylvanian and Laramide structural features are also shown.* Sources: Reiter, M., Edwards, C. L., Hartman, H., & Weidman, C. (1975). Terrestrial heat flow along the Rio Grande rift, New Mexico and southern Colorado. *GSA Bulletin, 86*(6), 811–818. https://doi.org/10.1130/0016-7606(1975)86<811:THFATR>2.0.CO;2; Edwards, C. L., Reiter, M., Shearer, C., & Young, W. (1978). Terrestrial heat flow and crustal radioactivity in northeastern New Mexico and southeastern Colorado. *GSA Bulletin, 89*(9), 1341–1350. https://doi.org/10.1130/0016-7606(1978)89%3C1341:THFACR%3E2.0.CO;2

in this analysis to assess geothermal potential within the Delaware Basin in New Mexico. Kelley described the challenges of determining an accurate correction for the bottom-hole temperature data in the Raton Basin in great detail.[128] Similar challenges were encountered when trying to correct bottom-hole temperature data for the San Juan and Delaware Basins. In the end, we decided to evaluate uncorrected bottom-hole temperature measurements for the San Juan and Delaware Basins and used corrected values in the Raton Basin. Once interesting anomalies are identified, we will refine our corrections for each anomalous area in these basins. The method for determining the geothermal gradient is outlined in Kelley.[129]

Raton Basin and Las Vegas Basin

The locations of the wells in the Raton and Las Vegas basins analyzed by Kelley are shown in **Figures 3.25** and **3.26.**[130] Kelley developed a bottom-hole temperature correction for the Raton Basin.[131] Both the map and the cross-section in the figures highlight the fact that

CROSS-SECTION THROUGH NORTHEASTERN NEW MEXICO

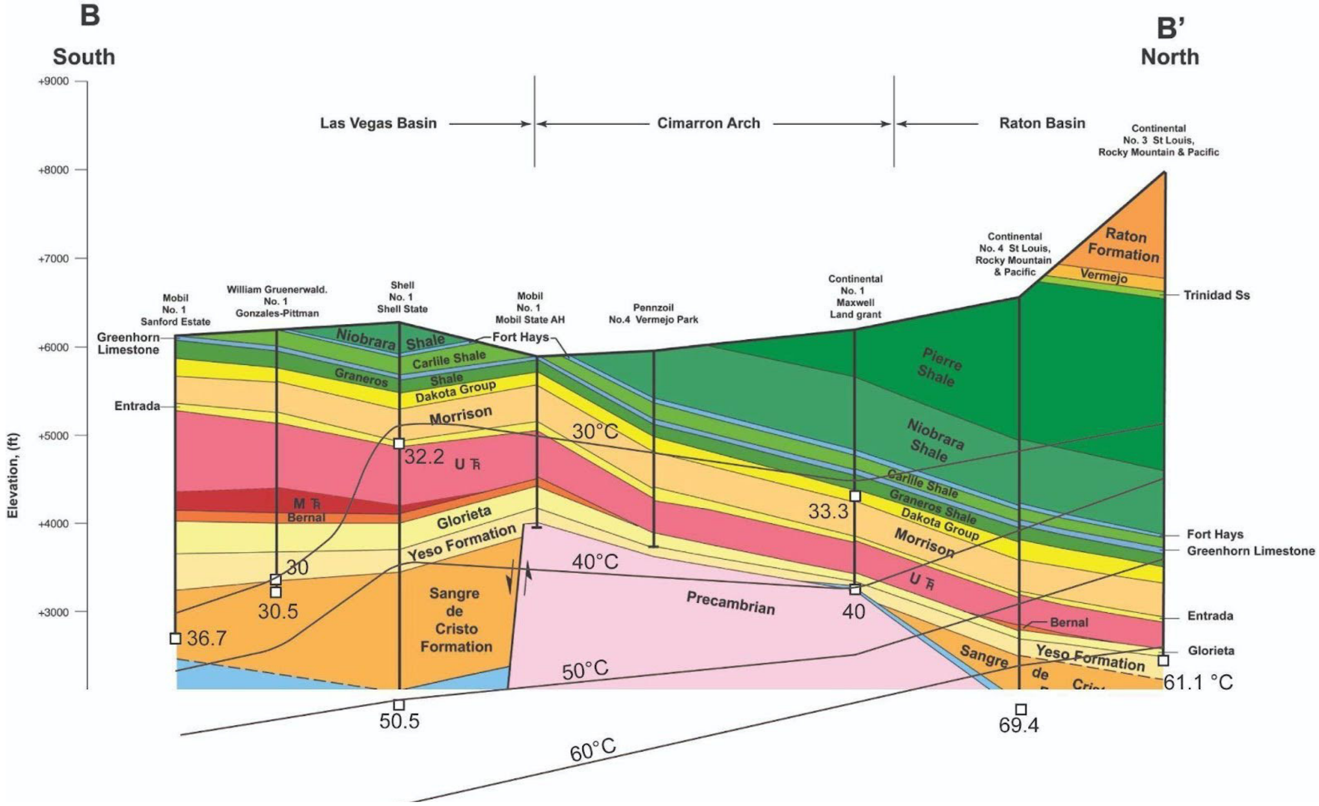


Figure 3.26. *South to north cross-section through northeastern New Mexico modified from Broadhead. Dashed lines are isotherms based on bottom-hole temperature data. Elevated geothermal gradients coincide with preserved Pierre Shale, which has a low thermal conductivity. UTr = upper Triassic strata. MTr = middle Triassic strata. Source:* Broadhead, R. F. (2008). *The natural gas potential of north-central New Mexico: Colfax, Mora, and Taos Counties* (Open-file Report 510). New Mexico Bureau of Geology and Mineral Resources. http://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=510

geothermal gradients and the subsurface temperatures are higher in the Raton Basin near the Colorado–New Mexico state line. Regional-scale gradients using corrected bottom-hole temperatures from drill holes deeper than 1 kilometer are 31.2°C ± 2.6°C/kilometer (88.2°F ± 36.7°F/kilometer) for the Las Vegas Basin and 46.1°C ±9.6°C/km (115.0°F ± 49.3°F/kilometer) for the Raton Basin with surface intercept values of 10.8°C (51.4°F) and 6.3°C (43.3°F), respectively. The highest measured bottom-hole temperature in northeastern New Mexico is 135°C (275°F), corrected to 150°C (302°F) at 2,156 meters.

Kelley concluded that the thermal structure of the Raton Basin is controlled in part by the thermal conductivity structure of the basin.[132] The presence of the thick low-thermal-conductivity Pierre Shale section in the northern part of the basin causes the subsurface temperatures to be higher compared with the southern part of the basin, where the Pierre Shale has been removed by erosion. Although the 150°C (302°F) isotherm is at a depth of between 2.6 and 2.7 kilometers below Stubblefield Canyon (**Figure 3.25**), low fluid-production rates in the underpressured Entrada and Glorieta Sandstones may preclude economic development of geothermal resources in the Raton Basin.

San Juan Basin

Both published heat flow data[133,134] and the industry temperature logs and bottom-hole temperature data analyzed by Kelley[135] record elevated modern subsurface temperatures in the northern part of the basin, consistent with the elevated observed heat flow and the high modern elevation of the San Juan Mountains to the north.[136] **Figure 3.27A** shows the distribution of data used in this analysis of the San Juan Basin. The San Juan Basin

BOTTOM-HOLE TEMPERATURES IN THE SAN JUAN BASIN

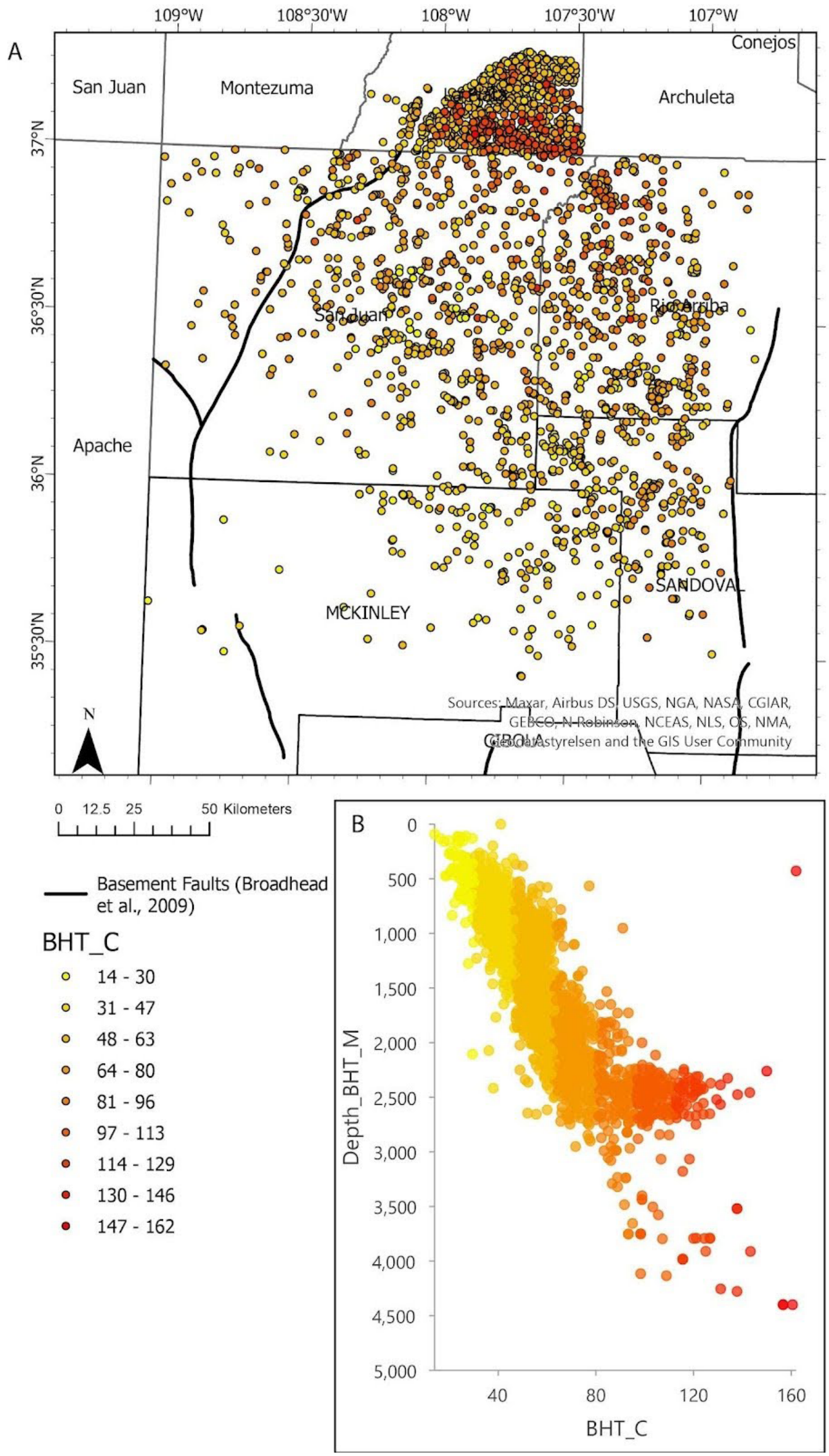
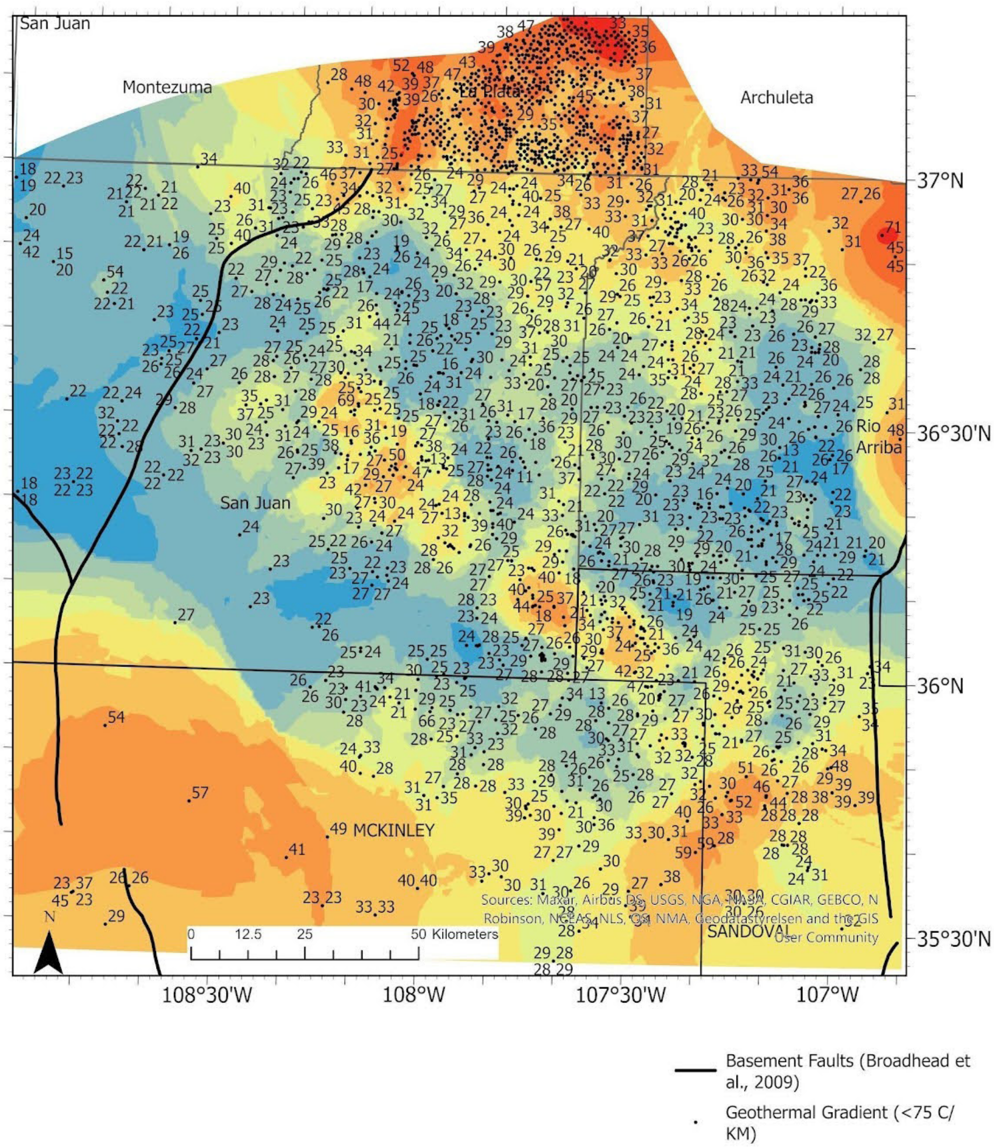


Figure 3.27. *(A) Bottom-hole temperature data locations in the San Juan Basin color scaled by temperature magnitude. Black lines are basement faults from Broadhead et al, (2009). (B) Plot of uncorrected BHT (°C) versus depth (meters), color scale same as A. Bottom-hole temperature data from New Mexico Bureau of Geology and Mineral Resources Subsurface Library and Dixon (2002).* Sources: Broadhead, R. F., Mansell, M., & Jones, G. (2009). *Carbon dioxide in New Mexico: Geologic distribution of natural occurrences* (Open-file Report 514). New Mexico Bureau of Geology and Mineral Resources. https://doi.org/10.58799/OFR-514; New Mexico Bureau of Geology and Mineral Resources. (n.d.). *New Mexico Subsurface Library.* https://geoinfo.nmt.edu/libraries/subsurface/search/; Dixon, J. (2002). *Evaluation of bottom-hole temperatures in the Denver and San Juan Basins of Colorado* (Open-file Report OF-02-15). Colorado Geological Survey, Division of Minerals and Geology, Department of Natural Resources. https://coloradogeologicalsurvey.org/publications/evaluation-bottom-hole-temperatures-denver-san-juan-basins-colorado

bottom-hole temperature data span a depth range of 90 meters to 4,400 meters, with uncorrected temperatures ranging from 14°C to 162°C (57°F–324°F; **Figure 3.27B**, compare with **Figure 3.10**). The mean geothermal gradient, calculated from uncorrected bottom-hole temperatures, for the entire San Juan Basin is 29°C/km (1.6°F/100 ft). Note the higher temperatures at depths of about 2,500 meters on the temperature-depth plot in **Figure 3.27B**; these points are from the warmer northern part of the basin (**Figure 3.28**). The cause of high geothermal gradients in north-central McKinley County (lower-left corner of the map; **Figure 3.28**) is uncertain.

Isotherm mapping was performed using uncorrected bottom-hole temperature data, extracting key temperatures for mapping subsurface grids. Data cleaning for mapping was accomplished by selecting one data point per well, and in the case of multiple bottom-hole temperature measurements per well, the deepest bottom-hole temperature data point was used. In the southwestern portion of the basin, an area with sparse drilling control, two equilibrium temperature logs from the New Mexico Bureau of Geology and Mineral Resources (2024) subsurface library were projected using their calculated gradient. The 90°C (194°F) isotherm was chosen

GEOTHERMAL GRADIENT IN THE SAN JUAN BASIN



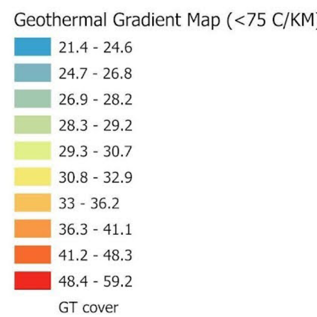


Figure 3.28. *Map of uncorrected geothermal gradient (°C/kilometer) in the San Juan Basin. Spurious geothermal gradients greater than 75°C (167°F)/kilometer have been excluded. The Bayesian kriging method was employed to create a grid, which considers the mean of the values at coincident locations. Black lines are basement faults.* Source: Broadhead, R. F., Mansell, M., & Jones, G. (2009). *Carbon dioxide in New Mexico: Geologic distribution of natural occurrences* (Open-file Report 514). New Mexico Bureau of Geology and Mineral Resources. https://doi.org/10.58799/OFR-514

ISOTHERM MAP FOR THE SAN JUAN BASIN

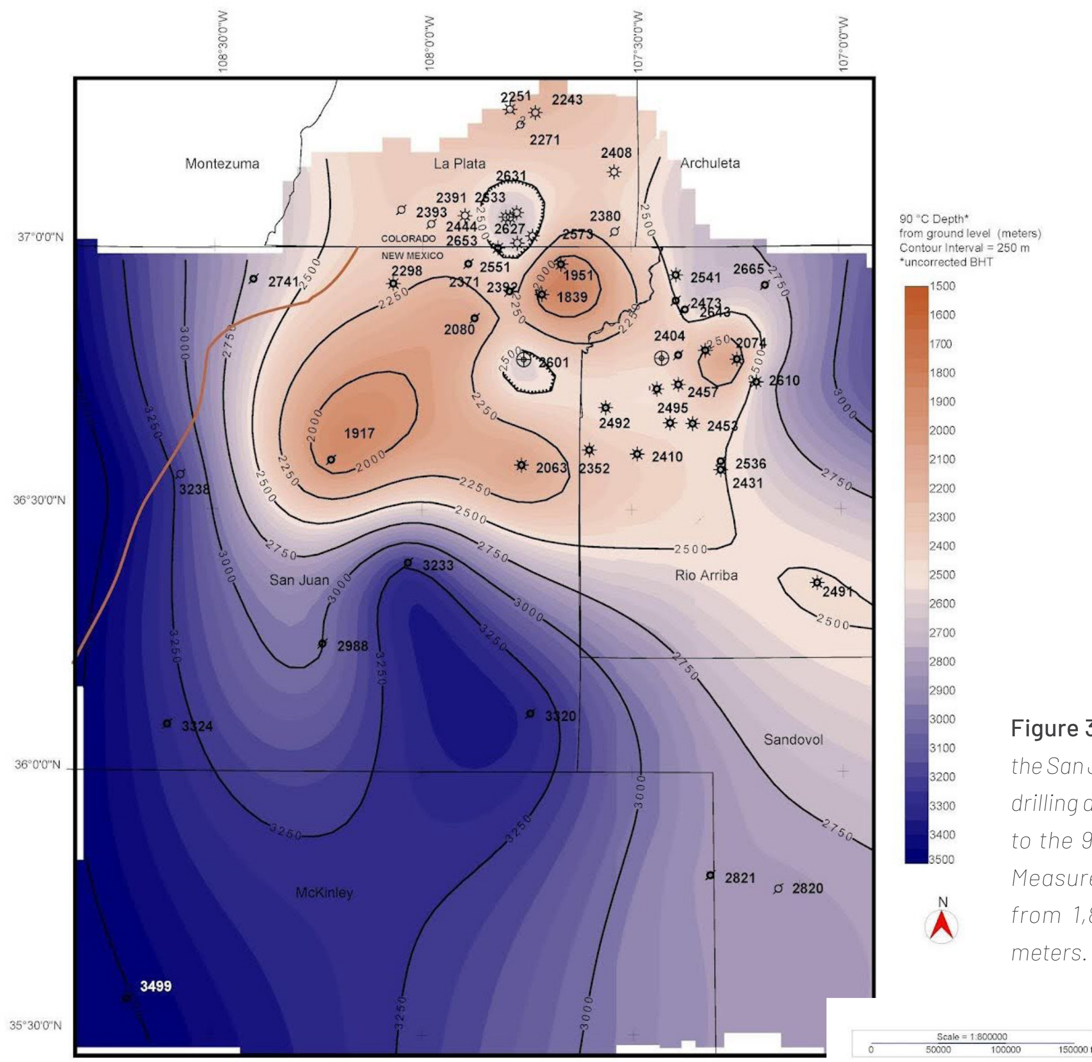


Figure 3.29. *Isotherm map for the San Juan Basin showing the drilling depth from ground level to the 90°C (194°F) isotherm. Measured drilling depths are from 1,890 meters to 3,500 meters. Source: Luke Martin.*

as a modeling decision point because a minimum of 90°C (194°F) is required for binary power plant production[137] where a working fluid with a boiling point lower than water is utilized. Many other cultural, environmental, reservoir, and economic parameters affect the viability of a geothermal project. Here, we present a depth-to-90°C (194°F) isotherm map, subtracting the ground level to 90°C (194°F) isotherm (**Figure 3.29**).

In summary, the San Juan Basin is a conductive basin with an approximately 29°C (84°F)/kilometer (1.6 °F/100 ft) average geothermal gradient. The basin has undergone tectonic influences that contribute to the fracture density of the basin. The northern portion of the basin contains the highest geothermal gradients and a greater density of higher bottom-hole temperatures, and it is the deepest portion structurally. Mapping of uncorrected bottom-hole temperature isotherms indicates that the lowest temperature threshold for binary geothermal power generation (90°C or 194°F) may be found at depths from 1,890 meters to 3,500 meters below ground level across the basin.

Delaware Basin

The Delaware Basin is the deep-water portion of the larger Permian Basin in southeastern New Mexico and west Texas (**Figure 3.30**). During the Late Cretaceous-Paleogene, the Permian Basin was affected by the Laramide orogeny. The few compressional and transpressional structures

CROSS-SECTION THROUGH THE PERMIAN BASIN

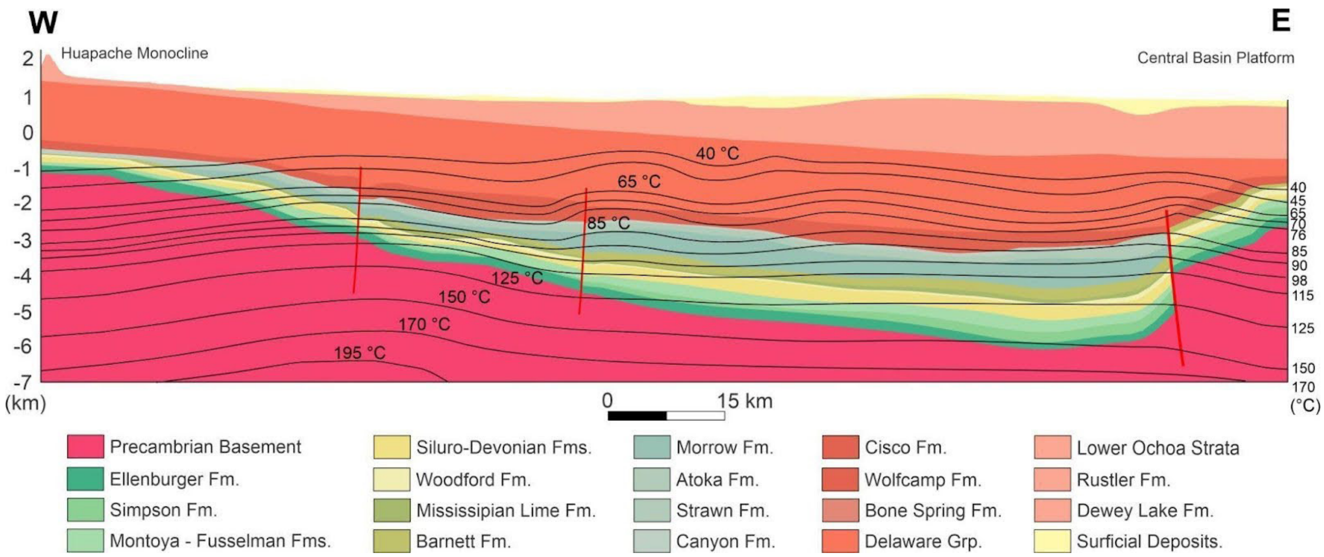


Figure 3.30. *Cross-section through the Permian Basin, New Mexico. The line of section is shown in Figure 3.31.* Sources: Lavery, D., Reyes Correa, M., Baca, A., Martin, L., & Attia, S. (2024). *3D geologic framework of the Delaware Basin, Eddy and Lea Counties, New Mexico* (Open-file Geologic Map 318). New Mexico Bureau of Geology and Mineral Resources. https://doi.org/10.58799/OF-GM-318; Aljubran, M. J., & Horne, R. N. (2024). Thermal Earth model for the conterminous United States using an interpolative physics-informed graph neural network. *Geothermal Energy, 12*(1), 25. https://doi.org/10.1186/s40517-024-00304-7

are located on the west side of the Permian Basin. The Huapache Monocline located to the west of the Delaware Basin in New Mexico is identified as a Laramide structure, and other structures on this side of the basin are the folds located at the north shelf and have been interpreted as inherited reactivated Precambrian-Paleozoic structures (see the present basin geometry in **Figure 3.30**)

More than 800 bottom-hole temperature records were integrated in this analysis to assess geothermal potential within the Delaware Basin in New Mexico (**Figures 3.10 and 3.31**). Bottom-hole temperatures in the Delaware Basin range from 23°C (73°F) to approximately 139°C, or 282°F (**Figure 3.10**), with data collected from depths between 116 meters and 6,984 meters. A total of 192 boreholes have bottom-hole temperatures values exceeding 100°C (212°F); the higher temperatures are located on the western side of the Delaware Basin near the border with the Guadalupe Mountains. The highest bottom-hole temperature recorded in the basin is 138.89°C (282.00°F), measured at 6,984 meters (22,913 feet). This value was obtained in the southern part of the Delaware Basin depocenter in New Mexico and is associated with the Precambrian basement. The distribution of bottom-hole temperatures in the Delaware Basin is not uniform; it spans from the northwest to the southeast of the basin in New Mexico (**Figure 3.32a**). In terms of depth, temperature values exceeding 100°C (212°F) range from 8,000 feet to 22,000 feet, with the shallower values concentrated in the northwest side of the basin (**Figure 3.32b**).

In summary, **Figure 3.5A** in the introduction and **Figure 3.32b** both indicate that temperatures needed for power production lie at great depths (about 7 kilometers) in the Permian Basin.

CONCLUDING REMARKS

As noted in the introduction to this chapter, a tremendous amount of geothermal exploration and research was done in New Mexico during the 1970s and 1980s, with most exploration wells drilled to depths of less than 200 meters. Despite these efforts, very little is known about the deep thermal and geological structure of the rift basins, particularly south of the Albuquerque Basin, because few deep wells were drilled during the early exploration

TEMPERATURE PREDICTION IN THE DELAWARE BASIN

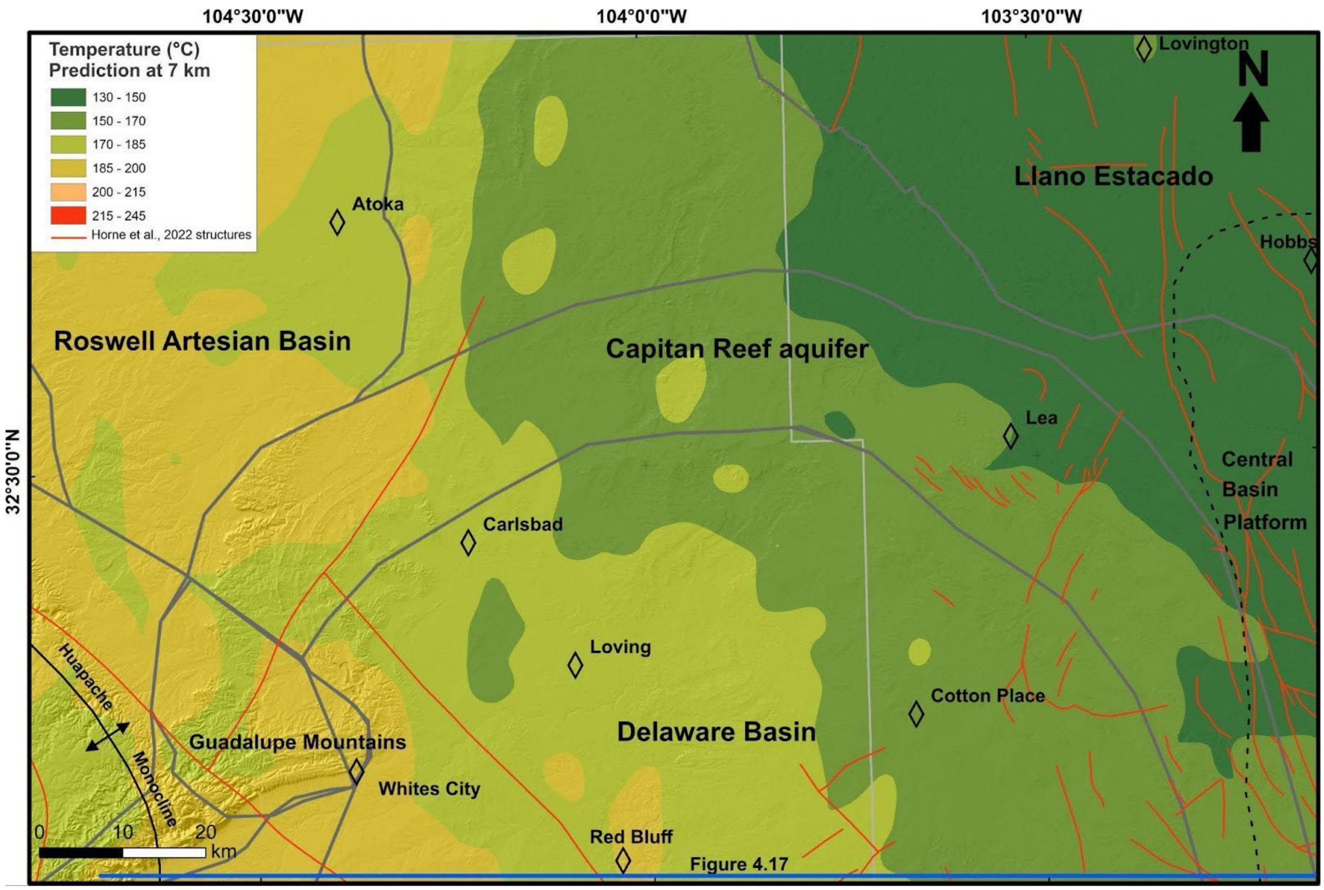


Figure 3.31. *Temperature prediction at 7 kilometers in the Delaware Basin. The blue line at the bottom of the map is the location of the cross section in Figure 4.16. White line is the boundary between Lea and Eddy counties in New Mexico. Sources:* Aljubran, M. J., & Horne, R. N. (2024). Thermal Earth model for the conterminous United States using an interpolative physics-informed graph neural network. *Geothermal Energy, 12*(1), 25. https://doi.org/10.1186/s40517-024-00304-7; Horne, E. A., Hennings, P. H., Smye, K. M., Staniewicz, S., Chen, J., & Savvaidis, A. (2022). Structural characteristics of shallow faults in the Delaware Basin. *Interpretation, 10*(4), T807–T835. https://doi.org/10.1190/INT-2022-0005.1

efforts. **Figure 3.33** shows that temperatures above 150°C (302°F) have been measured in a few wildcat oil wells in the southern part of the state and in oil wells drilled by Shell Oil Company during the 1970s in the Albuquerque Basin. Understanding the deep subsurface is key to successful siting of future next-generation projects. This gap in knowledge about the deep subsurface can be addressed by collecting new geophysical data (e.g., via SkyTEM, magnetotellurics, passive seismic), reprocessing old seismic lines, and ultimately drilling deep wells.

During earlier geothermal exploration efforts in New Mexico, an important observation was noted by Witcher and colleagues: Much of southwestern and west-central New Mexico was impacted by an episode of andesitic volcanism during the Eocene that deposited low-permeability debris flows that serve as aquitards within regional-scale hydrologic flow systems.[138] In places, highly fractured Proterozoic rocks that core Laramide highlands were buried beneath the debris flows, thus masking the presence of possible geothermal reservoirs in fractured basement rocks. Witcher and colleagues recognized that intrusions or faults that cut through the debris flows can act as conduits that bring hot water to the surface as hot springs (e.g., **Figures 3.12** and **3.24**).[139] These breaches through regional aquitards are called *hydrogeologic windows*. These authors created a subcrop map (**Figure 3.13**) that may serve as a useful tool for guiding future exploration efforts.

DISTRIBUTION OF BOTTOM-HOLE TEMPERATURE VALUES IN THE DELAWARE BASIN

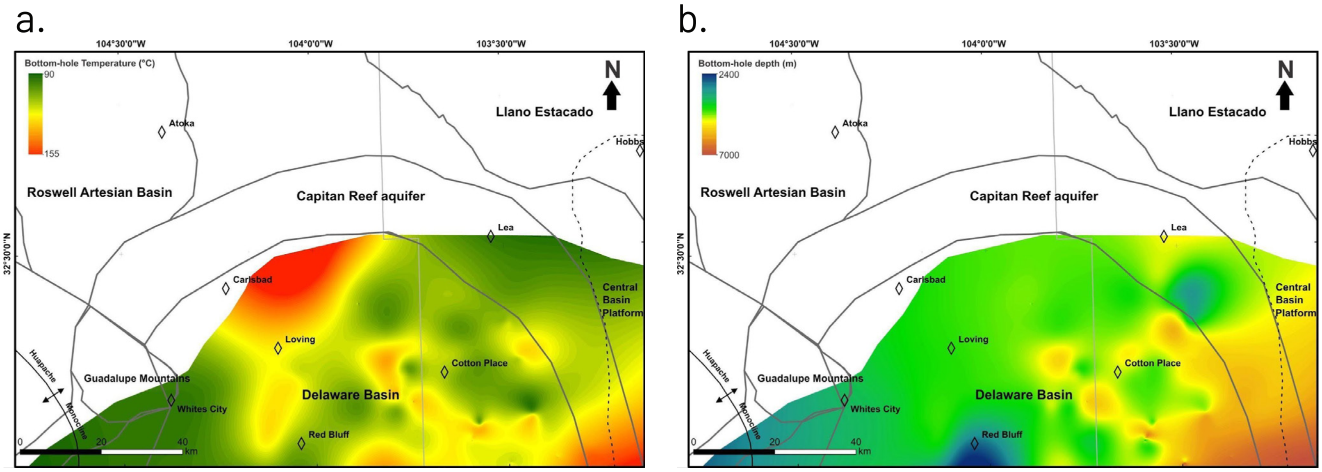


Figure 3.32. *(a) Map showing the distribution of bottom-hole temperature values greater than 91°C (196°F) in the New Mexico portion of the Delaware Basin. (b) Map depicting the depths at which bottom hole temperatures values exceed 100°C (212°F) within the Delaware Basin. Source: Martin Reyes.*

HOTTEST OIL WELLS IN NEW MEXICO

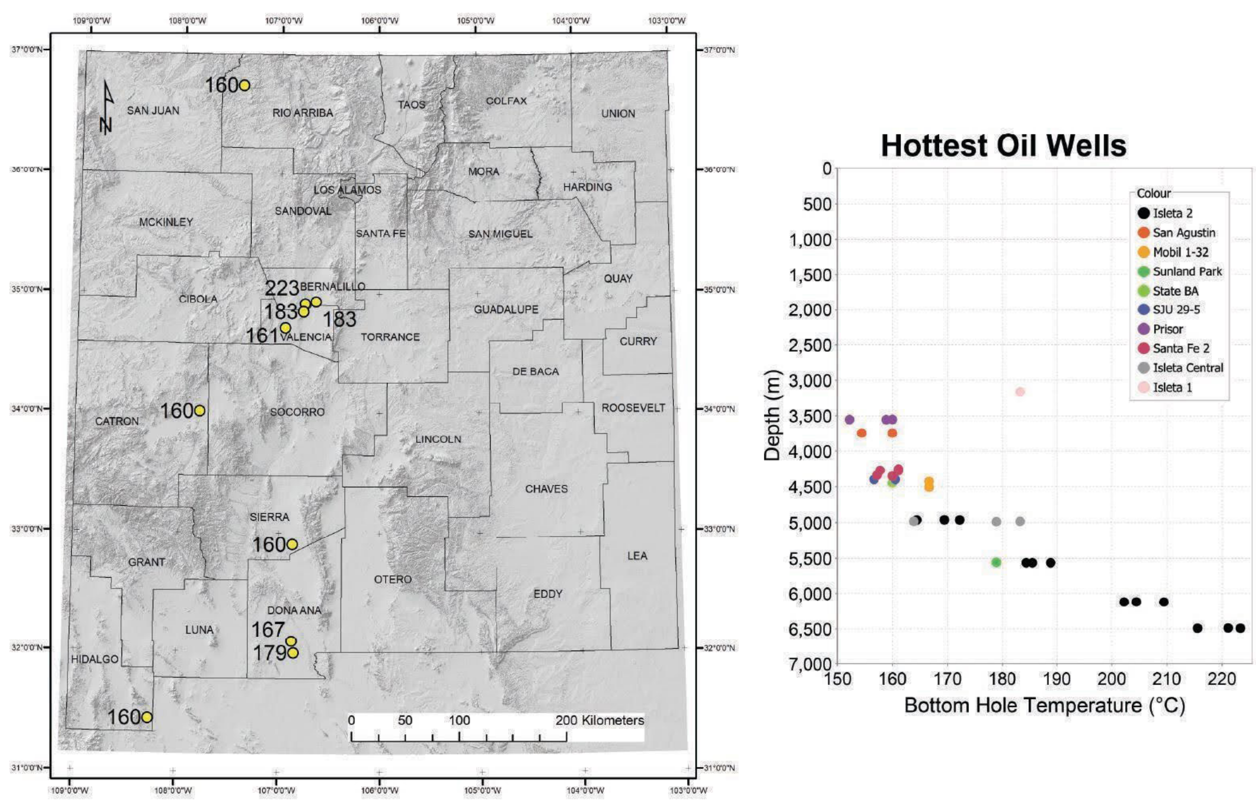


Figure 3.33. *Map and plot depicting examples of some of the hottest bottom-hole temperature data from deep oil wells across New Mexico. The bottom-hole temperature data points are uncorrected because there are few wells available in the vicinity of these sites to formulate a proper correction. Source: Shari Kelley.*

Expanding the Scope: Next-Generation Geothermal Opportunities

Veit Matt and Trent McFadyen, Project InnerSpace

New Mexico holds significant potential for the development of next-generation geothermal technologies in the state's sedimentary basins and deep subsurface for a variety of use cases, including heating and cooling for the built environment, industrial process heat, and the production of electricity.

New Mexico is one of only seven U.S. states that creates electricity from conventional hydrothermal systems—and as readers can see in the previous pages of this chapter, the state has plenty of subsurface resources it can use to develop much more conventional hydrothermal. Add to that: many portions of the state have substantial potential for conductive geothermal systems—also known as *next-generation geothermal*.

As explained in Chapter 1, "Geothermal 101," next-generation geothermal uses oil and gas technologies—horizontal drilling and/or hydraulic fracturing—to tap into subsurface heat even where there is no (or very slow) natural fluid flow as there is in hydrothermal geothermal and deep groundwater systems. By drilling into these hot dry rocks or hot (sedimentary or naturally fractured rock) aquifers, developers can enable the spread of a new era of geothermal projects across New Mexico.

The maps and text in this section complement the information in the previous pages, which is largely an examination of New Mexico's classic hydrothermal systems. By expanding the scope to look at heat extracted from all types of geothermal systems, we get a more comprehensive picture of New Mexico's geothermal potential. This section serves as a guide for readers without extensive geothermal

ESTIMATED SUBSURFACE TEMPERATURE AT 1 KM: 110°F (43°C) OR COLDER

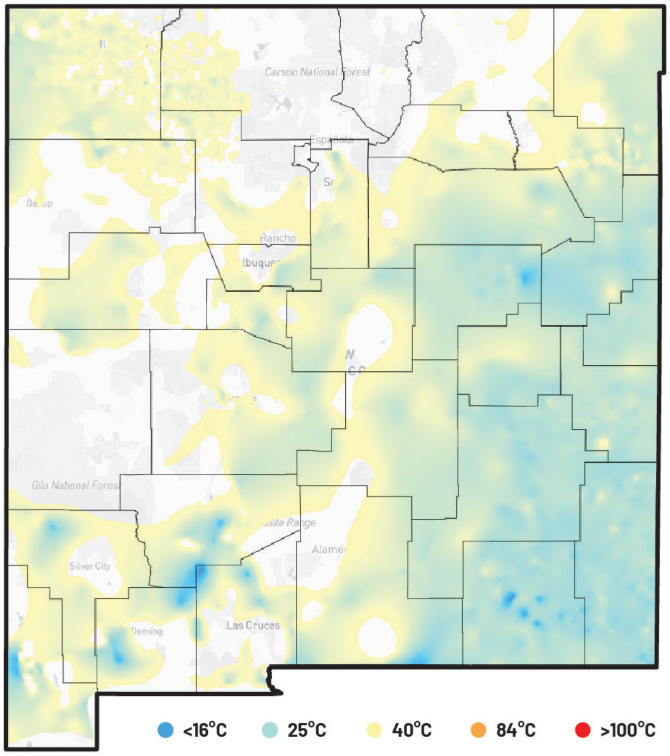


Figure 3.34. Based on available uncorrected well temperature data from both convective hydrothermal and conductive geothermal systems. The legend provides reference colors on a sliding scale of gradients. Source: Project InnerSpace (n.d.). GeoMap.

Disclaimer: Although the maps and analyses in this chapter highlight areas of geothermal potential, additional site-specific analyses—including economic and engineering and rock hydraulic property, fluid pressure, fluid composition, and fluid production rate analyses—are required to identify viable potential uses and drill-ready prospects.

ESTIMATED SUBSURFACE TEMPERATURE AT 1 KM: HOTTER THAN 110°F (43°C)

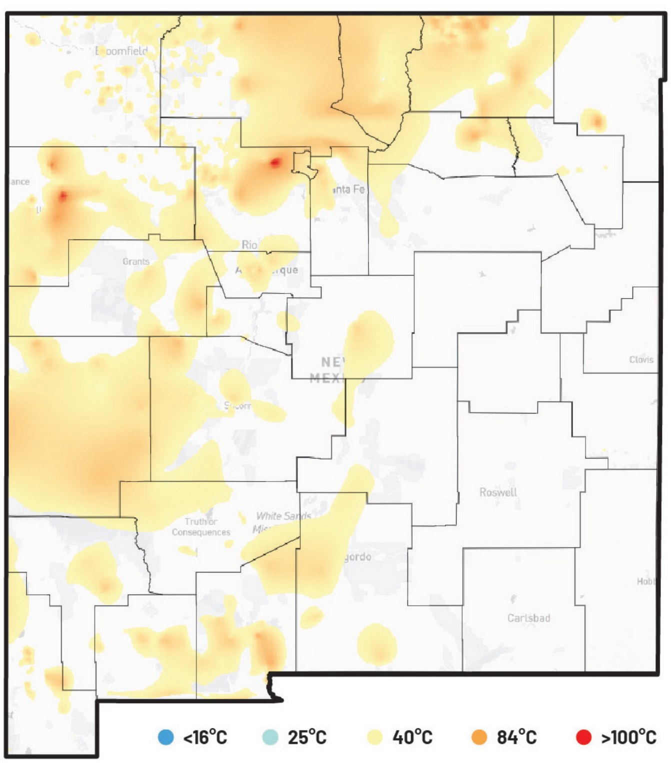


Figure 3.35. Based on available uncorrected well temperature data from both convective hydrothermal and conductive geothermal systems. The legend provides reference colors on a sliding scale of gradients. Source: Project InnerSpace, GeoMap

Note: While Figures 3.34 and 3.35 use red and blue shading, with red indicating hotter temperatures at 1 kilometer, red in Figures 3.36 and 3.37 represents areas requiring greater depth to reach the specified temperatures. Green shading shows shallower, more favorable geothermal locations (see legends for the figures).

expertise and provides additional analysis of New Mexico's subsurface. It also highlights the next-generation geothermal potential in the state's sedimentary basins and deep subsurface, with summary temperature-depth maps. Finally, it aims to help identify the lowest-hanging fruit: the geothermal applications that can most easily and most economically be developed.

The analysis uses data from Project InnerSpace's open-access GeoMap tool, which provides essential data and analytics for assessing the development potential of next-generation geothermal systems worldwide. Some of those data points and methods differ from the inputs used in the other part of this chapter. Although the maps in this chapter do not denote what kind of system should be developed where, the individual spatial analysis throughout the chapter guides towards potential "sweet spots", where additional investigation and exploration might be warranted.

In summary, New Mexico's observed and modeled subsurface temperatures show potential for geothermal to be used to (1) heat and cool buildings with both ground source heat pumps and thermal energy networks, (2) power industrial processes with direct-use geothermal, and (3) generate geothermal electricity in selected "hot spots." Regardless of what maps and methods are used, the findings remain clear: New Mexico has significant geothermal potential, as it is possible to develop one or another kind of geothermal energy solution in many locations across the entire state. (See **Figure 3.38** for a map of what geothermal applications are likely possible in which parts of the state.)

OVERVIEW OF NEW MEXICO'S SUBSURFACE

Subsurface Temperature

Whether based on directly measured or modeled data, determining the depths required to reach a given subsurface temperature is a fundamental aspect of assessing a location's potential for geothermal energy.

Temperature at 1 Kilometer

Figure 3.34 shows areas of New Mexico colder than about 110°F at a depth of 3,281 feet underground (≤43°C at 1 kilometer). Although deeper drilling can access hotter temperatures, geothermal energy at or below 110°F is limited to heating and cooling buildings and certain low-temperature industrial or agricultural processes.

As a complement to the previous map, **Figure 3.35** shows locations in New Mexico with subsurface temperatures hotter than 110°F at 3,281 feet deep (>43°C at 1 kilometer). These hotter locations, whether classic hydrothermal or next-generation conductive, lend themselves to increasingly high-energy applications, including possible electricity generation under the best circumstances. See Chapter 1, "Geothermal 101," for additional details about the temperatures of various geothermal applications.

Depth to a Given Temperature

While **Figures 3.34 and 3.35** show different temperatures at a constant depth of 1 kilometer, the following figures illustrate how different depths are required to reach a specific temperature. **Figure 3.36** shows the depths needed to reach 212°F (100°C) across New Mexico, a temperature that could power many industrial processes (see Chapter 4, "Geothermal Heating and Cooling," for more information).

Figure 3.37 shows the depths needed to reach 300°F (≈150°C), the general minimum temperature threshold for generating geothermal electricity.[1] Green, yellow, and light orange areas reach 300°F (≈150°C) at shallower than 15,000 feet (≈4,600 meter)—depths regularly reached by U.S. oil and gas drillers.

OVERVIEW OF GEOTHERMAL APPLICATIONS GIVEN AVAILABLE ESTIMATED SUBSURFACE TEMPERATURES

New Mexico can develop geothermal energy in some form across the entire state. As suggested in the previous maps, given the temperatures and depths shown in **Figures 3.34 through 3.37**, certain geothermal

1 Franzmann, D., Heinrichs, H., & Stolten, D. (2025). Global geothermal electricity potentials: A technical, economic, and thermal renewability assessment. Renewable Energy, 250, 123199. https://doi.org/10.1016/j.renene.2025.123199.

ESTIMATED MINIMUM DEPTH TO REACH TEMPERATURES OF 212°F (100°C)

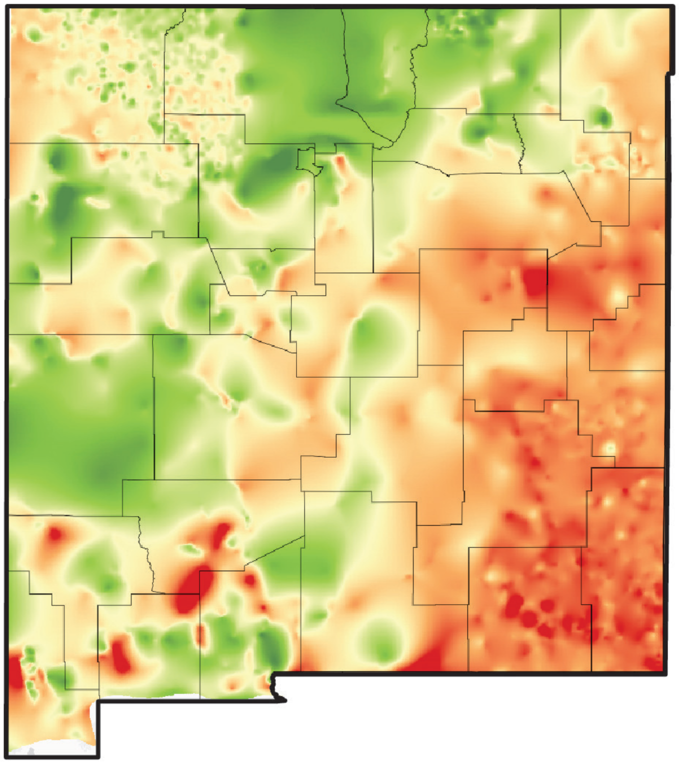


Figure 3.36. Based on available uncorrected well temperature data. The legend provides reference colors on a sliding scale of gradients. Source: Project InnerSpace, GeoMap.

- <1500m
- 1500-2500m
- 2500-3500m
- 3500-5000m
- >8000m

ESTIMATED MINIMUM DEPTH TO REACH TEMPERATURES OF 300°F (150°C)

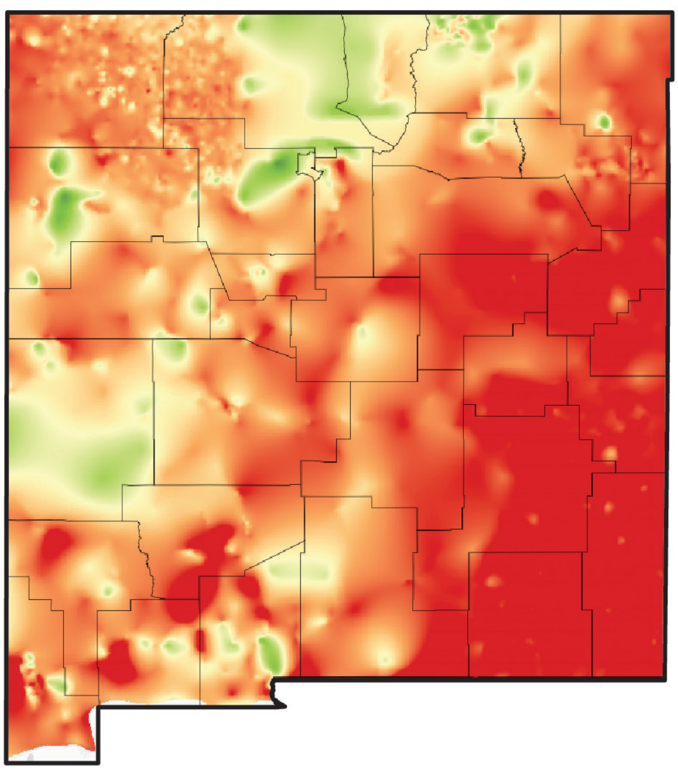
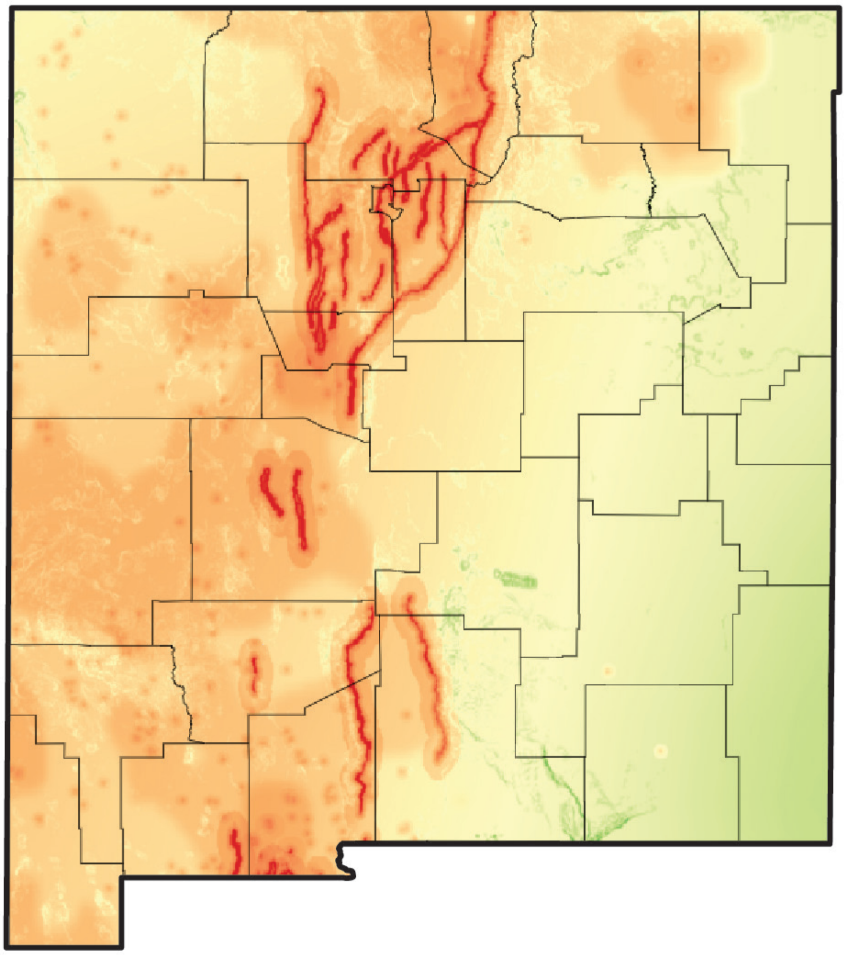


Figure 3.37. Based on available uncorrected well temperature data. The legend provides reference colors on a sliding scale of gradients. Two of the locations with the highest electricity potential—Gila Wilderness in the southwest and the Valles Caldera National Preserve in the north—currently have bans on development. Source: Project InnerSpace. GeoMap.

- <1500m
- 1500-2500m
- 2500-3500m
- 3500-5000m
- >8000m

GEOTHERMAL OPPORTUNITIES IN NEW MEXICO



- Power generation
- Potential power generation
- Direct use and direct heating
- Low-temp industrial heating/cooling
- Geothermal heating/cooling

Figure 3.38. The map combines various factors, including but not limited to: Project InnerSpace's thermal model, conductive geothermal thermal gradient, shear wave velocity, proximity to active faults, and the slope of the topography. Source: GeoMap.

applications are more viable in some parts of New Mexico. **Figure 3.38** uses a weighted overlay analysis to map the favorability of developing different geothermal technologies across the state. Orange into red areas may be suitable for electricity generation. Lime green to yellow areas provide opportunities to use geothermal for low-temperature industrial and agricultural processes and for thermal energy networks. Dark green portions of the map are likely limited to using ground source heat pumps for heating and cooling buildings. Deeper drilling adds costs but might open up more opportunities.

Significant basin-by-basin analysis underlies the entirety of this analysis and can be viewed online in a draft report at https://storage.googleapis.com/project-innerspace-beta/pdf_resources/State-Geothermal-Evaluation-New-Mexico.pdf.

This full analysis reviews the methodologies used to develop the temperature maps in this section and introduces additional favorability-related analyses, such as conductive geothermal gradients, formation depth structures, and general rock-property information. The full scope of analysis is valuable for anyone attempting to further explore for specific geothermal development sites.

NEW MEXICO TEMPERATURE DATA AND CONDUCTIVE GEOTHERMAL GRADIENTS

The Project InnerSpace temperature data used to evaluate the deep next-generation geothermal potential of New Mexico is part of a U.S.-wide data set that has been compiled from numerous publicly available data sets.

INPUTS AND FACTOR CLASS

Inputs			Factor Class					
Used in Global Weighted Overlay Analysis (GeoMap)	**unit**	**weight% of total**	**0**	**1**	**2**	**3**	**4**	**5**
Proximity to Active/Recent Volcanoes	km	10	>10km	10km-5km	5km-3km	3km-2km	2km-1km	<1
Proximity to Thermal Springs	km	10	>5km	5km-3km	3km-2km	2km-1km	1km-0.5km	<0.5
Project InnerSpace Geothermal Gradiant Model	mW/m^2	30	<30	30-50	50-60	60-75	75-100	>100
Proximity to Active/Recent Faulting	km	30	>15km	5km-15km	5km-3km	3km-2km	2km-1km	<1
Average (Vs) in the Lithospheric Mantel Depth Range Between 110k m and 150 km	mW/m^2	20	>4.4189	4.3411-4.4189	4.2633-4.3411	4.1856-4.2633	4.1078-4.1856	<=4.1078

This analysis is based on the deep conductive geothermal gradient calculated based on temperature measurements taken at depths greater than 200 meters (≈650 ft) to minimize erroneous values related to "deep" circulating cold meteoric surface waters. To further improve the geothermal gradient map, erroneous negative values (<0.0°C/Km, <0.0°F/1,000ft) as well as excessively high thermal gradient values possibly associated with classic shallow hydrothermal systems (>100°C/Km, >55°F/1,000ft) have been removed (see **Equation 1**, **Figure 3.39, Figure 3.40**).

Well temperature data is concentrated in areas with current and historic oil and gas exploration and production (for example, the Permian, San Juan, and Raton basins). Data suitable for analyzing next-generation geothermal potential is less reliable outside these areas because most of the publicly available temperature measurements come from water wells. These wells are usually drilled to shallower depths to produce fresh or low-salinity water suitable for consumption and agricultural use (such as irrigation, livestock). In these low-density or no-data areas, detailed geophysical inversion modeling could improve estimated geothermal gradients.

The temperature-depth plot (**Figure 3.39**) shows the difference between the raw measured well temperature data and the provided corrected well temperature data. The difference in average regional thermal gradient between raw and corrected temperature values is highlighted by the "best-fit" linear trend lines. The average geothermal gradient based on the corrected temperatures is about 12% higher than the gradient based on the raw temperature data. Locally, the difference in geothermal gradient estimates can be significantly higher or lower.

To evaluate the geothermal potential of an area, one of the basic parameters to be calculated and mapped is the geothermal gradient, representing the increase of the rock temperature with depth:

Equation 1:

$$\text{Geothermal Gradient} = \frac{\text{Subsurface Temperature} - \text{Surface Temperature}}{\text{Measurement Depth}}$$

The calculation of the regional geothermal gradient maps for New Mexico is based on a smoothed average surface temperature National Oceanic and Atmospheric Administration (NOAA) map and the depth-temperature data collected by Project InnerSpace (**Figure 3.39**).

LOCATION AND DISTRIBUTION OF TEMPERATURE DATA IN NEW MEXICO

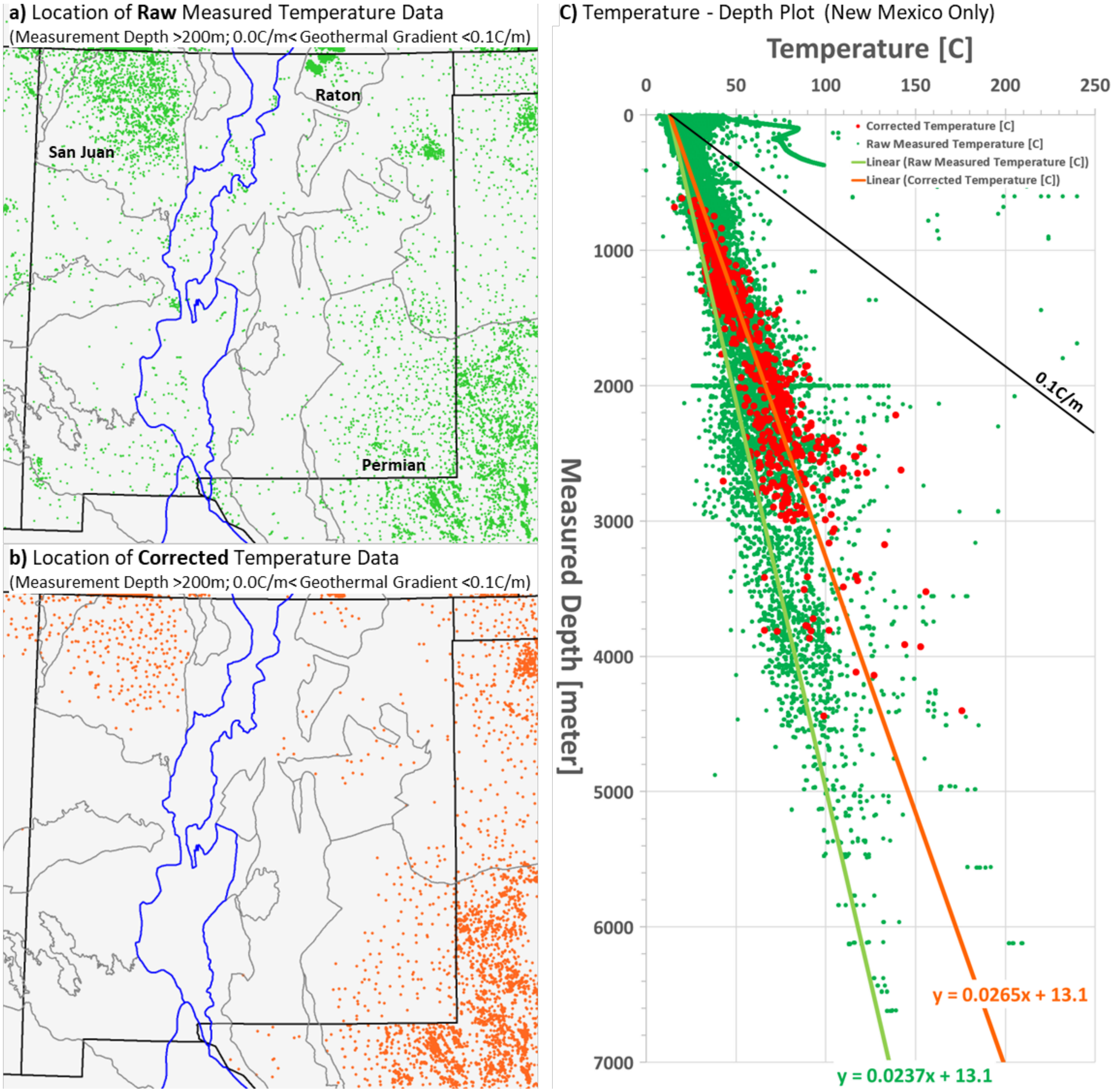


Figure 3.39. Location and distribution of (a) the raw measured temperature-depth and (b) the provided corrected temperature-depth data used. (c) Temperature-depth plot showing the difference between the used raw measured temperature data and the provided corrected temperature data. The equations for the linear best-fit lines are shown at the bottom of the plot area. The blue polygons show key basins along the central Rio Grande rift system. The gray polygons represent the outline of other prominent Paleozoic, Laramide, and Tertiary basins. Source: Project InnerSpace

UNCORRECTED AND CORRECTED DEEP CONDUCTIVE GEOTHERMAL GRADIENT MAPS FOR NEW MEXICO

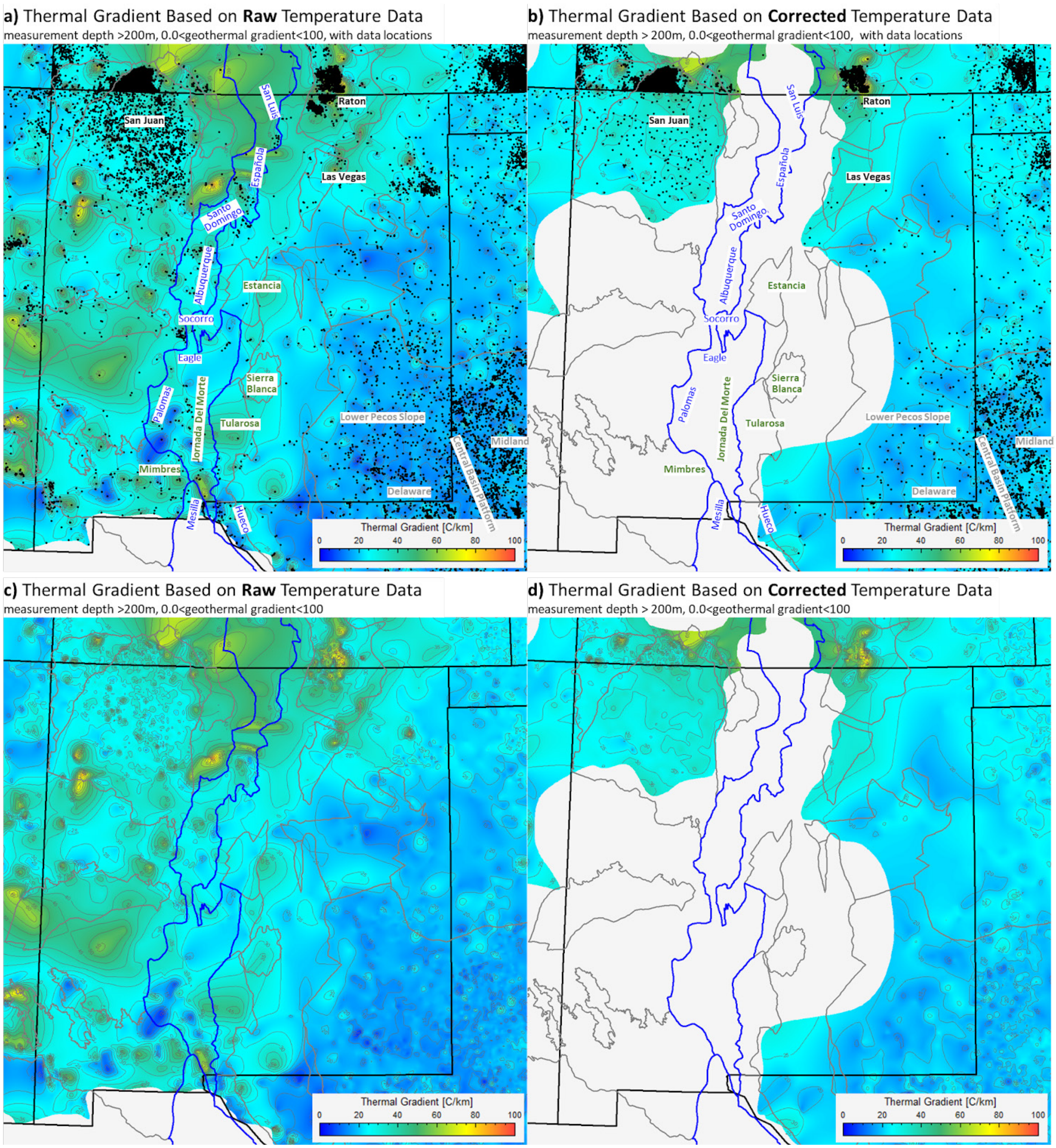


Figure 3.40. (a) and (b) include data control point locations, and (c) and (d) do not include data control point locations. The blue polygons show key basins along the central Rio Grande rift system. The gray polygons represent the outline of other prominent Paleozoic, Laramide, and Tertiary basins. Source: Project InnerSpace

UNCORRECTED AND CORRECTED DEEP CONDUCTIVE GEOTHERMAL GRADIENT MAPS FOR NEW MEXICO

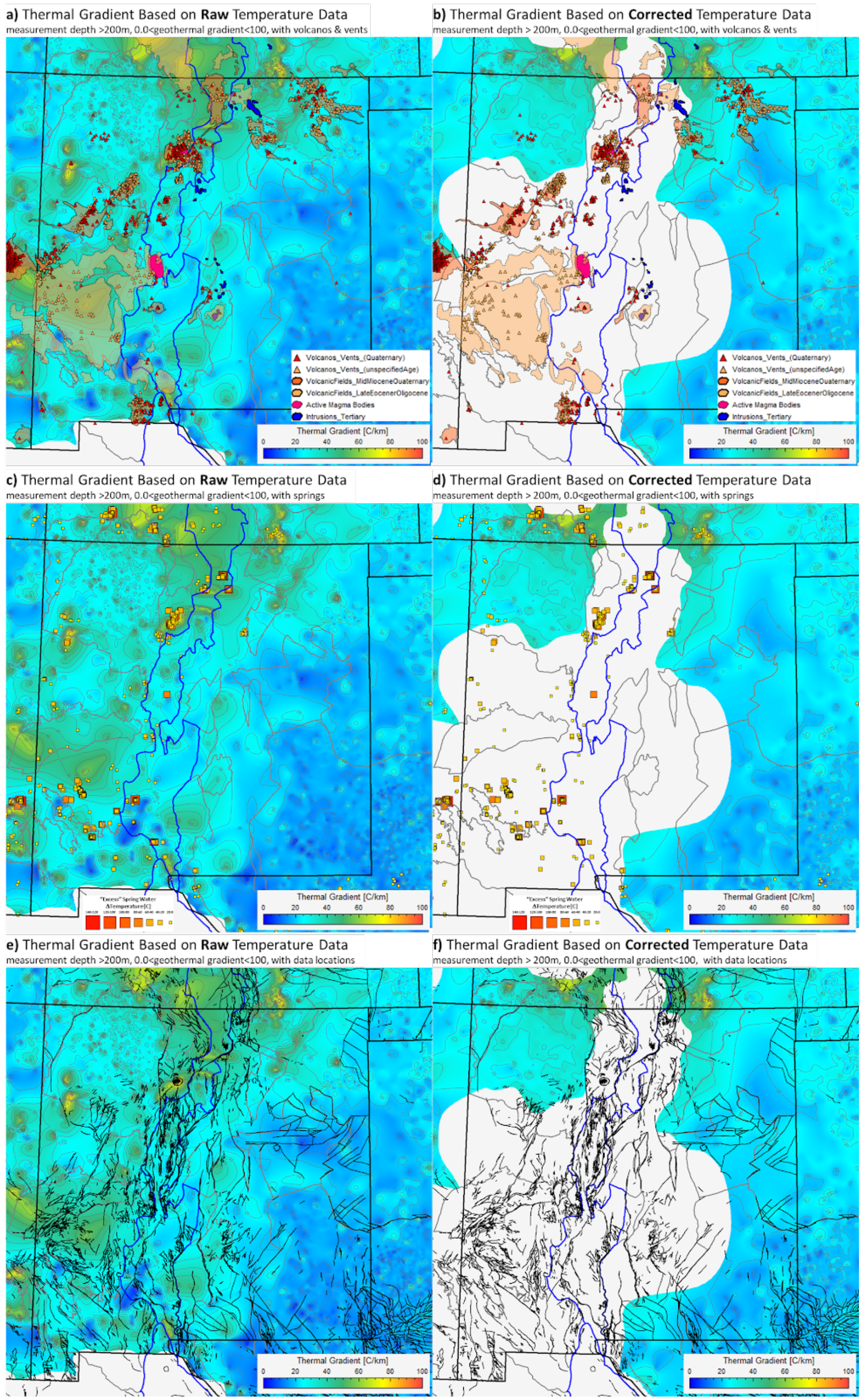


Figure 3.41: (a) and (b) with identified volcanoes and volcanic vents Tertiary and Quaternary in age; (c) and (d) with mapped "hot" springs (the provided Δ temperature represents the spring water temperature in excess of the average surface temperature); (e) and (f) with mapped faults. The blue polygons show key basins along the central Rio Grande rift system. The gray polygons represent the outline of other prominent Paleozoic, Laramide, and Tertiary basins. Sources: Repasch, M., Karlstrom, K., Heizler, M., & Pecha, M. (2017). Birth and evolution of the Rio Grande fluvial system in the past 8 Ma: Progressive downward integration and the influence of tectonics, volcanism, and climate. Earth-Science Reviews, 168, 113–164. https://doi.org/10.1016/j.earscirev.2017.03.003; Sussman, A. J., Lewis, C. J., Mason, S. N., Geissman, J. W., Schultz-Fellenz, E., Oliva-Urcia, B., & Gardner, J. (2011). Paleomagnetism of the Quaternary Bandelier Tuff: Implications for the tectonic evolution of the Española Basin, Rio Grande rift. Lithosphere, 3(5), 328–345. https://doi.org/10.1130/L128.1; Zimmerer, M. J. (2024) A temporal dissection of the late Quaternary volcanism and related hazards with the Rio Grande rift and along the Jemez Lineament of New Mexico, USA. Geosphere, 20(2), 505–546. https://doi.org/10.1130/GES02576.1

ISOTHERMAL DEPTH MAPS

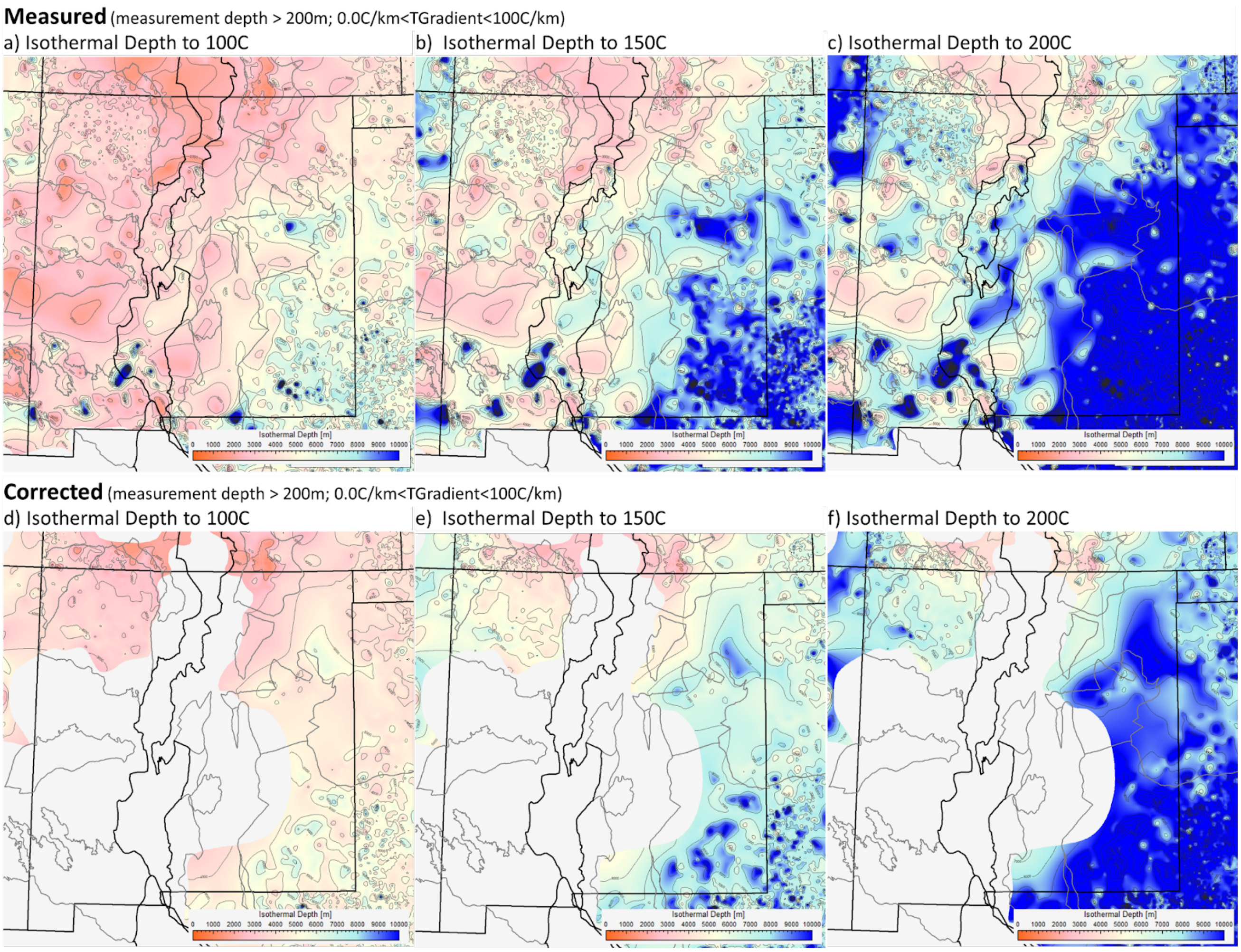


Figure 3.42: Isothermal depth maps based on uncorrected thermal gradients: (a) 100°C; (b) 150°C; and (c) 200°C. Isothermal depth maps based on corrected thermal gradients: (d) 100°C; (e) 150°C; and (f) 200°C. The black polygons show key basins along the central Rio Grande rift system. The gray polygons represent the outline of other prominent Paleozoic, Laramide, and Tertiary basins. Source: Project InnerSpace

ISOPACH AND TEMPERATURE MAPS

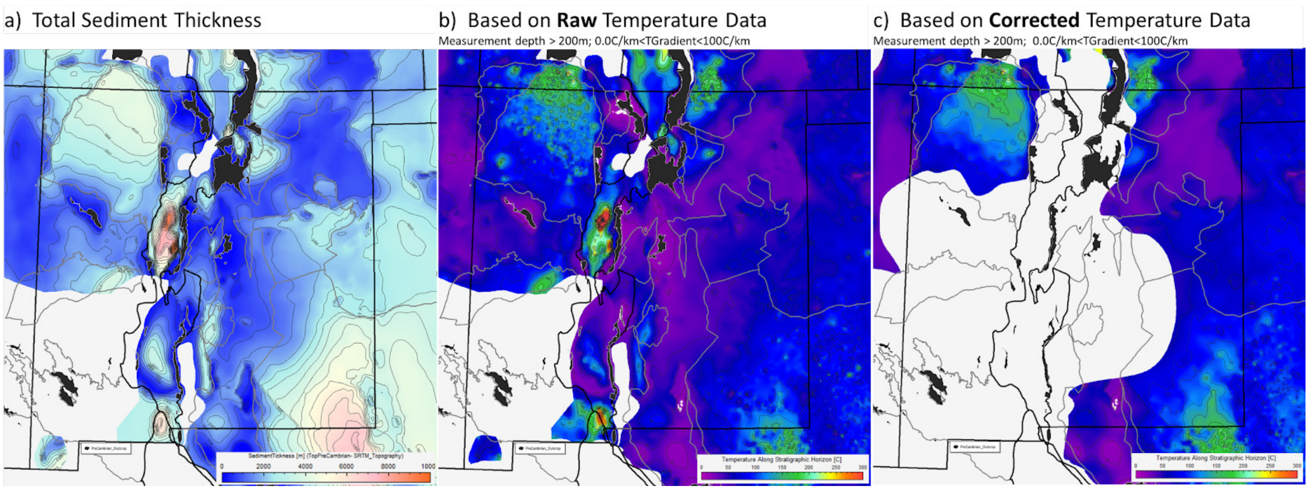


Figure 3.43. (a) Estimated total thickness of sediments (= depth to Precambrian basement); (b) Temperature along the top Precambrian basement based on the uncorrected thermal gradient map; (c) Temperature along the top Precambrian basement based on the corrected thermal gradient map. The black polygons show key basins along the central Rio Grande rift system. The gray polygons represent the outline of other prominent Paleozoic, Laramide, and Tertiary basins. Project InnerSpace..

New Mexico can be subdivided into two main sectors: the "cold" southeast corner of the state vs. the "hot" rest of the state. The "cold" sector is dominated by "old" Paleozoic tectonics and structures and related stratigraphic intervals and sediments, while the "hot" sector has been very active in the Cenozoic, as shown by the extensional tectonics and related Tertiary and Quaternary igneous and volcanic activity (**Figure 3.41a and b**). The high thermal gradient areas align well with the identified volcanoes and volcanic vents, as well as with the identified hot springs (**Figure 3.41c and d**). A mismatch between the igneous, volcanic, and hydrothermal features and the shown geothermal map is most likely related to the lack of available depth-temperature data. These possibly low thermal gradient areas represent areas for future studies and could benefit from additional new deep geothermal test wells.

While a slight correlation between the presence of hot springs and available faults can be seen, correlation between the available mapped faults (**Figures 3.41e** and **f**) and the presented geothermal gradient map is difficult to evaluate; not every existing fault at every scale has been, or can be mapped.

As shown in **Figures 3.36** and **3.37** and again in **Figure 3.42**, in New Mexico's "hot" sector, 100°C can be reached at between 2 kilometers and 3 kilometers, 150°C is reached at between 4 kilometers and 5 kilometers depth, and 200°C requires drilling to between 6 kilometers and 7 kilometers.

Figure 3.43 shows the temperature along the top of the Precambrian basement. By definition, the deeper the basement, the hotter the temperature (i.e., the deepest parts of the various basins). As expected, zones of decreased or increased rock temperature also coincide with the areas of decreased or increased geothermal gradient (**Figure 3.40**). This is most prominent in the deeper parts of the Delaware Basin, which shows relatively low temperatures due to the low local geothermal gradients *and* the higher temperatures in the San Juan and Raton Basins at moderate depths. The large amount of "white space" is due to the lack of temperature data as well as missing top Precambrian basement depth information. We encourage other researchers to gather additional top basement depth data to update, correct, and extend the existing map data set.

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Chapter 4

Geothermal Heating and Cooling: Applications for New Mexico's Industrial, Agricultural, Municipal, and Residential Sectors

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As is covered in other chapters of this report, geothermal has a long history in New Mexico, dating back centuries to Native American use of hot springs, all the way up to the state's first utility-scale geothermal electricity plant, the 15 megawatt Lightning Dock plant, in use today in the town of Animas in Hidalgo County.[1]

In part, the reason the plant is located in Animas is that in the 1960s and 1970s, research by the New Mexico Bureau of Geology and Mineral Resources,[2] prompted by rising oil prices, led to exploratory drilling and feasibility studies in various places in the state.[3] While those studies had limited success, Animas became home for a time to the nation's largest rose-growing greenhouse, powered by geothermal, and it is still home to the AmeriCulture geothermal tilapia farm.[4] The subsurface potential that prompted that early research holds true today: Directly using the Earth's heat for applications such as heating, cooling, agriculture, and industrial processes can significantly lower fuel costs and reduce emissions.

Nearly all of New Mexico has subsurface conditions capable of providing low to medium levels of heat (about 32°F–482°F, or 0°C–250°C), which could support a variety of direct use applications for industry, agriculture, and the built environment. The lower-temperature resources (32°F–212°F, or 0°C–100°C) are suitable for agricultural heating and low-temperature industrial processes. Medium-temperature resources (212°F–482°F, or 100°–250°C) can support uses in dairy processing, chemical production, and other industrial heating needs. Developing these geothermal resources in New Mexico offers a promising opportunity to tap clean, underground heat to meet growing thermal demands in these sectors.

This chapter explores the most promising locations and sectors in New Mexico for geothermal direct use by highlighting existing thermal energy usage. It also considers the potential for the state's industrial, agricultural, and building sectors to adopt geothermal heat. It examines the state's thermal energy demand, as well as how direct-use geothermal could help fulfill those requirements. Capitalizing on this potential can strengthen New Mexico's position as an energy leader, create new jobs for its workforce, and provide a sustainable and clean source of heat for local industries and agricultural enterprises.

To identify and prioritize the most promising geothermal direct-use applications in New Mexico, a twofold methodology was employed: (i) Assess thermal energy demand across various industries and temperature ranges statewide; and (2) cross-analyze with geothermal resource availability across the state. By mapping existing industrial and agricultural thermal demands by county and aligning them with geothermal temperature gradients at depth, we were able to identify regions where current heat demand could be fulfilled with geothermal.

GEOTHERMAL DIRECT USE IN INDUSTRY AND AGRICULTURE AROUND THE WORLD

Global case studies from regions with geothermal potential similar to New Mexico—including the state of Nevada, and regions in Iceland, Italy, and New Zealand—offer valuable lessons for scaling direct-use geothermal. Nevada's model for geothermal development includes a coordinated regulatory framework with streamlined permitting, effective state and federal agency collaboration, a focus on environmental and water management, and strong public-private partnerships. Taken together, these components create a supportive environment for geothermal investment.[5] In New Zealand, geothermal energy has been integrated into the country's traditional industrial processes.[6] This is a good example for New Mexico's mining and energy-intensive industries, as it illustrates how geothermal heat can support traditional sectors. Italy has leveraged geothermal resources for both electricity generation and direct-use applications such as district heating and greenhouses,[7] making it another relevant example for New Mexico, particularly in rural

2022 TOTAL ENERGY CONSUMPTION ESTIMATES BY END-USE SECTOR, RANKED BY STATE

Rank	Residential		Commercial		Industrial[a]		Transportation[b]		Total[a,b]	
	State	Trillion Btu	State	Trillion Btu	State	Trillion Btu	State	Trillion Btu	State	Trillion Btu
1	Texas	1,633.4	Texas	1,546.1	Texas	7,338.5	Texas	3,268.8	Texas	13,780.6
2	California	1,203.7	California	1,193.1	Louisiana	2,950.5	California	2,915.8	California	6,882.4
3	Florida	1,182.6	New York	969.8	California	1,539.3	Florida	1,738.8	Florida	4,325.0
4	New York	1,024.8	Florida	930.4	Pennsylvania	1,445.3	New York	1,128.1	Louisiana	4,246.0
5	Illinois	925.5	Illinois	743.9	Indiana	1,180.0	Illinois	892.8	Pennsylvania	3,736.9
34	Oregon	180.9	Oregon	134.0	New Mexico	248.0	Kansas	266.9	Nebraska	846.4
35	Nevada	157.3	Nevada	129.9	Oregon	233.2	New Mexico	230.0	West Virginia	835.5
36	West Virginia	153.8	Nebraska	122.7	Arizona	219.5	Connecticut	225.9	Alaska	724.1
37	Nebraska	143.0	West Virginia	107.0	Utah	201.0	Nebraska	199.7	Connecticut	707.6
38	Idaho	123.3	New Mexico	102.7	South Dakota	165.8	West Virginia	191.7	Nevada	706.1
39	New Mexico	107.9	North Dakota	90.0	Idaho	148.2	Alaska	189.0	New Mexico	687.6
40	New Hampshire	94.1	District of Columbia	82.6	Nevada	142.9	Idaho	169.9	North Dakota	670.6

[a]U.S. total includes -55.8 trillion Btu of net imports of coal coke that are not allocated to the states.

[b]U.S. total includes 25.5 trillion Btu of other bio fuels not allocated to the states.

Figure 4.1: 2022 Total energy consumption estimates by end-use sector, ranked by state. Source: U.S. Energy Information Administration. (2022). *Table C.11. Total energy consumption estimates by end-use sector, ranked by state, 2022*. State Energy Data System. https://www.eia.gov/state/seds/sep_sum/html/pdf/rank_use.pdf

and industrial areas. Iceland's emphasis on geothermal for local energy security,[8] with a focus on heating and industrial applications,[9] demonstrates geothermal's potential to reduce reliance on imported fuels. These examples highlight the importance of taking a diversified approach to geothermal development.

HEAT USE IN OIL AND GAS PRODUCTION

In New Mexico, total energy consumption figures are heavily influenced by natural gas production.[10] New Mexico remains a top 10 natural gas producer in the United States (3,160,057 million cubic feet produced in 2023);[11] the state exports much of its output to neighboring states such as Arizona and Texas. Two natural gas processes require a high amount of thermal energy: gas separators and gas dehydrators. Heat is often used to separate natural gas from other components such as liquids and impurities. In gas dehydration facilities, heat is used to remove water vapor from a natural gas stream. These processes typically occur where most of New Mexico's natural gas production takes place—in the Permian Basin in the southeastern part of the state and the San Juan Basin in the northwestern part.[12] Although most processes in petroleum refineries occur above 482°F (250°C), about 35% of the processes (e.g., separation of impurities, crude oil stabilization, water treatment, storage facilities, and surface equipment operations) use lower-temperature operations.[13]

HEAT USE IN MANUFACTURING, AGRICULTURE, AND THE BUILT ENVIRONMENT

In 2018, fuels accounted for about 68% of manufacturing energy consumption nationally, with feedstocks constituting the rest.[14] According to the Manufacturing Energy Consumption Survey (MECS) for the West Census Region, fuel for manufacturing in the West consumed 1,234 TBtu of energy in 2018.[15] Of that thermal energy, conventional boiler use and direct-use process heating accounted for 44.7%, or 552 TBtu (see **Figure 4.2**).[16] Adding combined heat and power (CHP) and/or co-generation process increases the amount to 732 TBtu (59.3%); however, it is challenging to separate out how much of CHP is attributed to heat for processes as opposed to generating electricity.

Unfortunately, MECS data is not released on a state-by-state basis, so we don't have exact figures for New Mexico. In 2018, however, the National Renewable Energy Laboratory (NREL) derived New Mexico-specific manufacturing fuel consumption estimates by combining the 2014 MECS with Census Bureau data. The data set provides thermal energy use estimates, broken down by industry and end use (e.g., boilers, CHP and co-generation, and process heating).[17]

MANUFACTURING END USES OF FUEL CONSUMPTION IN WESTERN STATES

End Use	Electricity	Fuel Oil	Diesel Fuel	Gas	Natural Gasoline	Coke and Breeze	Total	Percentage of Total
Total Fuel Consumption	406	4	18	699	17	90	1234	100.00%
Indirect Uses Boiler Fuel	6	1	2	266	2	33	310	25.12%
Conventional Boiler Use	6	*	1	118	1	4	130	10.53%
CHP and/or Cogeneration Process	–	1	1	149	*	29	180	14.59%
Direct Uses-Total Process	311	3	7	374	12	57	764	61.91%
Process Heating	29	3	2	343	10	35	422	34.20%

Figure 4.2: Selected manufacturing end uses of fuel consumption in 2018 for the West Census region in TBtu. Source: U.S. Energy Information Administration. (2021). *2018 MECS survey data.* https://www.eia.gov/consumption/manufacturing/data/2018/?src=%E2%80%B9%20Consumption%20%20%20%20%20Manufacturing%20Energy%20Consumption%20Survey%20(MECS)-f1#r5.

** = Estimate less than 0.5*

— = estimation is not applicable

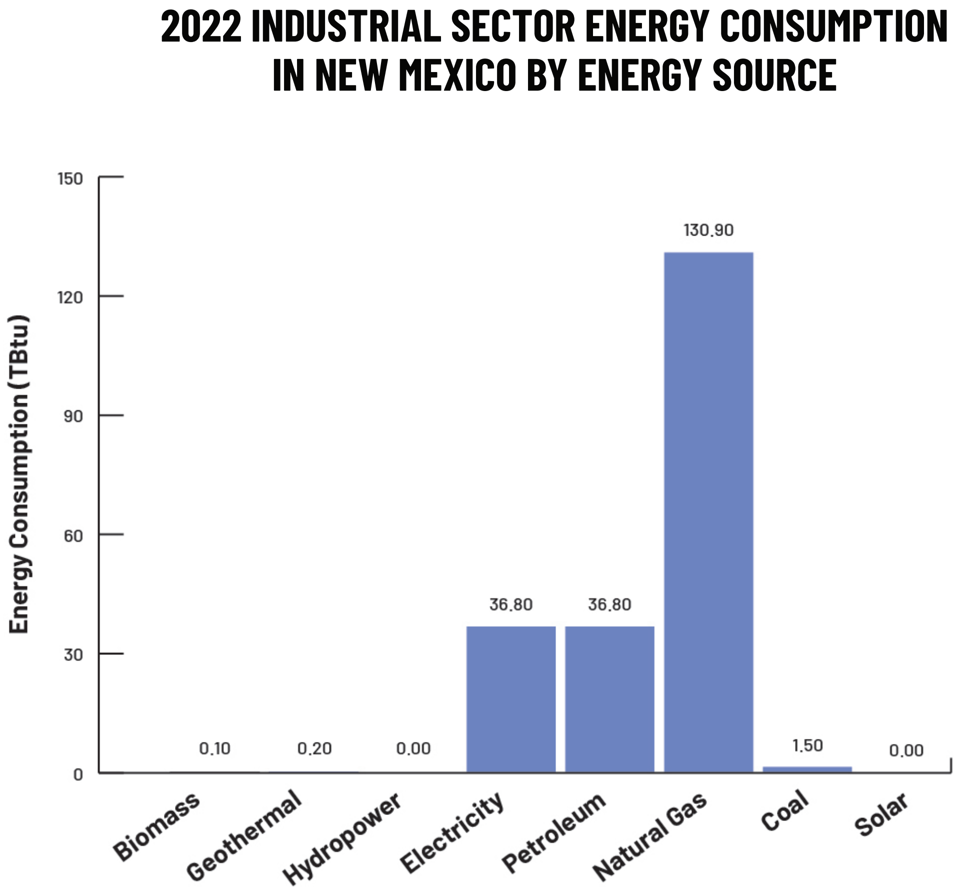

Figure 4.3: New Mexico industrial energy consumption by source. Source: U.S. Department of Energy. (2019). *GeoVision: Harnessing the heat beneath our feet.* https://www.energy.gov/sites/prod/files/2019/06/f63/GeoVision-full-report-opt.pdf

Agriculture is a major user of heat. The U.S. Department of Agriculture (USDA) estimates that across the United States, the agricultural sector used 1,872 TBtu of energy, representing approximately 1.9% of the total U.S. primary energy consumption in 2016.[18] Between 2012 and 2015, the sector became more energy-intensive, with energy consumption increasing by more than 10%, compared with 6% growth in agricultural output.

As shown in **Figure 4.1** and corresponding data, New Mexico represents 0.73% of the total U.S. energy consumption.[19] Assuming this percentage holds steady, and applying it to USDA's national estimate, we could expect New Mexico's agricultural sector to consume 13.67 TBtu annually.

In 2022, New Mexico's residential and commercial building sectors consumed 107.9[20] and 102.7[21] TBtu, respectively. Although data on heating supplied by natural gas for the commercial sector is unavailable, roughly 76% of New Mexico's housing units are heated by natural gas,[22] which cost New Mexico's residents approximately $429 million in 2023.[23]

Currently, a significant portion of the state's thermal demand is generated by burning fossil fuels. **Figure 4.3** offers a detailed breakdown of New Mexico's 2022 industrial sector consumption by energy source.

HEAT USE AND EMISSIONS IN THE LAND OF ENCHANTMENT

According to data from New Mexico's Environment Department, the state emitted 67.5 million metric tons of carbon dioxide equivalent in 2021 not including methane emissions.[24] About 29% of those emissions came from the oil, gas, and mining sector, and 23% came from industrial uses, including agriculture; the residential and commercial sectors accounted for 6%.[25] Many of those emissions become concentrated, and have the most impact, in the regions and counties where the activities occur.

MANUFACTURING HEATING FUEL CONSUMPTION IN NEW MEXICO BY TEMPERATURE, 2014

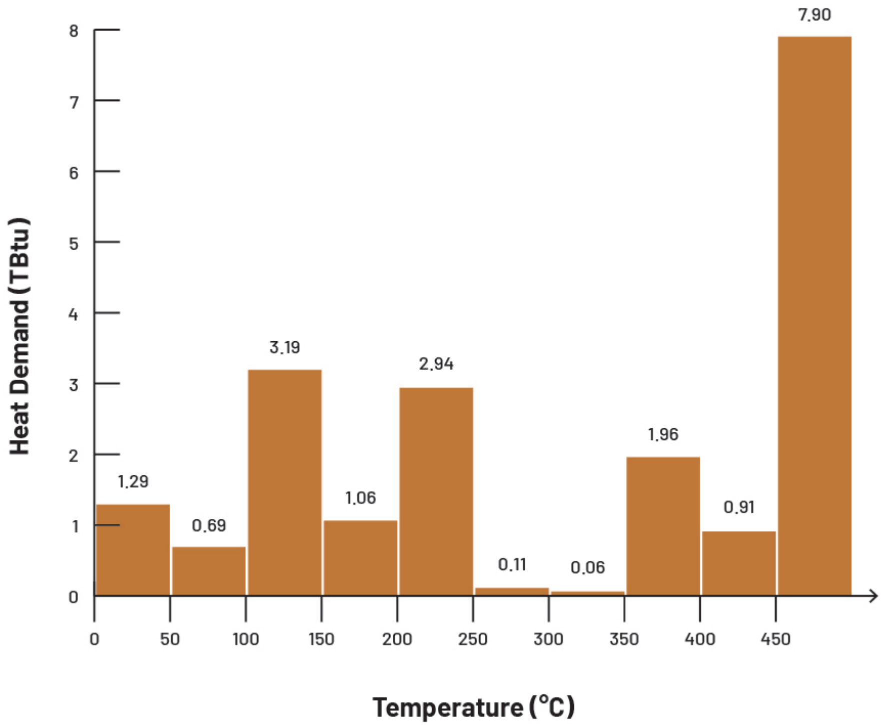

Figure 4.4: New Mexico manufacturing heating fuel consumption by temperature, 2014. Source: McMillan, C. (2019). *2018 industrial energy data book*. National Renewable Energy Laboratory. https://data.nrel.

By using geothermal energy for direct use, New Mexico could reduce a substantial portion of those agriculture and industrial-use emissions and reduce emissions from heating and cooling of the built environment. And it could be used in the low end of the oil and gas sector's thermal operations to meet about 10% of demand.[26]

MANUFACTURING PROCESS HEATING BY TEMPERATURE RANGE AND COUNTY

Despite some early direct-use successes (e.g., geothermally heated greenhouses and aquaculture), much of New Mexico's geothermal potential remains underused in the industrial sector. Geothermal energy is rarely used for manufacturing processes that require heating or cooling. Expanding geothermal use in these applications could unlock significant untapped potential in the state.

An important note: Unlike gas or electricity, which can be easily dispersed through pipelines or power lines, heat is harder to move across long distances. As a result, demand for any direct-use geothermal heat project for the sectors would need to be undertaken relatively close to the heat resource, so it is key to look to the locations where the demand and the subsurface heat overlap. Opportunely, energy demand between 32°F and 482°F (0°C to 249°C) in New Mexico is concentrated in specific regions.

Although the available NREL data on industrial thermal demand is more than a decade old, it provides the most comprehensive breakdown of New Mexico's process-heat consumption. New Mexico's total industrial energy demand has stayed relatively stable in recent years, so the 2014 data set provides a valuable reference point. The NREL data set includes some information on temperatures needed for processes, but a more detailed breakdown of specific process temperature requirements could enhance the analysis. To that end, we have incorporated granular information from a 1985 U.S. Energy Information Administration study that surveyed 108 different manufacturing processes

COUNTIES WITH HIGHEST MANUFACTURING SECTOR HEATING DEMAND

County	Demand (TBtu) 32°F-302°F	County	Demand (TBtu) 32°F-482°F
Eddy	**1.36**	Eddy	**2.50**
McKinley	**1.04**	Bernalillo	**1.97**
Bernalillo	**0.72**	McKinley	**1.75**
Lea	**0.58**	Lea	**1.12**
Chaves	**0.41**	Chaves	**0.42**
Doña Ana	**0.36**	Doña Ana	**0.39**
Roosevelt	**0.34**	Roosevelt	**0.37**
Curry	**0.17**	Santa Fe	**0.20**
Santa Fe	**0.07**	Curry	**0.17**
Valencia	**0.02**	San Juan	**0.07**

Figure 4.5: New Mexico counties with highest manufacturing sector heating demand (32°F-302°F (0°C -150°C) and 32°F-482°F (0°C-250°C) in TBtu. Source: Authors' analysis.

PROCESS HEATING DEMAND (32°F TO 302°F) FOR SELECTED INDUSTRIES BY SELECTED COUNTIES

	Dairy product mfg.	Petroleum and coal products mfg.	Pulp, paper, and paperboard mills	Phosphatic and fertilizer mfg.	Fruit and vegetable preserving and specialty food mfg.	Basic chemical Mfg.
Eddy	0.00	0.42	0.00	0.62	0.01	0.11
McKinley	0.00	0.29	0.75	0.00	0.00	0.00
Bernalillo	0.04	0.00	0.00	0.00	0.27	0.00
Lea	0.00	0.19	0.00	0.00	0.05	0.12
Chaves	0.41	0.00	0.00	0.00	0.00	0.00
Doña Ana	0.05	0.00	0.00	0.00	0.14	0.00
Roosevelt	0.34	0.00	0.00	0.00	0.00	0.00
Curry	0.17	0.00	0.00	0.00	0.00	0.00
Santa Fe	0.00	0.04	0.00	0.00	0.00	0.00
Valencia	0.00	0.00	0.00	0.00	0.00	0.00

Figure 4.6: Process heating demand (32°F-302°F, 0°C-150°C) for selected industries by selected counties (TBtu). Source: Authors' analysis.

HEATING DEMAND FOR NEW MEXICO INDUSTRIES IN SELECTED TEMPERATURE RANGES

Industry	32°F-120°F	122°F-210°F	210°F-302°F	302°F-392°F	392°F-482°F
Petroleum refineries	0.93				2.34
Other basic inorganic chemical manufacturing	0.23	0.01	0.40	0.10	0.03
Breakfast cereal manufacturing	0.03	0.01	0.25	0.24	
Frozen fruit, juice, and vegetable manufacturing	0.03	0.01			
Dried and dehydrated food manufacturing	0.01				
Phosphatic fertilizer manufacturing		0.62			
Aircraft manufacturing		0.01			
Pulp, paper, and paperboard mills			0.75		
Dairy product manufacturing: Cheese manufacturing			0.61		
Dairy product manufacturing: Dry, condensed, and evaporated dairy product manufacturing			0.34		
Lime and gypsum product manufacturing				0.30	0.47
Asphalt paving mixture and block manufacturing				0.15	
Cement manufacturing				0.15	
Ethyl alcohol manufacturing					0.03
Surgical and medical instrument manufacturing					0.01
Total	1.23	0.66	2.35	0.94	2.88

Figure 4.7: Heating demand in TBtu for New Mexico industries in selected temperature ranges. Source: Authors' analysis of NREL data set combined with process temperature data.

(including various industrial cooling needs).[27] By combining the NREL data with these detailed temperature requirements, we have a clearer picture for New Mexico.

Reviewing the data across New Mexico's industrial landscape reveals distinct patterns. (See **Figures 4.4** to **4.7**.) The highest demand for thermal energy occurs at temperatures above 840°F (450°C), totaling about 7.9 TBtu annually.[28] Current geothermal technologies don't allow heat to be cost-effectively harnessed for direct use at this extreme end of the temperature range.

However, nearly half of New Mexico's manufacturing heat demand (about 9.17 TBtu) is below 482°F (250°C). That is something geothermal can accommodate.[29] (See **Figures 4.4** to **4.7.**)

The following sections discuss industries with thermal demand in several temperature ranges.

DISTRIBUTION OF INDUSTRIAL DEMAND FROM 32°F TO 120°F BY COUNTY

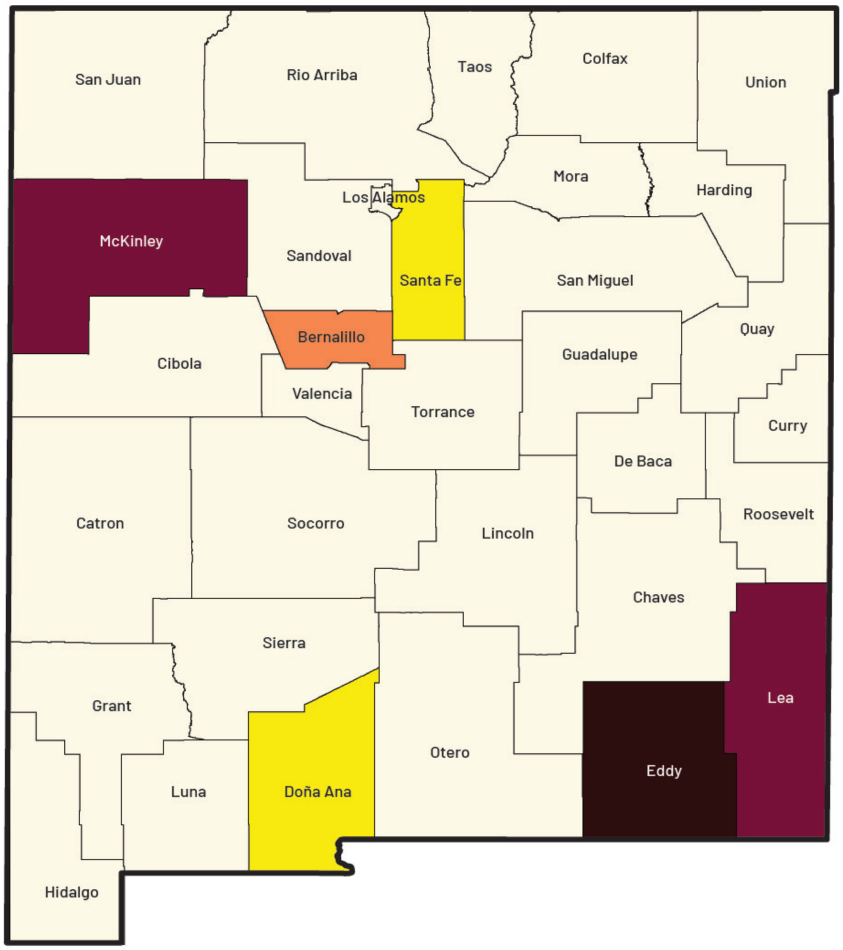

Figure 4.8: Distribution of industrial demand by county for temperatures between 32°F and 120°F (0°C and 49°C). Source: Authors' analysis of NREL data set combined with process temperature data.

NEW MEXICO'S THERMAL ENERGY DEMAND: 32°F–120°F (0°C–49°C)

From the analysis of thermal demand, Eddy and Lea Counties—where much of New Mexico's oil and gas extraction occurs—have the state's largest demand in the range of 32°F to 120°F (0°C to 49°C).[30] Although the geothermal resource in these counties is minimal compared with the rest of New Mexico, geothermal still offers enough potential applications to meet the thermal load in these counties, making them ideal candidates for low geothermal heat direct-use applications. Processes operating between 0°C and 49°C (32°F–120°F)[31] in the oil and gas industry—including separating impurities, crude oil stabilization, water treatment, storage facilities, and surface equipment operations—produce 10% of the emissions from petroleum refining. All of these processes could incorporate direct-use geothermal.

McKinley County also has a high demand for heat below 120°F (49°C). The bulk of this energy is used for water treatment associated with produced waters from oil and gas operations[32] and climate control for freight at the inland port in Gallup.[33] House Bill 361, which passed in 2025, allows for abandoned and orphaned oil and gas wells to be repurposed for geothermal. Given the high overlap of wells in these counties and their need for heat, it is likely that some of these wells, if converted to geothermal, could provide much of this heat.

The remaining thermal demand in the 32°F–120°F (0°C–49°C) range is centered in the counties of Bernalillo,

DISTRIBUTION OF INDUSTRIAL DEMAND FROM 122°F TO 210°F BY COUNTY

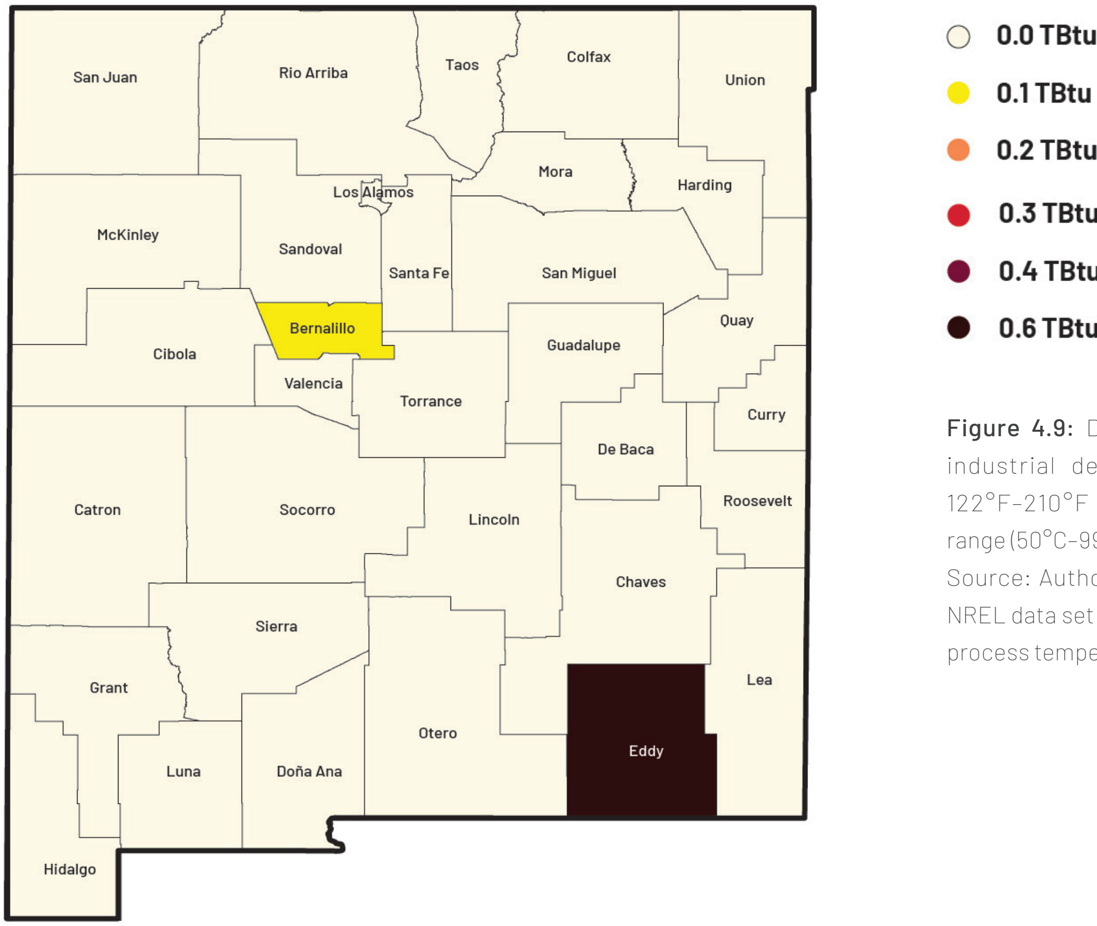

Figure 4.9: Distribution of industrial demand in the 122°F–210°F temperature range (50°C–99°C), by county. Source: Authors' analysis of NREL data set combined with process temperature data.

Doña Ana, and Santa Fe. The industries with demand in this range primarily manufacture inorganic chemicals, frozen goods (e.g., fruit, juice, vegetables), cereals, and dehydrated food products (a process done via geothermal heat in many other regions in the world).[34]

NEW MEXICO'S THERMAL ENERGY DEMAND: 122°F–210°F (50°C–99°C)

Of the 0.69 TBtu needed in the 122°F–210°F (50°C–99°C) temperature range, all but 0.04 TBtu are for phosphatic fertilizer manufacturing[35] in Eddy County. Although it is technically feasible for geothermal direct-use to meet this demand, this approach wouldn't be economical because there aren't enough subsurface resources in Eddy (or Lea) counties. As technology improves and drilling costs continue to decrease over the next 5 to 10 years, these industries should revisit the option of geothermal direct use.

The remaining TBtu comes from the heating used to manufacture inorganic chemicals, frozen goods (e.g., fruit, juice, vegetables), cereals, and select aircraft equipment in Bernalillo.[36] Bernalillo's strong subsurface potential means these industries can tap into this geothermal heat now.

NEW MEXICO'S THERMAL ENERGY DEMAND: 212°F–302°F (100°C–149°C)

Thermal demand in the 212°F to 302°F (100°C to 149°C) range is more widespread across New Mexico. The total energy demand in this heat range is 3.19 TBtu,[37] and in many places, that demand is in close proximity to the necessary heat resources for geothermal development.

DISTRIBUTION OF INDUSTRIAL DEMAND FROM 212°F TO 302°F BY COUNTY

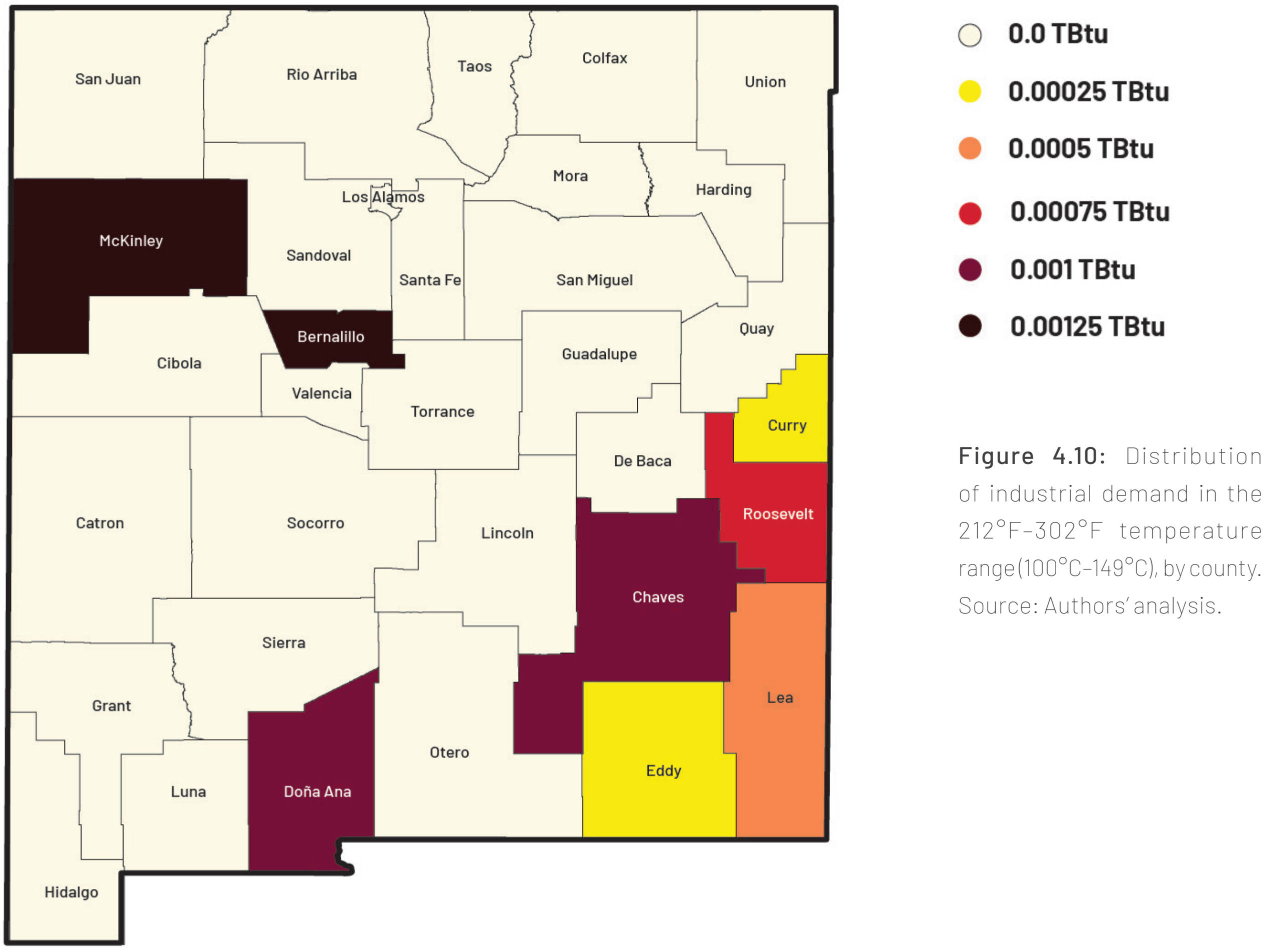

Figure 4.10: Distribution of industrial demand in the 212°F-302°F temperature range (100°C-149°C), by county. Source: Authors' analysis.

As mentioned, geothermal doesn't have a lot of potential yet for meeting the higher-temperature thermal demand in Eddy and Lea counties, but that story changes in the southeastern counties of Chaves, Curry, and Roosevelt. Almost all of New Mexico's process heating demand for dairy product manufacturing is found in these three counties (except for small operations in Bernalillo and Doña Ana). Dairy production in Chaves County needs the most heat, at 0.41 TBtu, followed by Roosevelt (0.34 TBtu) and Curry (0.17 TBtu). **Figure 4.10** shows the full distribution in this temperature range by county.

Geothermal heat is used in dairy product manufacturing throughout the world. The temperatures available in the subsurface of areas in which most of the state's dairy manufacturing takes place means that these dairies should be considered low-hanging fruit in New Mexico.

Chaves County is home to one of the world's largest mozzarella cheese factories, operatred by Leprino foods, which processing more than 6 million pounds of dairy each day.[38] Leprino launched its first climate action strategic planning initiative in 2021 to minimize its environmental footprint.[39] It isn't clear whether a transition to geothermal was part of that initiative, but considering that Leprino has engaged in climate impact conversations in the past, it would be wise to explore the use of geothermal heat with the company. Similar opportunities could be looked into for Southwest Cheese LLC in Curry County, as the company processes nearly 4 billion pounds of raw milk each year, making it one of the largest cheese processing plants in the world.[40] In Roosevelt County, another area with sufficient subsurface heat, both the Dairy Farmers of America and Carter's Milk Factory have operations in the city of Portales.

DISTRIBUTION OF INDUSTRIAL DEMAND FROM 302°F TO 480°F BY COUNTY

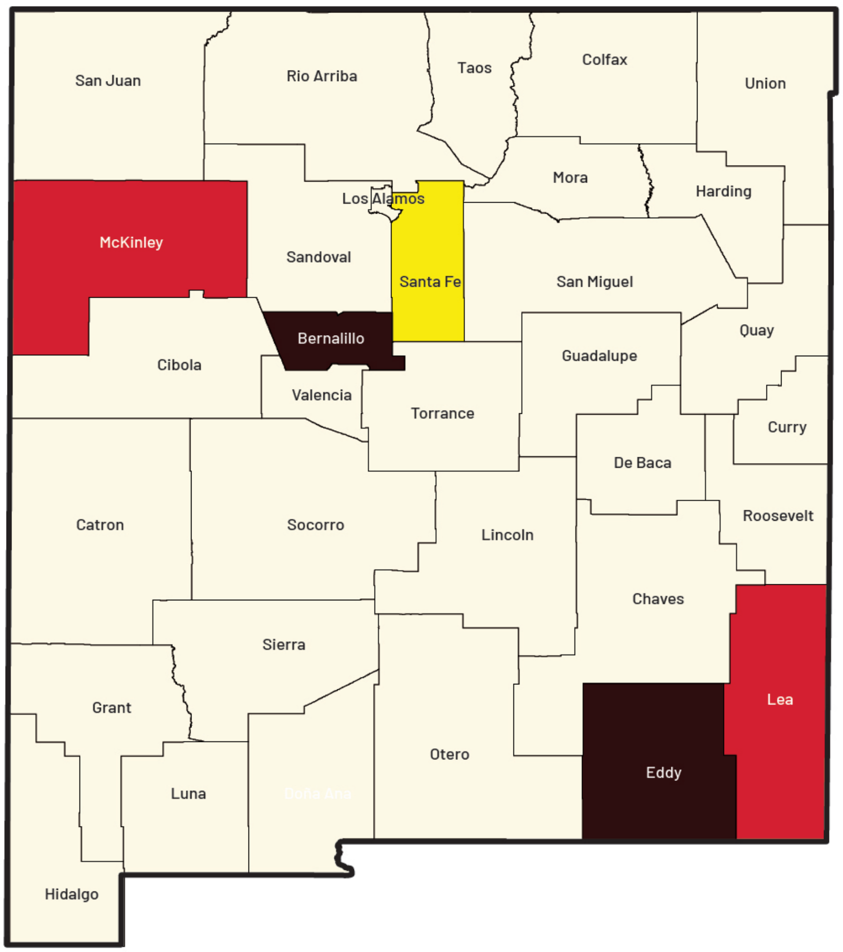

Figure 4.11: Distribution of industrial demand in the 302°F–480°F temperature range (150°C–249°C), by county. Source: Authors' analysis..

McKinley County is home to all of New Mexico's pulp, paper and paperboard mills, which account for 0.75 TBtu in the 212°F–300°F (100°C–149°C) range.[41] Pulp and paper manufacturing is another industry with global examples of geothermal's ability to provide heat.[42,43] The major player in New Mexico is the McKinley Paper Company in Prewitt, New Mexico. Until 2019, the mill's steam was supplied by the Escalante Generating Station. Since then, officials have considered the development of a hydrogen production facility, but it faces considerable challenges.[44] Just as it has been used with other pulp and paper facilities across the globe, geothermal direct use could be an immediate option to replace the thermal demand for the McKinley Paper Company.

Bernalillo County's high thermal demand in this temperature range comes from the manufacturing of inorganic chemicals (0.4 TBtu) and cereal (0.25 TBtu), both industries for which geothermal has a track record of supplying heat.[45,46] With Bernalillo's subsurface potential, the companies based there could create quick and economical decarbonization pathways by developing geothermal direct use for their thermal demands.

NEW MEXICO'S THERMAL ENERGY DEMAND: 302°F–480°F (150°C–249°C)

Thermal demand in the 302°F–480°F (150°C–249°C) range accounts for 4 TBtu of New Mexico's manufacturing sector. Petroleum refineries, which are responsible for a good portion of New Mexico's demand in this range, are primarily concentrated in Eddy and Lea counties. As mentioned earlier, the heat needed for these processes is located too deep to currently provide economic geothermal heat. However, given the substantial heat demand and known geothermal gradients, McKinney (0.00075 TBTu), Bernalillo (0.00125 TBTu) and Santa Fe (0.00025 TBtu) counties are prime candidates for direct-use geothermal in processing operations such as crude oil distillation, cement production, and heavy manufacturing (see **Figure 4.11** for the distribution by county). **Figure 4.7** shows the major industries with heat demand in this range.

HEATING AND COOLING DEMAND FOR RESIDENTIAL AND COMMERCIAL BUILDINGS

The state of New Mexico is forecasting that 5.7% (3.9 MMTCO2e) of its 2025 GHG emissions will come from the commercial and residential sectors.[47] This amount is largely due to the energy required to keep buildings at comfortable indoor temperatures, typically between 68°F and 73°F (20°C–23°C). In colder months, buildings must be heated, and in warmer months, they must be cooled. While outdoor temperatures can soar above 90°F (32°C) in summer or drop below 30°F (-1°C) in winter, the shallow ground beneath buildings remains a relatively constant 55°F (13°C) year-round. This natural stability presents a major opportunity to reduce emissions and energy costs through the use of geothermal technologies.

Established geothermal systems such as ground source heat pumps, geothermal district heating, and thermal energy networks can help meet heating and cooling demands efficiently.[48] (One company focusing on geothermal heating and cooling for buildings is Bedrock Energy, which has geothermal heating and cooling systems in Texas, Utah, and Colorado and plans to expand into New Mexico by 2026.) Thermal energy networks are especially well suited for—and would benefit—New

THE IMPACT OF GEOTHERMAL HEAT PUMPS

An Important Study from Oak Ridge National Laboratory

In 2023, Oak Ridge published *Grid Cost and Total Emissions Reductions Through Mass Deployment of Geothermal Heat Pumps for Building Heating and Cooling Electrification in the United States*. The study provided national-scale data on the impacts of widespread geothermal heat pump use. Using proportional scaling for New Mexico, it found:

Primary energy consumption reduction: New Mexico accounts for about 0.5% of the U.S. population. Assuming similar energy-use patterns, the state could see a 2.96 terawatt-hour (TWh) reduction in primary energy consumption annually by 2050.

Emissions reduction: Based on New Mexico's energy usage profile and Oak Ridge's projected 7 gigatons of CO_2-equivalent national reduction, the state could avoid 35 million metric tons of CO_2 emissions by 2050.

Electricity generation savings: Extrapolating from Oak Ridge's national 593 TWh savings, New Mexico could save approximately 3 TWh annually in electricity generation by 2050, particularly in cooling applications.

Peak demand mitigation: Heat pump deployment in New Mexico's high-temperature zones could contribute to reducing peak summer electricity demand by 5% to 10%, which would help alleviate grid stress during heat waves.

These estimates highlight the potential benefits of scaling geothermal heat pump use in New Mexico. These extrapolations are adjusted for New Mexico's size and energy usage patterns.

Liu, X., Ho, J., Winick, J., Porse, S., Lian, J., Wang, X., et al. (2023). Grid cost and total emissions reductions through mass deployment of geothermal heat pumps for building heating and cooling electrification in the United States. Oak Ridge National Laboratory. https://info.ornl.gov/sites/publications/Files/Pub196793.pdf

NEW MEXICO'S RESIDENTIAL COOLING DEMAND BY COUNTY

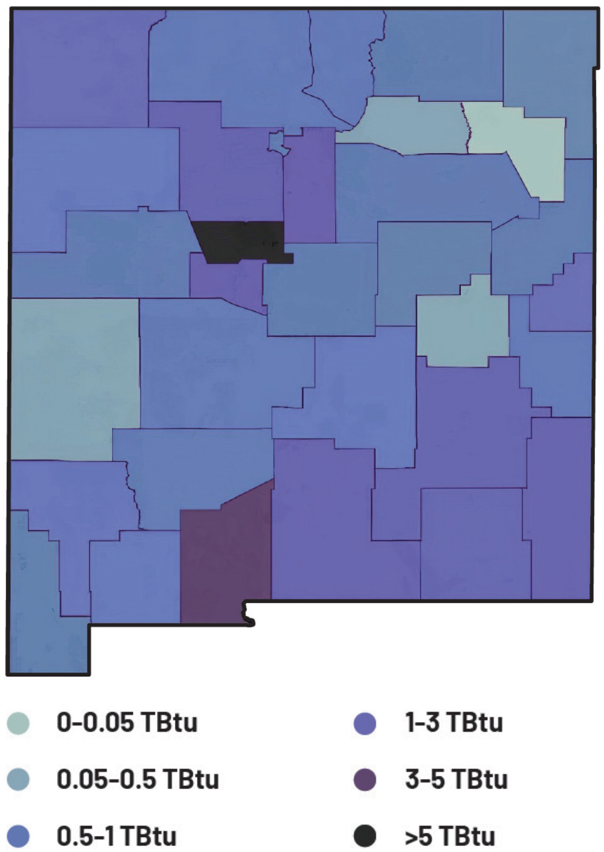

Figure 4.12: New Mexico residential cooling demand, by county. Source: Project InnerSpace. (2025). *Residential: County Cooling Total* [Data set]. Surface Module (United States of America). GeoMap. https://geomap.projectinnerspace.org/geomap/.

NEW MEXICO'S COMMERCIAL COOLING DEMAND BY COUNTY

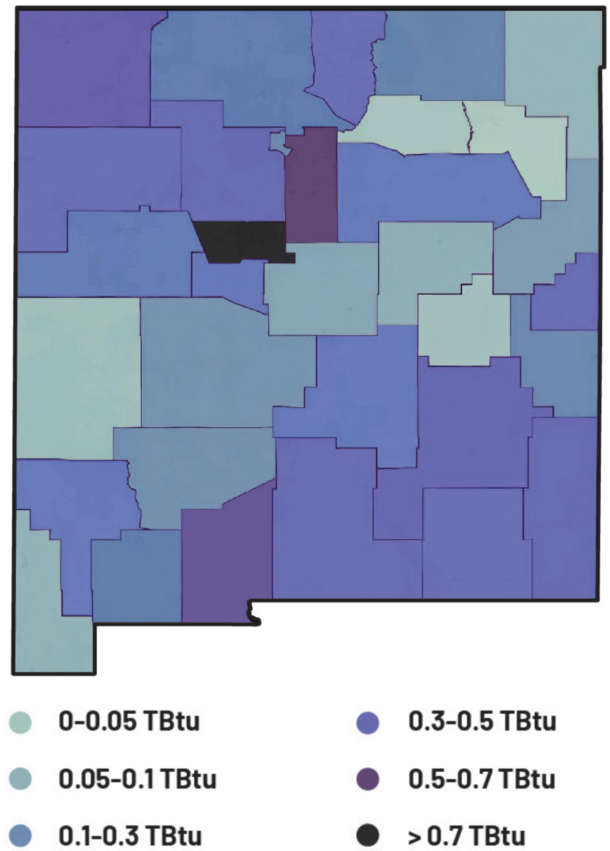

Figure 4.13: New Mexico commercial cooling demand, by county. Source: Project InnerSpace. (2025). *Commercial: Cooling Demand* [Data set]. Surface Module (United States of America). GeoMap. https://geomap.projectinnerspace.org/geomap/.

Mexico's urban areas, including Albuquerque, Las Cruces, Santa Fe, Roswell, Farmington, Hobbs, and Carlsbad. Taken together, these cities comprise about half of New Mexico's population. Other communities might adopt ground source heat pumps on a building-by-building basis. **Figures 4.12** through **4.15** highlight areas in New Mexico where these opportunities align with concentrated demand for heating and cooling.

Transitioning to geothermal climate control would significantly accelerate achievement of the state's climate goals, particularly considering that 76% of residential heating produces emissions.[49] More broadly, New Mexico should prioritize incorporating geothermal in areas considered "low-hanging fruit"—that is, regions and industries operating below 302°F (150°C) that overlap with accessible geothermal resources—to maximize the near-term effects of direct-use geothermal heating and cooling.

AGRICULTURAL HEATING BY TEMPERATURE RANGE AND COUNTY

Agriculture uses a lot of energy, especially in states such as New Mexico where heating is essential for both crop production and post-harvest processing. The state's agricultural sector relies heavily on energy for irrigation and heating, with 92% of the land classified as

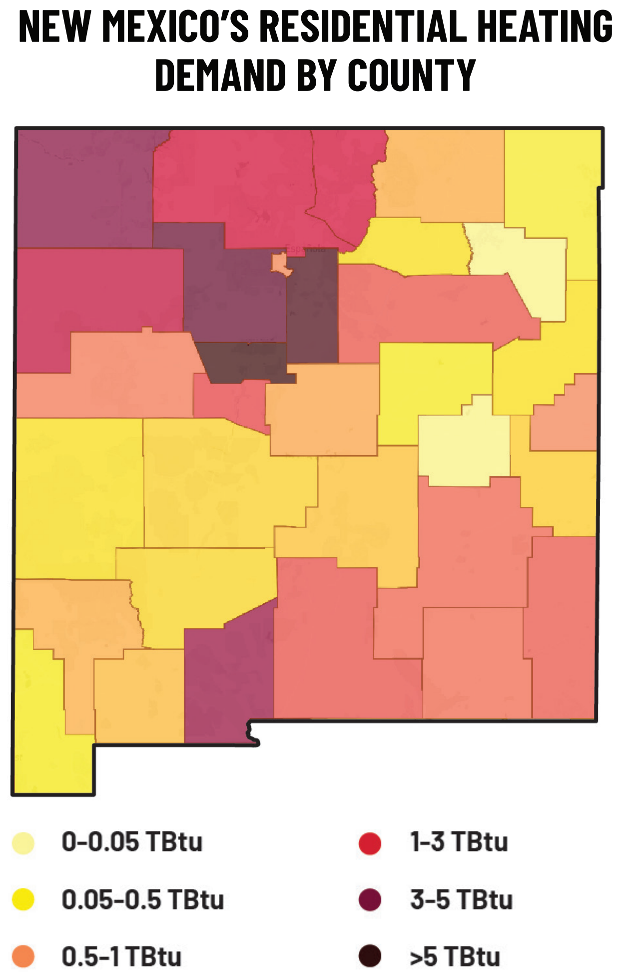

Figure 4.14: New Mexico residential heating demand, by county. Source: Project InnerSpace. (2025). *Residential: County Heating Total* [Data set]. Surface Module (United States of America). GeoMap. https://geomap.projectinnerspace.org/geomap/.

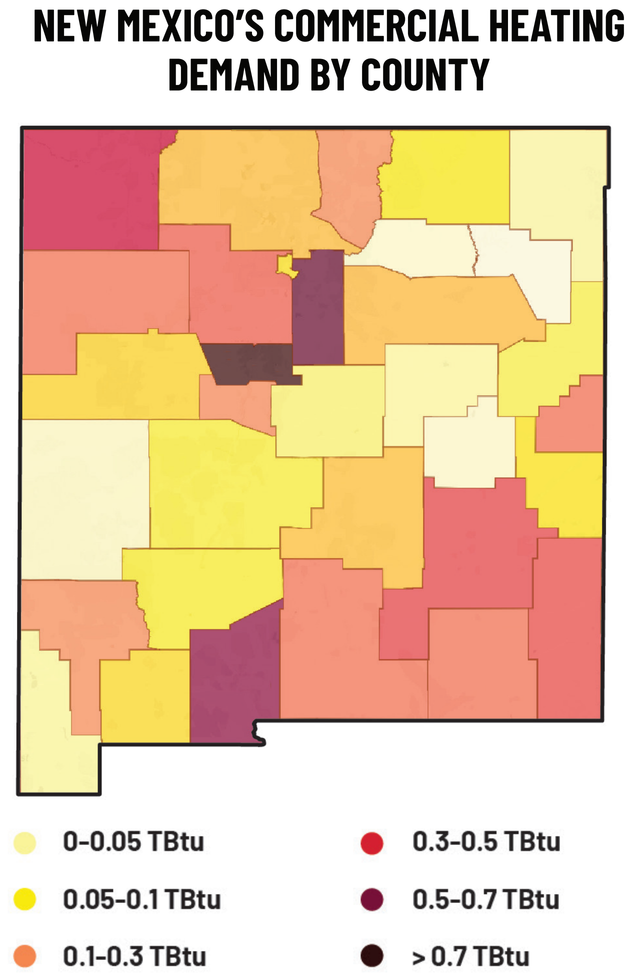

Figure 4.15: New Mexico commercial heating demand, by county. Source: Project InnerSpace. (2025). *Commercial: Space Heating Demand* [Data set]. Surface Module (United States of America). GeoMap. https://geomap.projectinnerspace.org/geomap/.

rangeland suitable for grazing.[50] Farmers and ranchers throughout the state also cultivate vital feed crops such as hay, corn, and grain sorghum to support livestock. The state's arid climate and high summer temperatures require energy-intensive practices to maintain these high levels of productivity.

Most agricultural thermal demand is in the 212°F–300°F (100°C–150°C) range, which is used in applications such as crop drying, greenhouse climate control, and food processing. Cooling requirements in agriculture (e.g., for cold storage of produce, milk chilling) are concentrated in the 32°F–75°F (0°C–24°C) range. In New Mexico's agricultural facilities, maintaining these controlled temperatures is essential to ensure productivity and product quality. Geothermal heating systems can efficiently provide heat for livestock barns, greenhouses, and crop drying facilities, and geothermal cooling (or heat exchange via ground source heat pump technology) can help regulate temperatures in food storage and processing units. As agricultural practices evolve, there will be even more potential for adopting renewable energy sources such as geothermal to reduce the carbon footprint in these heating-intensive food-processing industries.

Figures 4.16 and **4.17** show there's an overlap of favorable geothermal potential with demand, indicating

NEW MEXICO GEOGRAPHICAL DISTRIBUTION OF AGRICULTURAL HEATING DEMAND

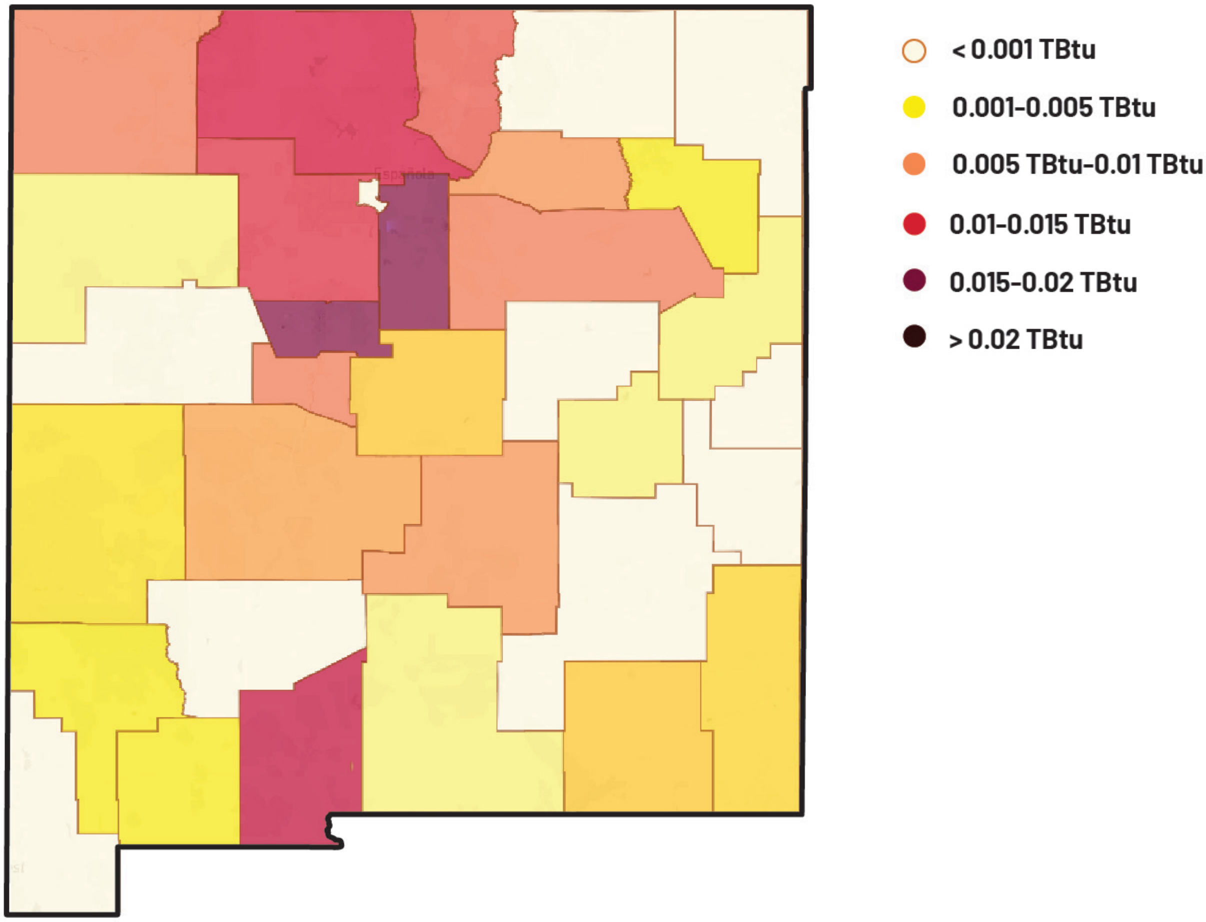

Figure 4.16: New Mexico geographical distribution of agricultural heating demand. The top five agricultural counties in New Mexico in terms of heat demand are Santa Fe (0.01459 TBtu), Bernalillo (0.01459 TBtu), Doña Ana (0.01094 TBtu), Rio Arriba (0.0099 TBtu), and Sandoval (0.00886 TBtu). Source: Project InnerSpace. (2025). *Agricultural Heating Demand* [Data set]. North America Surface Module (United States of America). GeoMap. https://geomap.projectinnerspace.org/geomap/

an opportunity for the state to reduce its reliance on natural gas, electricity, and propane for heating in these operations. The relatively low heating and cooling temperature needs of New Mexico's agriculture sector make it an ideal candidate for using ground source heat pumps and direct-use geothermal systems.

CONCLUSION

New Mexico's path to scaling geothermal direct-use systems lies in aligning thermal demands with geothermal opportunities. In counties such as Chaves, Curry, Roosevelt, McKinley, Bernalillo, and Doña Ana, there is a clear overlap between industrial and agricultural thermal energy needs—particularly in the 32°F to 480°F (0°C to 249°C) range—and the availability of subsurface geothermal heat. These counties host activities with high heat demand—such as dairy processing, pulp and paper manufacturing, and crop dehydration—for which geothermal has proven viability.

Although New Mexico generates a significant share of its electricity from solar and wind, these intermittent sources have limited utility for industrial thermal energy needs due to challenges with grid integration, storage, and the requirement for consistent heat, among other

GEOTHERMAL OPPORTUNITIES IN NEW MEXICO

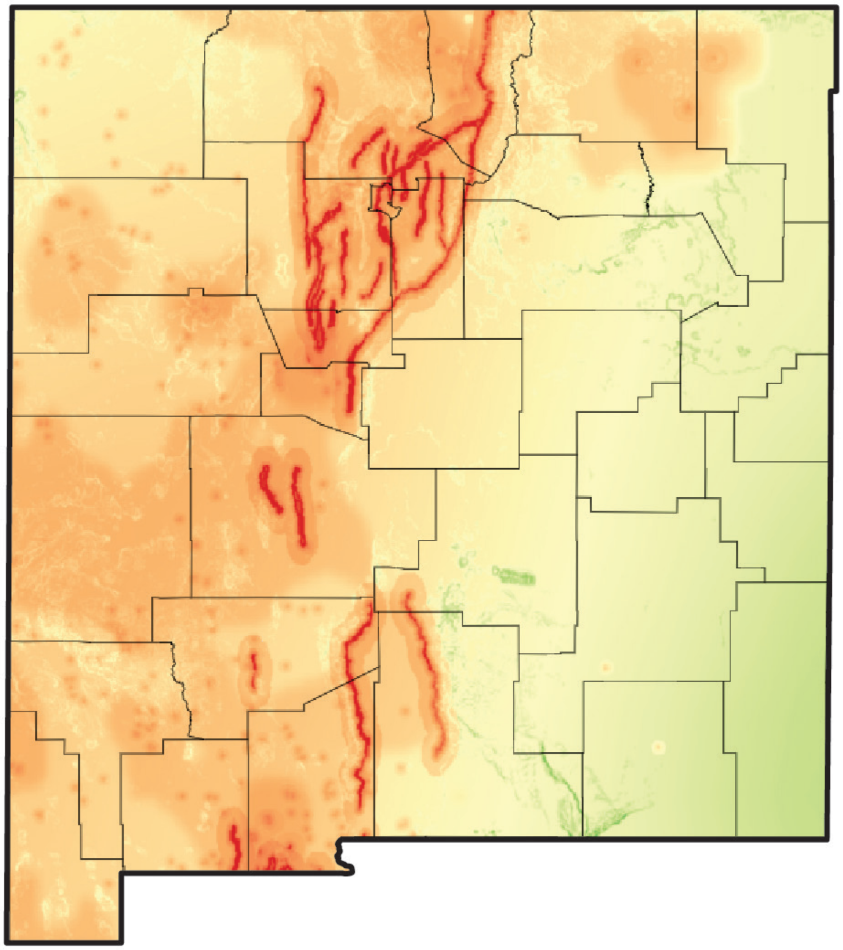

Figure 4.17: Geothermal opportunities in New Mexico. Source: GeoMap

factors. Geothermal direct-use delivers reliable, around-the-clock heat at a range of temperatures, making it particularly well suited for industrial processes that need uninterrupted thermal energy.

Despite its potential, geothermal currently supplies only 0.09% of New Mexico's industrial energy needs.[51] The state's industries stand to benefit greatly from transitioning to this untapped resource. Counties such as McKinley, Bernalillo, and Doña Ana are particularly well positioned for near-term deployment of geothermal. Add to that, the urban areas across New Mexico would benefit from the installation of thermal energy networks and ground source heat pumps, as these would be economical, stable, and secure and would reduce local, state, and regional GHG emissions.

It's worth repeating: Almost every county in New Mexico could effectively use geothermal heat for local demand. The state already has a geothermal industry primed to expand. To do so, New Mexico's policymakers and geothermal producers should prioritize development in the counties where the heat demand matches the most beneficial geothermal supply. These place-based strategies can reduce emissions, drive down energy costs, and create durable local jobs. With its abundant subsurface resources and a growing need to decarbonize heating across industries, agriculture, and buildings, New Mexico is uniquely positioned to become a national leader in geothermal direct use.

The Big Overlap: Areas, Industries, and Types of Geothermal

Location	Industry	Geothermal Type
Bernalillo County	Food processing industries (e.g., frozen goods and cereals); low-temperature industrial heating; inorganic chemical manufacturing; greenhouse heating, crop drying, and food storage	**32°F–120°F** Direct use, simple piping, minimal treatment **120°F–210°F** Heat exchangers, reinforced piping, filtration **210°F–482°C** Multiple wells, reinjection, industrial-grade controls
Chaves County	Dairy product manufacturing	**212°F–300°F** Multiple wells, reinjection, industrial-grade controls
Curry County	Dairy product manufacturing	**212°F–300°F** Multiple wells, reinjection, industrial-grade controls
Doña Ana County	Food processing industries (e.g., frozen goods and cereals); greenhouse and nursery heating, crop drying (pecans, green chiles, onions), viticulture, and food storage	**32°F–120°F** Direct use, simple piping, minimal treatment **212°F–300°F** Multiple wells, reinjection, industrial-grade controls
Eddy County	Oil and gas operations	**32°F–120°F** Direct use, simple piping, minimal treatment
Lea County	Oil and gas operations	**32°F–120°F** Direct use, simple piping, minimal treatment
McKinley County	Water treatment; heating at the Gallup Inland Port; paper processing	**32°F–120°F** Direct use, simple piping, minimal treatment **212°F–482°F** Multiple wells, reinjection, industrial-grade controls
Rio Arriba County	Greenhouse heating (tomatoes and cucumbers), crop drying (hay, grains, chicos, beans), livestock (barnhouse and water supply heating), and food storage	**32°F–120°F** Direct use, simple piping, minimal treatment **122°F–210°F** Heat exchangers,reinforced piping, filtration
Roosevelt County	Dairy product manufacturing	**212°F–302° F** Heat exchangers,reinforced piping, filtration
Sandoval County	Greenhouse and nursery heating, crop drying (hay and grains), livestock production, and food storage	**32°F–120°F** Direct use, simple piping, minimal treatment **122°F–212°F** Heat exchangers,reinforced piping, filtration
Santa Fe County	Food processing industries (e.g., frozen goods and cereals); greenhouse heating, crop drying, and food storage	**32°F–120°F** Direct use, simple piping, minimal treatment **302°F–482°C** Multiple wells, reinjection, industrial-grade controls
City centers such as Albuquerque, Las Cruces, and Santa Fe	High residential and commercial heating and cooling loads	**32°F–120°F** Direct use, simple piping, minimal treatment

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Chapter 5

Leveraging Oil and Gas Technologies, Labor, and Workforce to Advance Geothermal in New Mexico

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Travis Broadhurst, University of New Mexico

Mining, oil, and gas have long shaped New Mexico's economy and society. Turquoise mined from the Cerrillos Hills and Burro Mountains was used for trading long before Europeans arrived. Lead, copper, silver, and gold mines produced a lot of metal during colonial times.[1] In the 1880s, people mined coal; by 1911, they were drilling for oil, and by 1921, for natural gas.[2] Today, New Mexico is vital to the U.S. energy landscape. In 2023, the state was the second-highest producer of crude oil and fifth-highest producer of natural gas.[3,4] The Permian Basin in the southeast of the state and the San Juan Basin in the northwest produce significant amounts of oil and gas and are recognized globally for their advanced subsurface exploration and extraction capabilities.[5]

According to the New Mexico Oil and Gas Association (NMOGA), the oil and gas industry supports approximately 134,000 direct and indirect jobs—roughly 6.4% of the state's 2.1 million residents. It also contributes around $13 billion annually to state and local revenues, equivalent to more than 30% of the state's total public budget.[6] About $7.4 billion—49% of all revenue—goes directly to the state's general operating fund.[7] As of 2022, New Mexico is the leading producer of potash in the country and ranks third in copper production.[8] The state also has significant reserves of coal, uranium, carbon dioxide, and helium.[9]

Despite the economic benefits, New Mexico's reliance on the mining and oil and gas industries has also exposed it to the volatility of resource markets, leading to cycles of booms and busts. This volatility has sparked a growing interest in diversifying the state's energy portfolio, driving the rapid expansion of renewable energy sources since 2015.[10]

Today, geothermal energy is still underdeveloped in the state, with only one active power plant, despite New Mexico being ranked sixth nationwide in estimated geothermal resources.[11] Scaling up would offer a significant opportunity to diversify revenues and capitalize on the state's existing oil and gas expertise, infrastructure, and workforce.[12] Successful geothermal development requires competencies in subsurface exploration, engineering, and natural resources production—skills already prevalent in New Mexico.

LOCATION OF NEW MEXICO OIL AND GAS ASSETS AND GEOMAP HEAT FLOW DATA

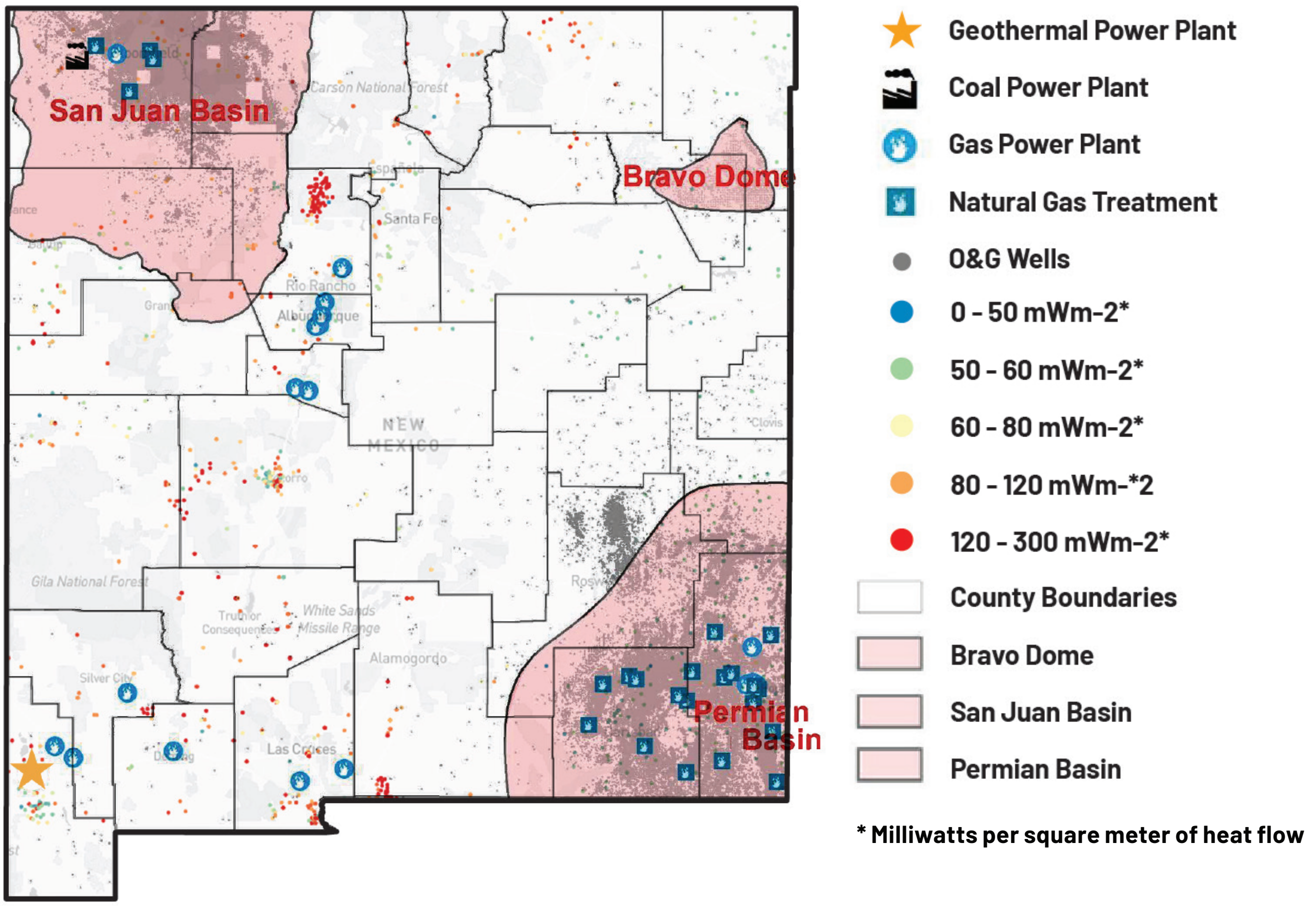


Figure 5.1: New Mexico oil and gas assets: oil and gas wells, natural gas treatment facilities, gas power plants, and main producing basins (Permian, San Juan Basin, and Bravo Dome, compared with the singular geothermal power plant. Sources: Go-Tech, *About Go-Tech*, https://octane.nmt.edu/gotech/Main.aspx; U.S. Energy Information Administration, *New Mexico energy infrastructure data*, https://www.eia.gov/beta/states/states/nm/data/dashboard/energy-infrastructure; U.S. Geological Survey (USGS), *Science data catalog*, https://data.usgs.gov/datacatalog/,.and GeoMap, https://geomap.projectinnerspace.org/map-selection/

New Mexico currently uses 10.7 gigawatts of electrical power each year. Because of its natural geothermal resources, New Mexico also has the technical power potential of 163.32 gigawatts, which means geothermal could enable the state to meet increasing energy demands 16 times over.[13]

This chapter delves into the synergies between geothermal and the oil and gas industry in New Mexico and identifies pathways between them to help ensure New Mexico remains an energy leader in the United States.

BACKGROUND

New Mexico Energy, Minerals, and Natural Resources

Oil and Gas and Mining

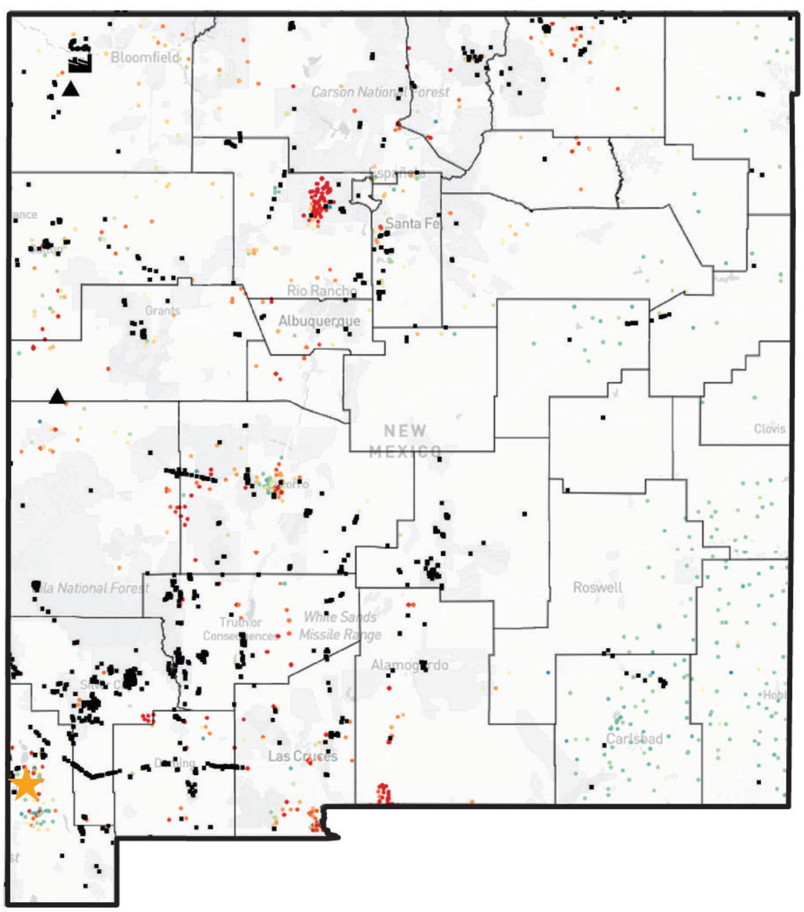
New Mexico's oil and gas industry expanded rapidly with the development of commercial oil reserves in the San Juan Basin in 1924.[14] This marked the start of large-scale exploration and production, followed by significant developments in the Permian Basin in the southeast.[15] New Mexico also has a notable history of carbon dioxide (CO_2) production, particularly in the Bravo Dome field in northeast New Mexico, one of the largest natural CO_2 reservoirs in the United States.[16]

Copper was first used by native people in New Mexico.[17] In 1910, industrial copper production began in Hurley, which has one of the largest pits in the world. Potash mining in the state accounts for 75% of domestic production.[18] Coal mining generated more than $500 million in revenue and 1,200 jobs statewide in 2014.[19] The state used to mine more than one-third of the nation's uranium,[20,21] and it still extracts rare earth minerals and critical minerals.[22]

Existing Subsurface Assets and Geothermal Potential

Mining assets in New Mexico have significant geographic overlap with geothermal resources (see **Figures 5.1** and **5.2**). In New Mexico there is overlap between where the mines are situated and high geothermal gradients, where the temperature increases rapidly as you go deeper into the subsurface.[23] Several minerals, such as epithermal copper and gold, are concentrated through hydrothermal processes because higher temperatures facilitate the movement and displacement of these metals deep within the Earth.[24] Lithium and boron are also often found in geothermal brines. Data sources like GeoMap show that New Mexico has lithium brine in several key areas, including in the Permian Basin. The presence of these minerals in geothermal regions highlights the potential for mineral extraction from geothermal brines. In Southern California, the Salton Sea Geothermal Field and Hell's Kitchen geothermal plant not only supply the region with power to the grid but also produce lithium extracted as a by-product of

LOCATION OF NEW MEXICO MINING ASSETS AND GEOMAP HEAT FLOW



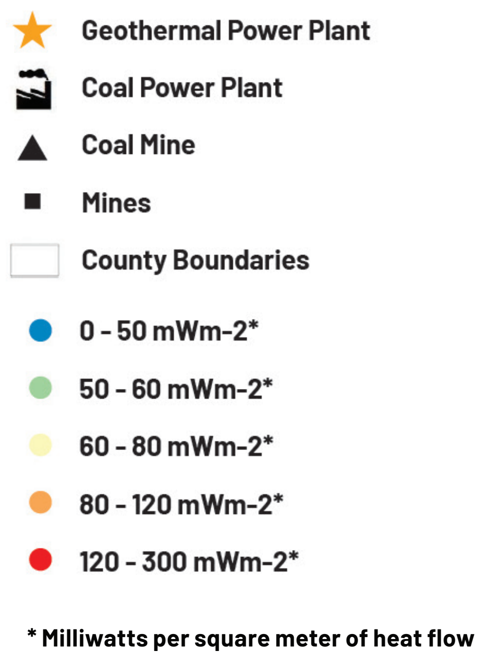


Figure 5.2: New Mexico mining assets (all types of mines, without gravel pits) compared with the geothermal power plant. Source: U.S. Geological Survey (USGS), https://data.usgs.gov/datacatalog/, and GeoMap, https://geomap.projectinnerspace.org/map-selection//

geothermal operations; the lithium can then be used in battery-grade products.[25,26]

Oil and gas assets, on the other hand, are typically located in sedimentary basins with lower heat gradients, which generally has made them less conducive to geothermal energy production. That said, advancements in technology and direct-use applications can harness lower temperatures, depending on the end uses, energy needs, and project design. (See more in Chapter 4.[27]) Although geographic overlap may not indicate a strong correlation between geothermal power generation potential and the Permian and San Juan oil and gas basins, the workforce, technologies, and infrastructure do.

ENGAGEMENT AND INTEREST IN GEOTHERMAL DEVELOPMENT IN THE OIL AND GAS AND MINING INDUSTRY

We conducted an in-depth review of 392 entities in New Mexico to assess their current engagement and interest in geothermal development. Respondents fell into eight categories (**see Figure 5.3**):

- Local operators (e.g., companies, small businesses, or individuals involved in resource extraction or energy development)
- Drilling companies (companies specializing in the physical drilling process)
- Service companies (a company that provides specialized products, equipment, and expertise to support exploration and production)
- Multistate operators (e.g., energy or resource companies, often with larger capital and infrastructure capabilities)
- Mining companies
- Geothermal firms (those focused on geothermal energy exploration, development, and production)
- Utilities
- Trade organizations

Local operators make up the largest portion of the entities reviewed (44%). While these firms often have deep localized expertise, many of them are small to midsized and may lack the capital resources or be hesitant to assume the risks associated with geothermal energy. These companies might represent the majority of companies by number, but larger companies typically account for the bulk of energy production in the state. Nonetheless, the significant number of local operators signals substantial potential for expansion of geothermal, especially if targeted support, incentives, or partnerships can help them enter geothermal development.

Drilling companies—which represent 22% of the entities studied—have the potential to repurpose existing drilling expertise and infrastructure for geothermal exploration. Appropriate training and investment could enable these companies to play a critical role in advancing geothermal development.

Service companies, which provide essential support activities such as equipment maintenance and logistics, account for just 14% of the entities reviewed, which underscores the opportunity for them to expand their operations into the geothermal sector and grow their business.

Multistate operators, primarily focused on fossil fuels, and often based outside New Mexico or even outside the United States, account for 8% of the entities but represent a large part of the oil and gas and mining activity.

Mining companies make up 7% of entities, largely because only major players were identified. As in the oil and gas industry, there are numerous small, local mining operators with limited assets, but just a few large, multistate operators hold significant assets within the state.

Geothermal firms and **utilities** each made up only 2% of the entities in the review. Oil and gas **trade organizations** made up 1% percent of entities but represented numerous other entities in the oil and gas industry (such as local operators).

The recent surge in New Mexico oil production, driven by unconventional drilling in the Delaware Basin, has been led by larger companies such as Chevron,[28] Devon Energy,[29] ExxonMobil,[30] and Occidental,[31] all

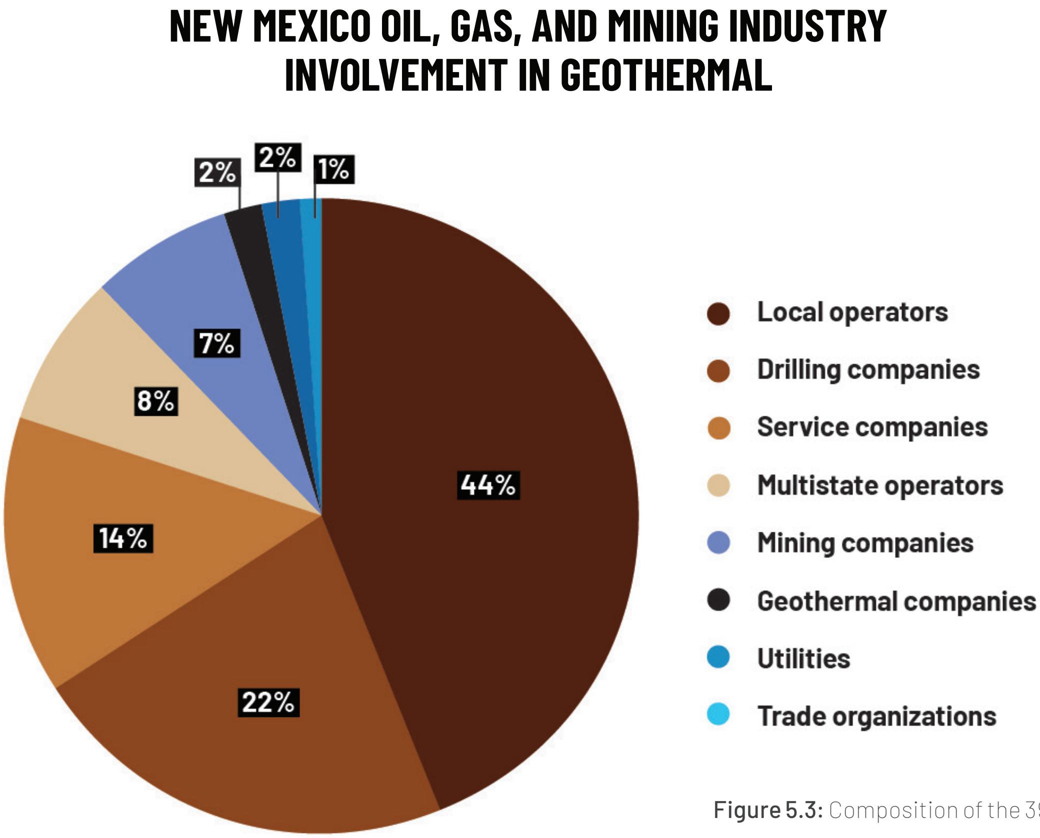


Figure 5.3: Composition of the 392 New Mexico oil and gas, mining, and utility entities identified during our research.

of which have shown some interest in geothermal. This underscores the importance of leveraging multistate operators to drive investments in geothermal energy and support long-term sector growth in New Mexico.

ENGAGEMENT IN GEOTHERMAL ENERGY

To understand the current level of interest and engagement in geothermal development in New Mexico, we conducted discussions, surveys, and a comprehensive literature and web review (**Figure 5.4**).

Geothermal Companies and Oil and Gas Trade Organizations (10 out of 10; 100% interest)

Geothermal-specific companies and oil and gas trade organizations active in New Mexico (e.g., NMOGA, Independent Petroleum Association of New Mexico, Geothermal Rising) of course show 100% interest in geothermal development, but their small total numbers (seven for geothermal and three for oil and gas organizations) indicate a limited presence in the state.

Multistate Operators (17 out of 33; 52% interest)

With more than half of large operators expressing interest, this group represents a significant potential driver for geothermal development. These entities likely see geothermal as complementary to their energy portfolios, particularly as they develop low-carbon energy sources. The nearly equal proportion of those that didn't express the same interest (16 of 33) suggests room for outreach and incentives.

Utilities (2 out of 7; 29% interest)

Utilities exhibit a moderate interest level, reflecting cautious but growing engagement in geothermal energy. Their critical role in energy marketing and distribution makes their involvement essential, but the relatively low

NEW MEXICO ENERGY ENTITIES' INTEREST IN GEOTHERMAL

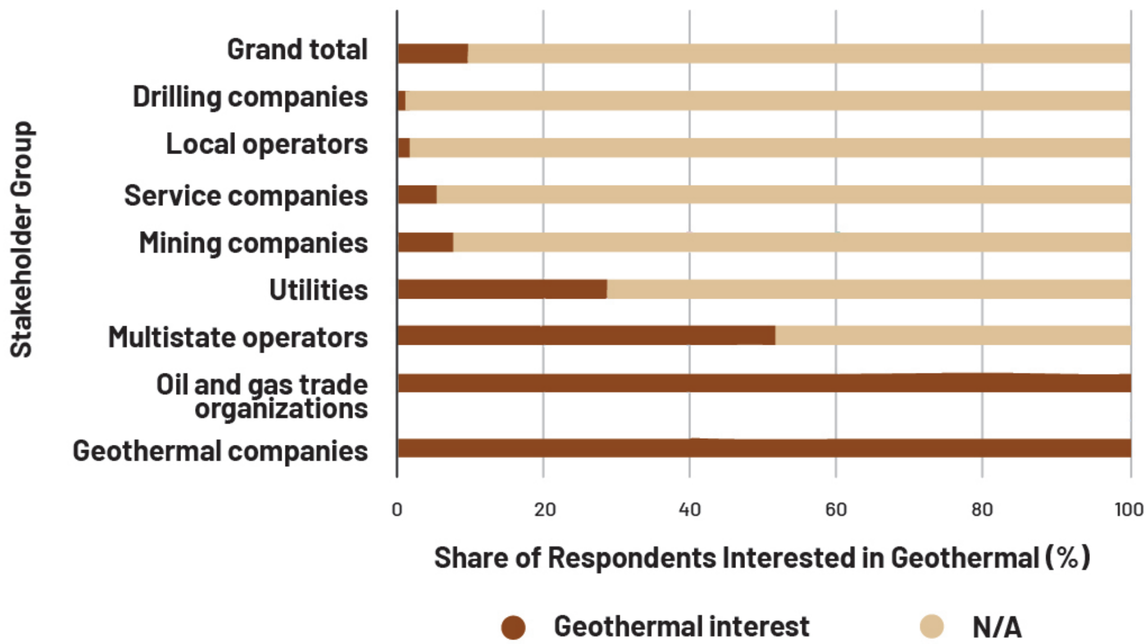


Figure 5.4: Current levels of engagement with and interest in geothermal development from New Mexico's energy stakeholder sectors. N/A (not available) indicates either a negative response or that no information was available. Sources: MIT Center for Energy and Environmental Policy Research. (2022). *The Roosevelt Project: Accelerating an equitable clean energy transition in New Mexico*. Massachusetts Institute of Technology. https://ceepr.mit.edu/wp-content/uploads/2022/12/2022-The-Roosevelt-Project-New-Mexico-Case-Study.pdf; New Mexico Energy, Minerals and Natural Resources Department.(n.d.). *OCD permitting: Operator search*. https://wwwapps.emnrd.nm.gov/OCD/OCDPermitting/Operators/Search/OperatorSearch.aspx

interest level indicates potential barriers (e.g., perceived risks, upfront costs, technological unfamiliarity) that need to be addressed. Discussions revealed that larger utilities (e.g., Public Service Company of New Mexico [PNM], El Paso Electric, Xcel Energy) are more interested in geothermal energy's potential for long-term energy storage in various geothermal energy systems. This capability could help balance the intermittent nature of solar and wind power, both of which have been extensively developed in New Mexico. Developing a 5 gigawatt geothermal goal for the state that includes geothermal energy storage (GES) could help drive interest in geothermal by utilities, as it makes renewables less intermittent.

Smaller utilities and cooperatives, on the other hand, expressed less interest than the larger ones. As described in Chapter 4, rural electric co-ops can include ground source heat pumps as a way to meet the state's clean energy goals. This may be an area to increase co-ops engagement in the sector.

Mining Companies (2 out of 26; 8% interest)

Mining companies show limited interest in geothermal energy. Given the geographical and operational overlap between mining and geothermal resources, this low level of interest highlights a missed opportunity. Greater outreach and tailored solutions—such as utilizing geothermal heat for mineral processing and exploring opportunities for recovery of minerals like lithium and other critical elements from geothermal brines—could significantly enhance mining companies' engagement and interest.

Service Companies (3 out of 56; 5% interest)

Service companies, which provide essential support to energy operations, show very low interest in geothermal development. Most of the companies that aren't interested in geothermal are small, while larger, multinational service companies and manufacturers do express interest. Smaller companies could expand their expertise to cater to geothermal projects, but their low engagement suggests a lack of awareness, a lack of demand within the sector, or a high level of risk associated with diversifying.

Local Operators (3 out of 173; 2% interest)

Local operators represent the largest group in terms of total number (173) but show minimal interest in geothermal development, which highlights a significant gap in potential. These entities generally lack the capital resources to explore geothermal. Most are small, family-owned businesses with existing assets in oil and gas that continue to make profits doing "business as usual" and thereby avoid the risks associated with venturing into a new industry. However, some of these companies are willing to attempt smaller projects that larger companies won't touch, so this attitude could change based on the profitability of oil and gas, financial risks, and the availability of geothermal resources close to companies' existing operations.

Drilling Companies (1 out of 87; 1% interest)

Although drilling companies have technical expertise that is highly relevant to geothermal development, their engagement remains minimal. This finding is not unexpected, as drilling companies typically don't initiate projects themselves; rather, they provide contracted services to entities that fund and manage the projects. The lack of interest may stem from limited demand and the nature of New Mexico's drilling sector, which is largely composed of small, independent operators that might lack the resources, market knowledge, or incentive to assume the risks associated with diversifying into geothermal development. Furthermore, with steady demand and active projects in the oil and gas sector, these firms face little immediate pressure to pursue opportunities in other industries. If the policies suggested in Chapter 7 are adopted, then New Mexico is likely to drill significantly more wells, offering potential opportunities for these companies.

Overall, only 10% of the 392 entities reviewed have shown interest in geothermal development. These groups—geothermal-specific companies, trade organizations, and larger energy operators—are leading the effort by actively exploring options to repurpose New Mexico oil, gas, and mining assets, technologies, skills, and workforce for geothermal development. The lack of engagement in the state from other critical sectors highlights substantial untapped potential and indicates that policy could help further engage these groups.

INITIATIVES SUPPORTING GEOTHERMAL EXPANSION IN NEW MEXICO

Several initiatives, including some originating from the oil and gas industry, are actively advancing geothermal energy development in New Mexico. Next, we describe a few key initiatives that we consider significant.

Outreach and Engagement

There is a growing wave of outreach and engagement among leaders and energy experts focused on advancing geothermal energy in New Mexico. Numerous geothermal-focused events took place in 2024, including the Advancing Geothermal Development in New Mexico workshop at New Mexico Tech (NMT), the Building an Advanced Energy Ecosystem in New Mexico conference, and the New Mexico Energy Initiatives workshop at NMT. In the first half of 2025 NM Tech hosted a geothermal meeting and the New Mexico Energy Summit hosted a geothermal panel.

These gatherings provided critical platforms for stakeholders to discuss the untapped potential of geothermal energy in New Mexico, share technological advancements, and address barriers to development. (Policy recommendation #14 in this report encourages the adoption of geothermal-specific apprenticeships and workforce training; see Chapter 7.)

At the Advancing Geothermal Workshop at NMT, 47 of the 175 registrants (27%) were from industry (**Figure 5.5**). Among the industry groups present, 60% were from the oil and gas sector, demonstrating the industry's

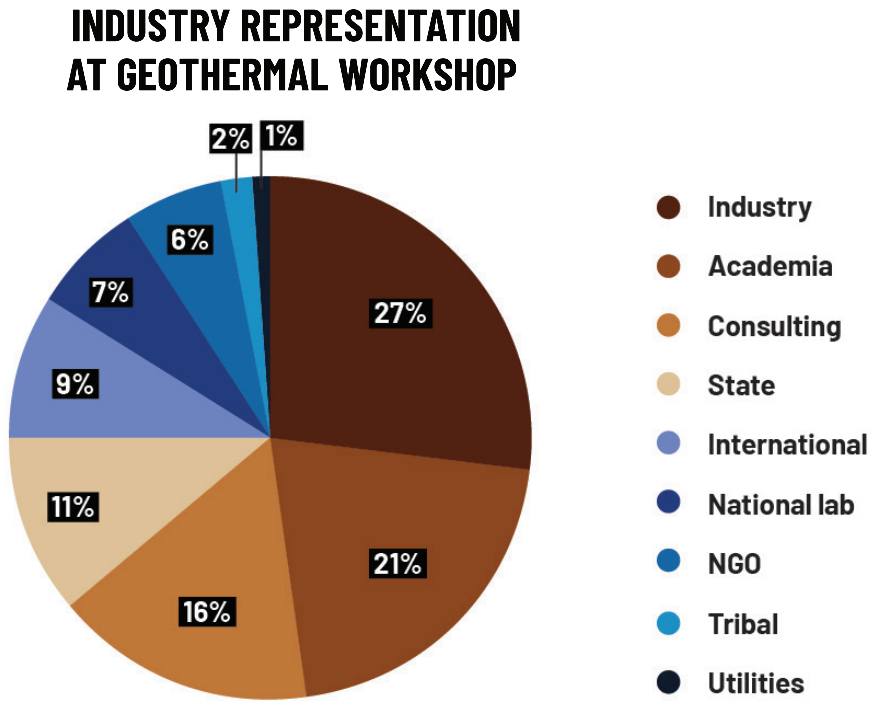


Figure 5.5: Demographics and industry representation at the Advancing Geothermal Development workshop at New Mexico Tech, with a focus on oil and gas.

growing recognition of geothermal energy's potential—and its alignment with their sector's expertise and infrastructure.

Private Sector Efforts in Next-Generation Geothermal

A handful of companies are currently pursuing geothermal development in New Mexico, with new interest entering the state from additional organizations.

Engineered Geothermal Systems (EGS)

One stakeholder that focuses on the use of EGS for utility-scale thermal and electric power generation projects has increased its presence in the state and is leveraging advanced commercial technologies, such as high-tech drill bits and other emerging drilling innovations. The company views New Mexico as a "logical leader in the next-generation geothermal industry," citing the state's resources, access to world-class universities and national laboratories, and large and experienced subsurface engineering and operations workforce.

In 2023, Fervo achieved a major milestone with an EGS by completing a successful 30-day production test at its Project Red site in Nevada.[32] The test demonstrated sustained power output of 3.5 megawatts, validating the commercial viability of an EGS and marking the first time that horizontal drilling and fiber-optic sensing—techniques borrowed from oil and gas—have been successfully applied at this scale in the geothermal sector. While Fervo is currently focused on Utah and Nevada, the company's breakthroughs reveal real potential for EGS applications in New Mexico's geothermal-rich regions.

Advanced Geothermal Systems (AGS)

AGS consists of a circuit of wellbores containing a fluid that is heated via the hot surface of the wellbore pipes, rather than through direct contact with the hot rocks. This system could play a key role in expanding New Mexico's geothermal footprint, and private sector efforts related to AGS are gaining momentum. Companies such as XGS Energy are working with closed-loop technologies to unlock the state's massive geothermal potential, and thermally conductive materials developed by XGS have been reported to increase heat recovery by between approximately 30% and 50% relative to conventional approaches.[33] These materials may offer deployment advantages in various regions of the state because they're less dependent on local water resources and geological conditions. These systems also reduce exploration risks, improve energy output efficiency, and enable development in regions previously considered unusable for traditional geothermal approaches.

SMALL MODULAR HEAT EXCHANGE UNIT

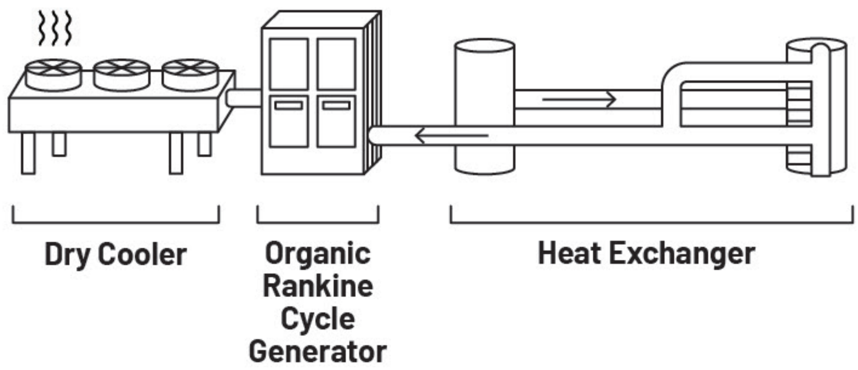


Figure 5.6: A small, modular unit manufactured by Gradient Geothermal at an active geothermal power plant in Nevada. Source: Adapted from Gradient Geothermal. HXC Geothermal System. https://www.gradientgeothermal.com/#HXC

Geothermal Energy Storage (GES)

Geothermal energy storage (GES) is an emerging form of next-generation technology that captures and stores energy using the natural heat and pressure in deep underground rock formations. Fluid is injected into a well during periods of low electricity demand or high renewable generation. The high-pressure reservoir acts like a subsurface battery, storing energy. When energy is needed, the fluid is released and flows back to the surface at high velocity, converting the pressure into mechanical energy that can be used for power generation. Unlike traditional geothermal systems that rely solely on high-temperature hydrothermal reservoirs, GES systems use deep wells in sedimentary basins.

Sage Geosystems—a pioneer in the GES space—applies their oil field experience and techniques to offer easily dispatchable firm power. The Department of Defense (DOD) recently identified Sage as a company whose novel technology will be critical for advancing energy resilience across U.S. military installations.[34] Considering that 5% of New Mexico land is occupied by DOD facilities[35] and intermittent renewables account for 46% of the state's electricity grid (see Chapter 2), GES systems present a unique pathway for New Mexico in next-generation geothermal opportunities.

Coproduced Geothermal from Oil and Gas

Coproduced geothermal resources represent a growing area of development. Traditionally used for direct applications like heating, agriculture, fisheries, and mineral recovery, low-temperature resources are increasingly used for power generation under the right conditions. Coproduced resources leverage hot fluids generated as by-products of oil, gas, and mineral extraction to produce heat or electricity, offering a dual benefit: reduced reliance on foreign energy sources and extended economic life of oil and gas fields.[36] In 2024, Colorado-based Gradient Geothermal highlighted an innovative approach involving small, modular power units at well sites or central facilities (see **Figure 5.6**). These systems extract heat from produced fluids to generate emissions-free electricity, which can be used on-site or supplied to the grid.[37] Gradient has deployed this technology in oil fields in several states to power on-site operations.[38] Leveraging existing oil and gas assets reduces the need for new drilling and exploration and minimizes upfront costs and environmental impacts. This approach not only facilitates cleaner energy but also provides oil and gas operators with a viable pathway to optimize energy use and decrease their carbon footprints, all of which are applicable to New Mexico's current oil and gas operations.

Exploration

New Mexico's rich geothermal resources and supportive policy environment make it an attractive destination for national and international exploration companies specializing in geothermal energy. TLS Geothermics recently expressed interest in New Mexico, expanding on previous work using proprietary geoscience-driven machine-learning tools. The company's approach is inspired by advanced techniques from the oil and gas industry that emphasize predictive modeling rather than reliance on surface manifestations.[39] Other groups with similar novel computational techniques, such as EnviTrace in Santa Fe,[40] could play a pivotal role in next-generation geothermal exploration.

PARTNERSHIPS

Geothermal stakeholders are increasingly forming partnerships in the global energy system to advance their projects. In the private sector, for example, Wells2Watts (an initiative led by Baker Hughes) repurposes inactive oil and gas wells into geothermal assets through closed-loop systems.[41] At the federal level, the Geothermal Energy from Oil and Gas Demonstrated Engineering (GEODE) consortium—funded by the U.S. Department of Energy and led by Project InnerSpace and the Society of Petroleum Engineers—brings together subject-matter experts from the oil and gas and geothermal industries to leverage best practices and knowledge to help expand the use of geothermal technology.[42] In New Mexico and Texas, the Permian Energy Development Lab, a consortium dedicated to energy innovation in the Permian Basin, has partnered with subsurface energy technology company Teverra to develop projects in geothermal energy and other advanced energy fields.[43] The Tribal Energy Consortium, an organization with members representing 20 Tribes in seven western states, is also working to connect Tribal entities interested in geothermal.[44]

TECHNOLOGY TRANSFER

Over the past 20 years, drilling for oil and gas has shifted toward unconventional resources that are harder to access, particularly in the Permian Basin of New Mexico and Texas. These resources require advanced drilling technology such as directional drilling, insulated drill pipe, and advanced casing methods. The importance of hydraulic fracturing, or fracking, can't be understated for enabling access to much larger areas within geological formations with greater precision.

Today, significant geothermal potential exists in hot, dry rock at greater depths and in more complex geologic settings. The oil and gas industry's proven ability to drill faster, to drill horizontal wells, and to surgically target and develop fractures to increase permeability is instrumental for the geothermal industry.[45] Horizontal wells are used in an increasing number of new geothermal technologies to maximize heat extraction, including in an EGS and an AGS, as well as in enhanced geothermal reservoir recovery systems.[46] A pilot project in Utah recently successfully demonstrated the stimulation of a well to increase permeability in tight, deep reservoirs.[47] Oil and gas equipment such as seismometers, distributed acoustic sensing, and reservoir tracers have proven invaluable for characterizing the success of unconventional geothermal operations.[48] For New Mexico to unlock its full geothermal potential, these technologies must be deployed at scale.

INFRASTRUCTURE REUSE

The reuse of oil, gas, and mining infrastructure presents a transformative opportunity to accelerate geothermal energy deployment. Add to all this, there are various ways that existing infrastructure can be repurposed to help reduce project costs, minimize environmental impacts, and fast-track the expansion of the geothermal sector.

Coproduction (Mining)
As mentioned earlier, one of the simplest ways to increase the efficiency of existing oil and gas wells and mines is by using the heat from the resource itself. Heat from mining operations can be used in other parts of a mining operation. For instance, the Lihir gold mine in Papua New Guinea generates several megawatts of electrical energy from a geothermal system within the ore body.[49] Though mines in New Mexico don't currently intersect at such high temperatures, there is potential for thermal and electrical energy generation at depths of 3,000 meters in much of the Rio Grande rift and southwest New Mexico,[50] areas with active mining operations (**Figure 5.8**).

Coproduction (Oil and Gas)
In oil- and gas-producing regions, water in host reservoir rocks is partially or fully artesian and flows to the surface during hydrocarbon production.[51] In the San Juan and Permian Basins, almost seven barrels of water are produced on average for every barrel of oil.[52,53] With this amount of liquid, any fluids at or close to the lower-end temperature for geothermal energy—100°C (212°F)—can be used to coproduce direct thermal energy or binary-cycle electric energy through a small wellhead unit.[54] The energy generated from each well would vary according to flow rate, fluid composition, system design,

and fluid temperature. However, given that wells that produce less than 10 barrels of oil a day—known as *stripper wells*—have produced more than 20% of New Mexico's crude oil in certain years,[55] we shouldn't overlook the potential impact of having many small energy producers. The Department of Energy is currently exploring this potential at several sites nationwide through the Wells of Opportunity program.[56]

Abandoned Mines

Repurposing abandoned mines, particularly those in high geothermal gradient regions, for geothermal energy storage and heating applications[57] can transform liabilities into assets and minimize costs. (This approach could also have several challenges, depending on a mine's location.) Abandoned mines can provide subsurface access to geothermal reservoir analogs, especially in regions where hydrothermal activity aligns with extracted mineral deposits. This access has offered valuable insights for scientific studies.[58] In New Mexico, when a mine reaches the end of its production life, it enters the Abandoned Mine Land (AML) program or the Mining Act Reclamation Program (MARP), in which mine lands are recontoured, hazardous openings are sealed, or disturbed areas are revegetated so the site can once again be a self-sustaining ecosystem.[59,60] Programs

OIL AND GAS WELL CONVERSION OPPORTUNITIES

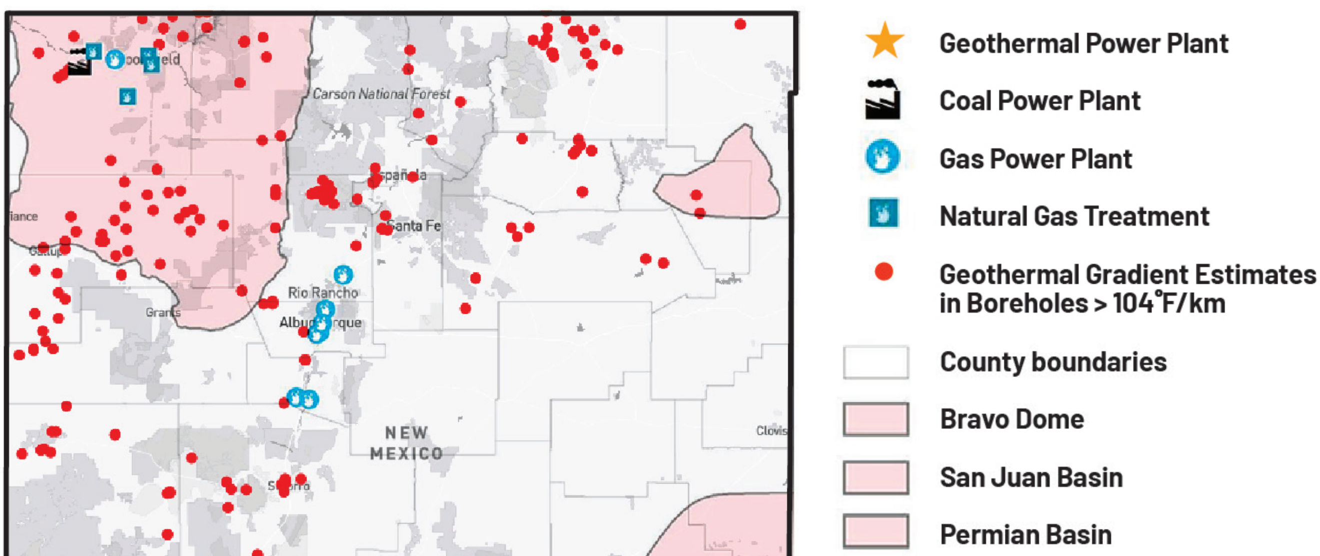


Figure 5.7: Location of hypothetical well conversion projects across New Mexico using existing oil and gas wells with bottom hole temperatures higher than 104°F/kilometer (40°C) for potential use in geothermal energy production. Source: GeoMap.

like these are vital to restoring New Mexico's natural ecology, but before a mine site is locked into AML or MARP, the mine's geological setting should be studied to determine whether there's a geothermal system below that could help support the state's energy transition.

Orphaned Wells

In 2023, New Mexico had 74,099 wells that weren't in operation and an estimated 1,700 unused and unplugged wells (orphan wells) that were environmental hazards and required remediation or plugging.[61,62] After 20 to 25 years, most oil and gas wells in tight formations, such as those in the Permian Basin, yield less than 6% of their initial produced volume.[63] Coal bed methane wells in the San Juan Basin tend to produce for between 20 and 30 years,[64] whereas geothermal wells can last for close to 100 years.[65] Some of the first geothermal wells ever drilled in the United States—such as MAGMA-1 in California at the Geysers—have been operating since 1955.[66]

Repurposing an abandoned, orphaned, or nonproductive well for geothermal use can significantly extend its lifetime and justify the large capital cost of drilling to reenter or deepen it. Reusing an existing well or well system could potentially replace up to 69% of a geothermal project's capital expenditures,[67] which occur during the drilling and exploration phases. (A company would save the median cost of $20,000 to decommission and plug a well).[68] This approach would also help reduce potential methane emissions from an improper plugging job.[69]

But there are challenges associated with converting plugged wells. Geothermal wells often need to go deeper than even the deepest oil and gas wells. Geothermal also uses a larger wellbore diameter than is typically used in oil and gas drilling.[70] Additionally, geothermal energy production may require multiple wells to establish a system for cycling water to the hot rock. The well's location would need to have suitable viable heat in the subsurface, and electricity transmission costs would need to be reasonable; many oil and gas wells, however, are located off the grid in remote areas. (**See Figure 5.7**.)

Current research around the world focuses on these challenges[71,72] due to the potential cost savings.[73] New Mexico is already pursuing this opportunity with the recent passing of HB 361, which authorizes the conversion of depleted oil or gas wells into a facility that provides energy storage or develops geothermal energy (see Chapter 7).[74]

Road and Structure Reuse

A final benefit exists in the use of surface infrastructure already in place from mining and oil and gas—that is, roads, mining platforms, wellpads, and operation centers. Geothermal operations can also, at times, repurpose pipelines, drill rigs, and large mining equipment. Along with the advantages of reducing the need to alter new terrain, use of existing infrastructure could enable developers to save on up-front costs and permitting time.[75]

SCIENTIFIC AND OPERATIONAL EXPERTISE

Proper geothermal project development requires extensive exploration to characterize the subsurface geology. This exploration typically involves structural geology, lithology, geochemistry, geophysics, and other methods that are integrated to characterize a potential reservoir. A major contributor to this knowledge base comes from existing oil and gas and mining operations, including lithologic data from mine shafts and well logs; geochemical data from produced fluids and ores; direct measurements of geophysical properties such as resistivity and density (which geophysics would otherwise have to infer); high-resolution seismic data; and direct temperature measurements. Oil and gas companies retain such data, which can be repurposed for geothermal exploration, reducing up-front risks as a result. Similarly, mining companies' knowledge of subsurface conditions, which is generally gained during exploration and planning, can be applied to identify viable geothermal resources. The data may be limited to shallower depths than the geothermal project will reach, but it is a solid start.

Oil and gas industry involvement in geothermal can lead to accelerated learning curves and substantial cost reductions.[76] One report specific to Texas found that 70% of entities interviewed in the oil and gas sector view any technical challenge posed by geothermal energy as solvable.[77] The large amount of geographic overlap of oil and gas companies from Texas in New Mexico is a good sign.

WATER RESOURCE MANAGEMENT

New Mexico is prone to droughts.[78] Given the high volumes of water extracted with each barrel of oil or million cubic feet of natural gas noted earlier, recycling produced water reduces reliance on the limited groundwater resources in the semi-arid areas of New Mexico. Produced water can be—and has been—used in new hydrofracturing projects and as a drilling fluid, and it has been reinjected for enhanced oil recovery as well. There are few restrictions in place for reinjecting produced water in energy operations, and this will be a critical skill to transfer for future geothermal operations in similar areas.[79]

Geothermal projects require water for drilling, operation, and potential well stimulation. It is feasible, if not imperative, for future projects look to existing produced fluids from oil and gas and any nearby mining operations to help meet these water needs.[80] Oil and gas operations are also required to monitor wastewater, sample fluid chemistry, eliminate spills,[81] and adjust fluid chemistry. New Mexico's Geothermal Resources Development Act[82] holds geothermal projects to the same standards, so the oil and gas industry is well positioned to transfer knowledge to geothermal development.

AVERAGE WEEKLY WAGES IN PRIVATE SECTOR IN NEW MEXICO (2023)

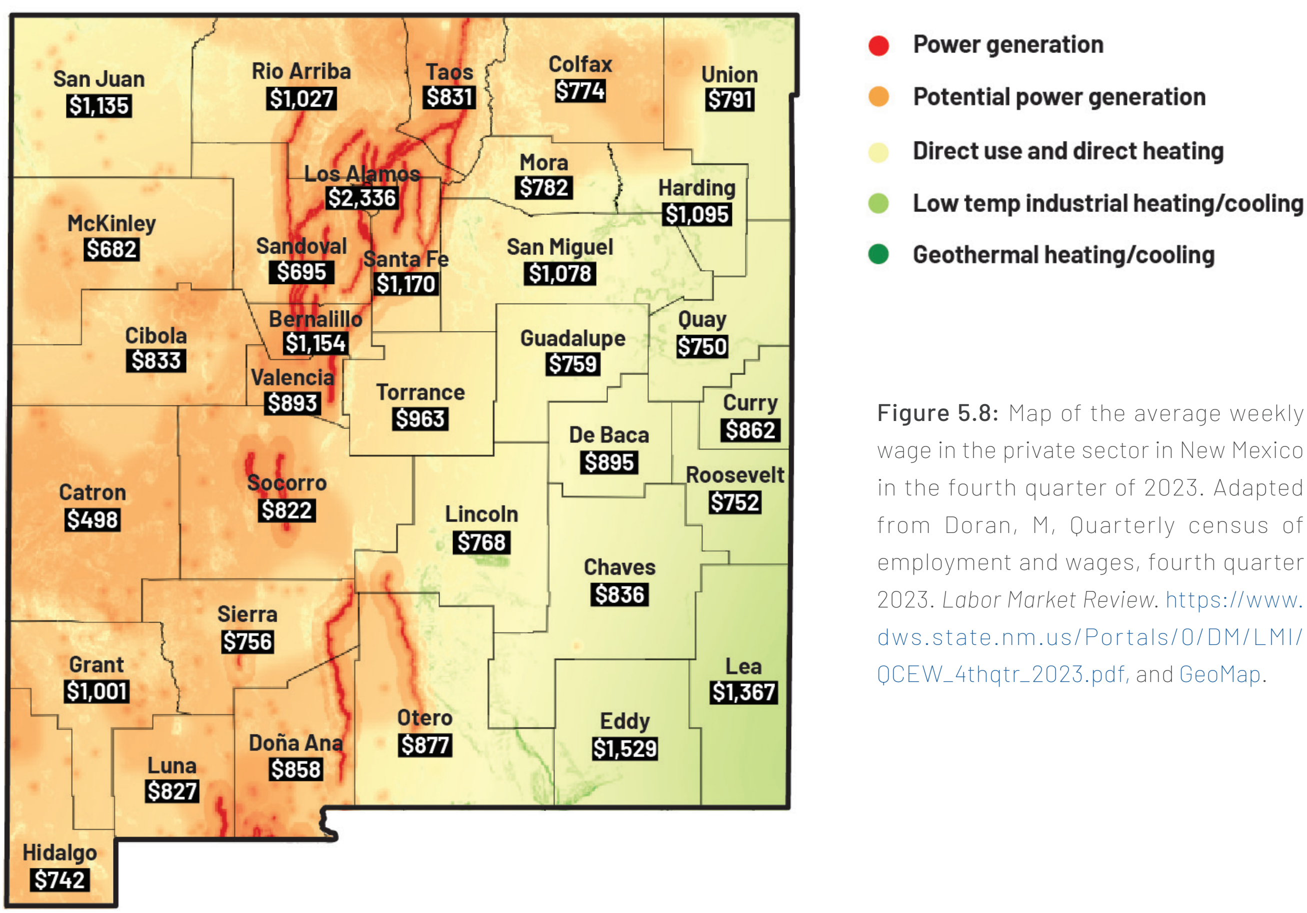


Figure 5.8: Map of the average weekly wage in the private sector in New Mexico in the fourth quarter of 2023. Adapted from Doran, M, Quarterly census of employment and wages, fourth quarter 2023. *Labor Market Review*. https://www.dws.state.nm.us/Portals/0/DM/LMI/QCEW_4thqtr_2023.pdf, and GeoMap.

WORKFORCE DEVELOPMENT

Current Workforce Trend and Wages

In New Mexico,the mining, quarrying, and oil and gas extraction sector accounted for 23,563 direct jobs in the fourth quarter of 2023.[83] Of these, 66.4% were in support activities, 20.2% in oil and gas extraction, and 13.4% in mining.[84]

Figure 5.8 shows that the state's highest average weekly wages are concentrated counties with either significant mining, oil, and gas production activities, such as Lea, Eddy, Grant, and San Juan, or counties associated with government, national labs, and urbanized economies, such as Santa Fe, Los Alamos, and Bernalillo.[85] This indicates salary disparities: Wealthier counties benefit from extractive industries, research facilities, or urban centers, while poorer rural areas lack infrastructure and income from energy resources. Interestingly, geothermal resource potential aligns with some of these lower-income counties, particularly in the south and southwest parts of the state, along the Rio Grande rift. Expanding geothermal energy in these regions could promote economic development.

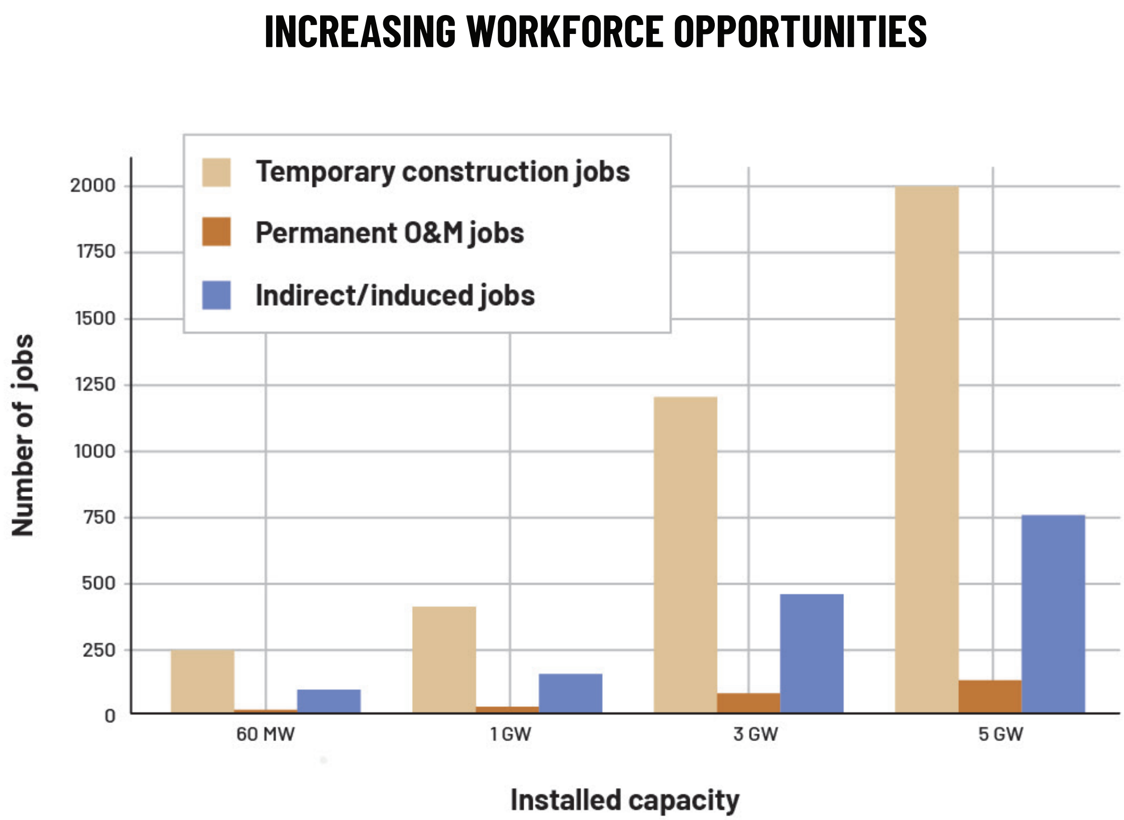


Figure 5.9: Employment impacts of geothermal energy expansion in New Mexico under various capacity growth scenarios and reasonable jobs creation ratios by 2040. GW = gigawatts; MW = megawatts. Sources: Hanna, R., Heptonstall, P., & Gross, R. (2024). Job creation in a low carbon transition to renewables and energy efficiency: A review of international evidence. Sustainability Science, 19(1), 125–150. https://doi.org/10.1007/s11625-023-01440-y; Research and Analysis Bureau. (n.d.). Nevada labor market information: Quarterly census of employment and wages (QCEW). State of Nevada Department of Employment, Training & Rehabilitation. https://nevadaworkforce.com/QCEW/index; Fendt, L. (2022, December 14). The push for a greener New Mexico–from immigrant oil workers. Searchlight New Mexico. https://searchlightnm.org/the-push-for-a-greener-new-mexico-from-immigrant-oil-workers/

Job Creation Benefits

To assess the potential for job creation from geothermal energy development in New Mexico, we developed four scenarios. Three are based on targeted development goals (reaching 1 gigawatts, 3 gigawatts, and 5 gigawatts of installed capacity by 2040),[86] while the fourth is a more conservative scenario based on current development trends and growth rates. We should note that data shows New Mexico has the technical potential of at least 163 gigawatts of geothermal.[87] Gigawatt-scale geothermal is increasingly viable, as Fervo Energy is demonstrating up to 2 gigawatts, proving the scale is technically and commercially achievable.[88] These data points show that it's possible (particularly if many of the policies suggested in Chapter 7 are implemented) that the state could surpass a 5 gigawatt goal. (A growth rate refers to the percentage increase in a given value—such as installed geothermal capacity—over time, typically calculated on an annual basis.) To model future capacity, we applied a standard exponential growth formula:

$$C(t) = C_0 * (1+r)^{t-1}$$

Where:

$C(t)$ = installed capacity at year (t)
C_0 = 15 MW (initial geothermal capacity in 2024)[89]
r = annual growth rate
t = number of years since the starting point

We calculated the needed growth rate for the four scenarios in New Mexico to be:

- To reach **1 gigawatt by 2040**, an annual growth rate of approximately **33%** of geothermal capacity is needed.
- To reach **3 gigawatts by 2040,** an annual growth rate of approximately **43%** is needed.
- To reach **5 gigawatts by 2040**, an annual growth rate of approximately **49%** is needed.
- A fourth scenario assumes a conservative **10% annual growth rate**, resulting in **only 60 megawatts added by 2040.**

Building on these scenarios, we estimated the potential for geothermal-related job creation in New Mexico (see **Figure 5.9**). We applied conservative full-time-equivalent job creation rates per megawatts based on what we found in our research:

- 4 jobs per megawatt for direct temporary construction jobs[90]
- 0.25 jobs per megawatt for direct permanent operations and maintenance jobs[91]
- 1.5 jobs per megawatt for indirect/induced jobs per megawatt[92]

These results—based on idealized, incremental capacity additions to the grid—are reasonable assumptions for modeling purposes, but they don't account for real-world constraints. We should also note that a skilled geothermal workforce will likely earn higher wages than those in most other occupations.[93]

Depending on the scale of deployment, geothermal could support thousands of jobs statewide by 2040. Under a 5 gigawatt growth scenario, geothermal development could create nearly 2,000 construction jobs, 750 indirect and induced jobs, and more than 125 permanent operations and maintenance jobs.

Job Quality and Longevity

The simulation referenced (**Figure 5.9**) uses a direct correlation between megawatts of geothermal capacity and job creation. (While this correlation may hold in some cases, we recognize the limitations.) Comparing New Mexico's oil and gas production with employment trends in the mining, quarrying, and oil and gas extraction sectors however, shows a clear decoupling between output and workforce size. This suggests that productivity gains, automation, and capital-intensive extraction methods have enabled significant increases in output without a proportional rise in labor demand. Another consideration is that much of the workforce could be transitory and live out of state (e.g., living in Texas, for work in the Permian Basin).

Rural New Mexico communities that have relied on oil and gas jobs for their livelihood and dealt with a lot of employment instability are looking for more stable, sustainable jobs with fewer associated risks.[94] A 2021 medical study found that New Mexico's oil and gas industry

RELEVANT SKILLS

Figure 5.10: The Congressional Research Service estimates that 61% of the oil and gas workforce is in "high-relevance occupations" that directly translate to the geothermal industry. Source: CRS: https://www.congress.gov/crs-product/R47405

has the second-highest mortality rate among all oil and gas workers in the country—and the second highest of all industries in New Mexico, after construction.[95] The leading causes of death included vehicle accidents and cardiovascular incidents, both of which are avoidable with proper work practices and training.

Historical trends based on the evolution of employment in extractive industries[96] suggests that increased geothermal capacity will not necessarily result in exponential job growth in New Mexico. However, unlike the cyclical nature of the oil and gas industry, geothermal development offers the potential for long-lasting, stable jobs in operations, maintenance, and indirect support services. A recent National Renewable Energy Laboratory study in California estimates that natural gas could create 0.13 jobs per thousand homes powered; the numbers of jobs per thousand are only 0.10 and 0.13 for wind and solar, respectively. For geothermal, however, that number increases to 0.40 jobs per thousand homes powered.[97]

Currently, approximately 61% of the state's oil and gas workforce is employed in "high-relevance occupations" that align closely with roles needed in the geothermal industry, highlighting strong potential for New Mexico's oil and gas workforce to find new roles.[98] State institutions are supporting this shift. The New Mexico Energy, Minerals, and Natural Resources Department is offering free training on heat pumps and zero-energy buildings,[99] and New Mexico Tech has launched a geothermal certificate program to help build a skilled local labor force for the state's clean energy future.[100]

CONCLUSION

New Mexico has a significant opportunity to create more jobs, economic development, and state and local revenue by using its existing oil and gas know-how to tap into its substantial geothermal resources. Our modeling shows that nearly 3,000 jobs would be added to the state if it produced just 5 gigawatts of its massive geothermal potential. Adding geothermal energy to New Mexico's employment portfolio would leverage skill sets and expertise from local workers in the mining and oil and gas sectors, provide additional employment cushions to two sectors notorious for boom-and-bust cycles, offer an avenue for the state to diversify its revenue stream, and greatly improve economic and employment outlooks in parts of the state that are lagging.

Geothermal energy has garnered strong interest, yet only 14% of the 2024 New Mexico Tech Advancing Geothermal Development Workshop's industry participants—and just 10% of overall industry stakeholders surveyed in this analysis—are actively exploring geothermal opportunities or developing projects in New Mexico. This lack of exploration demonstrates that critical challenges persist, despite the state's unique combination of abundant geothermal resources, extensive oil and gas infrastructure, and a skilled workforce. As outlined in Chapter 7, "Policy and Regulatory Pathways to Catalyze Geothermal in New Mexico," other incentives may be needed to help harness the potential of geothermal.

The future of New Mexico's geothermal landscape will be characterized by two contrasting groups of oil and gas and mining stakeholders: small, independent businesses with limited assets and larger companies with substantial resources. These groups face distinct challenges that hinder their expansion into geothermal activities.

BARRIERS TO STAKEHOLDER ENGAGEMENT

Large energy companies that could be leading the development face challenges such as the following:

- **Permitting complexity:** A lack of clear permitting processes discourages investment. Streamlining regulations and providing clearer guidance are critical steps to address this issue.

- **High up-front costs and risks:** Exploration and drilling require significant financial investment, posing substantial risks. State-backed loan guarantees, tax credits, or other financing mechanisms could attract developers and reduce financial obstacles. Repurposing existing infrastructure for geothermal use can also reduce costs and financial risk. Finally, pilot projects could help highlight the state's potential for other investors.

- **Land access issues:** Many promising geothermal resources are located on remote, Tribal, or federally controlled lands, distinct from areas with current and historical oil and gas development. Partnerships with federal agencies and infrastructure improvements are essential to unlocking these resources for potential exploration by stakeholders with the capital to finance such ventures.

Small businesses and independent operators face additional challenges:

- **Awareness:** Many small operators or independent service companies lack knowledge about New Mexico's geothermal potential and the economic benefits of diversifying their portfolio. Outreach programs can highlight geothermal benefits, high-paying job opportunities, and compatibility with existing skill sets in drilling and services.

- **Training and workforce development:** Specialized training programs that focus on the nuances of geothermal technologies can help small businesses repurpose their expertise for this sector.

- **Cost and risks:** Access to industry-standard data, software, analytical tools, and technologies is often cost-prohibitive, creating a significant barrier for new entrants and smaller organizations. Additionally, the financial and operational risks associated with diversifying into emerging sectors like geothermal energy are difficult for many small businesses to absorb.

- **Cultural and industry mindset:** A "business as usual" mentality within the traditional oil and gas sector hinders innovation. Advocacy campaigns that showcase successful geothermal projects and targeted engagement efforts can drive a cultural shift and inspire broader participation.

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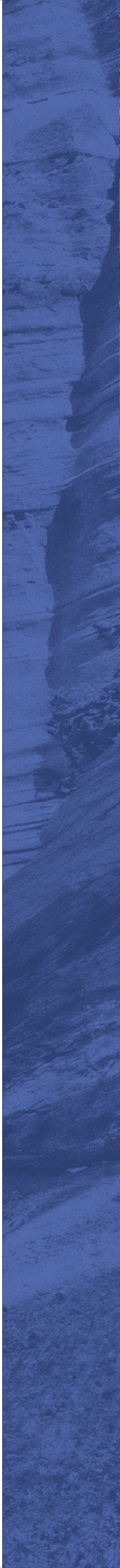
Part III

Legal, Regulatory, Environmental, and Stakeholder Considerations



Chapter 6

Who Owns the Heat? Navigating Subsurface Rights via New Mexico Regulation and Law

Missi Currier, President and CEO, New Mexico Oil and Gas Association

New Mexico and the Tribes of the region are poised to lead the way in advancing the use of geothermal energy. Many legal and legislative resources can be helpful in clarifying pathways for exploring and leasing of lands so that all residents can benefit from this clean, firm energy source. Principles for addressing both the ownership of geothermal resources and the rights of property owners can likely be derived from well-established rules developed over the years in New Mexico's property law—particularly related to oil and gas, coal mining, and water extraction.

New Mexico's surface land is approximately 78 million acres—nearly half of which is private land (almost 45%, including county and city land), and then a mix of state and federal land and Tribal and Pueblo land.

As this report makes clear, new technology makes it feasible to tap into the heat in the dry rock below the surface of the Earth. New Mexico is ideally and uniquely situated to be a major producer of geothermal energy production because of both its favorable geologies and the state's know-how in the oil and gas industry.

There are, however, potential legal bumps in the road. As geothermal energy is more widely used, energy developers will aim to establish lease agreements with more property owners that give the developers the rights to access and use the heat in the subsurface of owners' land. The state's long history of oil and gas development and mining means that

New Mexico has plenty of language covering the ownership of surface and subsurface properties and mineral estates. That language guides the severing of assets, especially if there aren't specific legal documents governing an estate.

Yet the state legislature has never directly addressed two big issues: (i) whether it definitively considers geothermal energy and associated properties to be separate from or part of a mineral estate, and (ii) who specifically owns the resources associated with geothermal energy (i.e., heat, water, steam). Without that clarity, a geothermal operator may not even know who they should speak with to legally establish a lease for geothermal exploration, development, and production.

Texas recently grappled with this very same bump in the road. In the Lone Star State's 1975 Geothermal Resources Act, the legislature abstained from determining if geothermal energy was owned by the mineral estate or the surface estate (in the absence of a controlling document with specific language).[1] To fix that problem, the Texas Legislature recently passed SB 785, which clarifies that heat, energy, steam, hot water, hot brines, and geopressured water aren't minerals under Texas law. That means that if there is a severance of the mineral estate from the surface estate in Texas, geothermal energy and its associated resources belong to the surface estate, unless there's a document that specifically conveys the geothermal energy and associated resources to the mineral estate.

The good news is that New Mexico's Legislature has been thoughtful about geothermal resources. The state covers aspects of geothermal extraction in its own constitution. New Mexico also passed legislation in 2016 in which it attempted to define *geothermal resources*, and it has also defined *geothermal heat* in regulations. As mentioned, for non-Tribal lands, New Mexico's history of oil and gas development has set a precedent for the leasing and development of properties on estates. The same holds for Tribal lands: Although each Tribe, Nation, or Pueblo is a unique sovereign in New Mexico governed by its own laws and federal laws, there's also plenty of case law precedence for the leasing of surface and subsurface properties.

Despite the state's advanced planning, a few aspects of the legal and regulatory language could appear contradictory.

There's a case to be made that the language found throughout New Mexico's legal and regulatory landscape supports the precedent that geothermal energy and associated resources are *not* a mineral. However, because there is so much legal structure in place around the business of mineral extraction, the state intends to *regulate* geothermal as a mineral. To put it more directly: Regulate it as a mineral, but that doesn't mean it's a mineral when it comes to property rights. (This is something that happens next door in Texas: When that legislature wrote its 1975 law governing geothermal resources, it laid out that geothermal energy and associated resources "shall be *treated and produced as* mineral resources" [emphasis ours], but they didn't define geothermal energy and associated resources as a mineral resource.[2])

This chapter explores the existing laws and precedents that could help govern the issues of heat ownership in New Mexico, such as laws and regulations related to ownership of surface and mineral estates; laws and regulations related to geothermal resources and geothermal energy; considerations for geothermal resources on Tribal land; and ways the legislature could help clarify and prevent potential confusion. Creating more legal certainty regarding who owns the heat will accelerate the development of geothermal across New Mexico.

OWNERSHIP

It may be helpful to start the conversation about ownership of geothermal properties at the core of the matter: getting legal access to the resource.

The majority of New Mexico's private land is located to the east of the Rio Grande rift zone.[3] Obtaining the rights to access and develop geothermal resources in New Mexico potentially involves several different landowners and resource development agencies. The responsibility for developing any kind of resource—whether water, minerals, or geothermal—falls under different entities.

New Mexico state law assumes that the owner or lessee of geothermal resources will file for a permit to drill an exploratory or extraction well for those resources.[4] Language in Chapter 71 of the New Mexico Statutes regarding energy and minerals requires individuals "applying for permits to explore, develop or produce geothermal resources to demonstrate that they have the right to produce the geothermal resources through ownership, leases, permits or other documentation."[5] In addition to this requirement, New Mexico's Energy, Minerals, and Natural Resources Department must allocate royalties from geothermal energy projects to the owners of these projects.[6] None of this language, however, explicitly classifies ownership of geothermal resources or geothermal energy into the surface or subsurface estate.

Land ownership in New Mexico is mixed, with 34.7% owned by the federal government; 11.9% owned by the 23 sovereign Tribes, Pueblos, and Tribal Nations present in the state; 7.8% is owned by the state itself. The rest—44.9%—is owned by municipal governments or is private land.[7]

THE AMERICAN RULE AND CASE LAW

To dig deeper into minerals and surface ownership, it's helpful to look at the "American Rule" and some case law.

According to the New Mexico Energy, Minerals, and Natural Resources Department, New Mexico is part of the bloc of states that follow the "American Rule" with regard to pore space ownership.[8] The American Rule essentially states that a surface owner owns the geologic pore space formation below the surface with rights to store resources within the pore space, while the mineral estate holder has the right to the minerals but not to the geologic formation itself.[9] (This rule wasn't established with geothermal resources in mind.) Geothermal heat—unlike other minerals within a given geothermal resource—can be a component of the pore space rather than the mineral estate, so geothermal heat is retained by the surface owner.

In 1929, *Jones-Noland Drilling Co. v. Bixby* laid the groundwork for limiting the mineral estate to the removable substance, which is separate from the structure of the Earth.[10] In this case, fee ownership of the soil of the Earth was retained by the surface estate holder, while ownership of the mineral estate (in this case, oil and gas) was severed and belonged to the holder of the mineral estate.[11]

In 2007, the Oil and Conservation Division of the New Mexico Energy, Minerals, and Natural Resources Department argued that the "subsurface [geologic formation] is legally part of the 'surface estate,' conveyed to or retained by the surface owner." [12] This argument concluded that the severance of the mineral estate from the surface estate doesn't result in a conveyance of the subsurface pore space.[13]

If we apply the American Rule and the court's ruling in *Jones-Noland Drilling Co. v. Bixby*, along with existing regulations, geothermal heat—a property of the subsurface rock formations—could ostensibly be part of the surface estate, meaning there's a reasonable case in New Mexico for treating geothermal energy as separate from the mineral estate. Surface estate owners could therefore retain ownership of the pore space formation but not the minerals within the pore space. The minerals present in geothermal resources could also be held by the owner of the mineral estate.

Water is also included in surface and subsurface ownership severance issues in many states, but it is a public resource in many Western states, including New Mexico. Groundwater resources are held by the state to be appropriated for beneficial use. In 2004, the case *New Mexico v. General Electric* addressed the state's ownership of an aquifer, with the court determining that although the saline water within the aquifer was the property of the state, the geological aquifer formation was not.[14] That case raised the question of state ownership of groundwater in relationship to geothermal resources and found that geothermal resources in water that must be pumped to the surface may be subject to permitting for water rights through the Office of the State Engineer.[15,16]

CONSTITUTION, COURTS, AND CODES

The majority of definitions in New Mexico's legal and regulatory language treat minerals as separate from geothermal resources and geothermal heat.

State Constitution

In 1967, the residents of New Mexico passed legislation amending the New Mexico Constitution—the supreme law of non-Tribal land—to help manage leases on state lands[17] and inserted the term *geothermal steam and waters*.[18] The revised passage reads, "Leases and other contracts, reserving a royalty to the state, for the development and production of any and all minerals *or for the development and operation of geothermal steam and waters* [emphasis ours] on lands granted or confirmed to the state of New Mexico." The additional language differentiated geothermal resources from the term *minerals*.[19]

That language, taken with other language in New Mexico Statutes and case law, also creates a reasonable interpretation that heat, steam, and water are not minerals. It would follow, then, that in the absence of a document in property records that says otherwise, heat, steam, and water should belong to a surface estate.

State Courts

When faced with surface and subsurface property disputes, courts in some Western states have followed the "ordinary and natural meaning" test.[20] In other words, when trying to determine property ownership, the courts evaluate whether the property in question would ordinarily and naturally be considered a mineral by people at the time when a relevant legal document was created.

In New Mexico, courts have treated the definition of *mineral* as seemingly separate from geothermal heat. Minerals, under state law, are defined as "substances" that are "extracted."[21] It is reasonable to assume that heat fails to meet the definition of a "substance" because it is not matter but rather is a state of particle excitation *within* a substance.[22] Heat and energy are intangible qualities of the Earth itself. Again, it seems reasonable to assume geothermal heat doesn't meet the definition of a mineral.

In Section 69 of the New Mexico Statutes, which covers mining, the state defines a mineral as a "nonliving commodity that is extracted from the earth for use or conversion into a saleable or usable product."[23] (The same statute clarifies that the act of mining does not include the exploration or extraction of geothermal resources.[24]) In this statute, the operative word is *commodity* as opposed to *substance*. Once again, a commodity could be considered something tangible, whereas heat and energy are intangible. So again, geothermal heat isn't viewed as a mineral.

Therefore if New Mexico definitively adopted the "ordinary and natural meaning" test applied in many Western states, it could be clear that heat is not a mineral,[25] and ownership of heat would be retained by the surface estate holder.

Regulatory Language

In line with all of the above, the definition for *geothermal energy*, found in New Mexico Statute 69-2-7 (which outlines the functions of the New Mexico Bureau of Geology and Mineral Resources) is as follows: "The natural heat of the earth or the energy, in whatever form, below the surface of the earth present in, resulting from or created by or that may be extracted from, this natural heat."[26] This definition is then expanded with this language: "Any person drilling a hole on state lands to a depth of ten feet or more who encounters or whose drill cuts into a geothermal energy source of one hundred degrees centigrade or more shall, within ninety days from the date of the penetration, report in writing to the director the depth, location and nature of the geothermal energy source."[27]

MIXED MESSAGES

Despite consistency in the state's constitution, state codes, and regulations, language in other New Mexico legal guidelines could confuse matters.

Acts, Statutes, and Codes

In February 2016, the New Mexico Legislature updated the Geothermal Resources Development Act[28] to grant the Energy Conservation and Management Division of the Energy, Minerals, and Natural Resources Department the ability to regulate geothermal energy.[29] More recently, this act has been further amended to encourage the deployment of geothermal in the state. (However, the act is silent on the issue of geothermal resources on privately owned lands.[30])

Despite the state's advanced planning for geothermal energy use, a few aspects of the legal and regulatory language could appear contradictory—and therefore confusing—which could hinder the development of geothermal energy.

The act does offer definitions that can apply to various aspects of expanded geothermal energy usage. Unfortunately, the definition of *geothermal resources* (also used in NMSA 19-13-2, 7-2-18.38, and 7-2A-24.1) is broad and introduces confusion in attempts to determine how to define geothermal properties specifically:

> The natural heat of the earth in excess of two hundred fifty degrees Fahrenheit, or the energy in whatever form below the surface of the earth present in, resulting from, created by or which may be extracted from this natural heat in excess of two hundred fifty degrees Fahrenheit, *and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases and steam in whatever form found below the surface of the earth,* [emphasis ours] but excluding oil, hydrocarbon gas and other hydrocarbon substances and excluding the heating and cooling capacity of the earth not resulting from the natural heat of the earth in excess of two hundred fifty degrees Fahrenheit, as may be used for the heating and cooling of buildings through an on-site geoexchange heat pump or similar on-site system.[31]

By adding "all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases and steam in whatever form found below the surface of the earth" and explicitly excluding other minerals that could also be extracted, such as oil and hydrocarbon substances, the language could seem contradictory to the state constitution, case law decisions, and other regulatory language, even though this definition was written later.

This addition could be especially confusing if interested parties were looking for language to help them understand how to expand leasing. Much of the state's language—including the definition of *geothermal energy* provided earlier—points to the idea that geothermal energy is *not* a mineral.

In this case, looking east could again be helpful: It is well known in Texas law that while a mineral may be suspended in a solution, the mineral belongs to the mineral owner and the solution belongs to the surface owner. The most common example is lithium suspended in brine or salt water. The lithium belongs to the mineral estate and the brine or salt water belongs to the surface estate. This notion was specifically incorporated into Texas regulations in SB 785 in a recent legislative session.[32]

To expand development of geothermal energy within New Mexico, the state and federal governments could take specific steps to clarify terms and eliminate potential confusion.

In addition to these examples, a few other areas of legal and legislative language could create confusion concerning ownership.

The Tax Code in Section 7 of the New Mexico Statutes includes "steam and other geothermal resources" under the definition of *mineral*.[33] The language refers to the same definition of *geothermal resources* as is used in the Geothermal Resources Development Act.[34] It's quite possible that the tax code includes geothermal resources as a mineral because of the minerals present in geothermal brines. It would follow, then, that the language was included to cover sources of tax revenue.

The state also has some confusing case law, including *Bogle Farms, Inc. v. Baca* (1996), which offers some interpretation of *minerals* in the context of patents for state lands.[35] In this case, however, the court determined that the term *mineral* must be determined on a case-by-case basis, considering the intent of each party and the public policy issues involved. In 2011, in *Prather v. Lyons*—another case relating to patents for state lands—the court applied the *Bogle Farms* ruling and examined the meaning of *minerals* in the context of this specific case. This case found that the interpretation of the term *minerals* is limited and does not apply to private lands.[36]

Later in this chapter, we discuss potential approaches to clearing up the confusion stemming from these various cases and statutes.

Geothermal Energy on Tribal Lands

Tribes have a unique trust relationship with the federal government, a sovereign-to-sovereign relationship with states, and a sovereign-to-sovereign relationship with one another.[37] A common saying in the Colorado River basin is "If you know one Tribe, you know one Tribe."[38] Each Tribe has its own set of governing laws, as well as applicable federal and state laws. Within New Mexico, there are 23 sovereign Tribes, Nations, and Pueblos,[39] as well as individual Indian land allottees.

In general, lease terms on Tribal and individual Indian lands are similar to federal lease terms, as approved by both the Tribe and the U.S. secretary of the interior.[40] (Currently, there is no specific public record of individual Tribal law within New Mexico pertaining to geothermal resources; however, some Tribes outside of New Mexico have laws related to geothermal resources.[41] These limited laws tend to treat geothermal resources not as a mineral but as a water source.[42])

In general, all allotted or Tribal Indian lands are exempted from New Mexico state laws regarding mining.[43] Geothermal project development for Pueblos, Tribes, and Nations is conducted with the Tribes, and the Bureau of Indian Affairs, within the Department of Interior under Title 25 CFR Part 225. Under federal law, an Indian land allottee may lease allotted lands for mining purposes.[44]

New Mexico state law doesn't have any specific references to geothermal resources and Tribal land, but Nations, Tribes, and Pueblos are eligible to receive funding from the state's Geothermal Projects Revolving Loan Fund.[45]

MOVING FORWARD WITH CLARITY

To expand development of geothermal energy, the state and federal governments could take specific steps to clarify terms and eliminate potential confusion.

One way forward could be for the judicial or legislative body to provide clarity on the state's adoption of the "ordinary and natural meaning" test. If this standard interpretation is applied in New Mexico, the state could create a more predictable environment for the meanings of *minerals* and *other minerals*, which would be a step toward clearly defining *geothermal energy* and the associated resources.

The state could also benefit from changing the unclear language in the definition of *geothermal resources* in the Geothermal Resources Development Act that includes "minerals in solution." The law recently passed in Texas, SB 785, amends that state's relevant statutes and provides that any minerals found in a geothermal geologic zone are not included in the definition of *geothermal energy* and its associated resources. This revised language could be especially helpful in New Mexico because, as mentioned, none of the definitions in the state's legal and legislative language governing geothermal heat or energy were intended to provide clarity on the ownership of these resources. Chapter 7 outlines specific policy recommendations for how to address this issue.

As for the tax code, after consulting with the appropriate tax officials in order to keep the state whole for tax purposes, legislators could consider removing *geothermal* from the definition of *mineral* under the tax code. Chapter 7 outlines 15 policy recommendations for how New Mexico can catalyze more geothermal development, one of which is to clarify the state's legal structures that indicate that the surface estate is the owner of the heat.

Finally, geothermal project development for Pueblos, Tribes, and Nations are conducted with the Tribes and the Bureau of Indian Affairs within the Department of Interior, and supported by the Bureau of Land Management.[46]

CONCLUSION

New Mexico and the Tribes that reside in the region are poised to lead the way in advancing the use of geothermal energy. Many legal and legislative resources could be helpful in clarifying legal pathways for exploring and leasing of lands to benefit from this clean, firm energy source. Principles for addressing both the ownership of geothermal resources and the rights of property owners can likely be derived from well-established rules developed over the years in New Mexico's property law—particularly related to oil and gas, coal mining, and water extraction.

Taken all together, one reasonable interpretation is that New Mexico treats geothermal resources as a mineral for *regulatory* purposes only and that the language found throughout the state's legal and regulatory landscape supports the precedent that geothermal energy and associated resources are *not* a mineral. As mentioned at the beginning of this chapter, the state might intend to *regulate* geothermal as a mineral, but that doesn't mean it *is* a mineral where property rights are concerned.

It would go a long way for the courts or legislature to chart a clear path forward, determining whether the titles to geothermal resources and geothermal energy are held by the surface estate owner or the mineral estate owner.

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Chapter 7

Policy and Regulatory Pathways to Catalyze Geothermal in New Mexico

Bruno Carrara

Fifteen policies across five categories of action, if enacted, could catalyze geothermal development, create jobs, increase economic development, and secure New Mexico's energy future.

Geothermal energy is not a new concept in New Mexico. Residents in the state have a long history of enjoying the state's numerous geothermal hot springs and baths. Native people in New Mexico were using the springs long before the Spanish arrived.[1] It is no surprise, then, that geothermal energy is listed as a valuable mineral resource in New Mexico's constitution.[2] In fact, New Mexico is the only state that explicitly mentions geothermal development in its constitution. And yet, New Mexico has significant untapped geothermal resources, including the potential of 163 gigawatts for electricity generation.[3]

Because geothermal energy is in use in the state today, New Mexico has established basic regulatory frameworks and policies to govern its use. The state also passed legislation in 2024 and 2025 to create more geothermal opportunities. But more work needs to be done so New Mexico can expand its resources—bolstering its skilled workforce in the process—and solidify geothermal as a cornerstone of its energy mix.

This chapter identifies 15 policies across five categories that, if enacted, would catalyze the expansion of New Mexico's clean and abundant geothermal resources. Collectively, these policies can help New Mexico create jobs, increase economic development, and meet its climate targets. Many of these policies would build parity for geothermal compared with other energy sources in current New Mexico law. Some are based on actions that other states have successfully implemented—in other words, the geothermal wheel does not need to be reinvented. Acting on these 15 policies will help New Mexico deliver on the promise it set up when it included "for the development and operation of geothermal" in its constitution in 1967.[4]

GEOTHERMAL POLICY RECOMMENDATIONS FOR NEW MEXICO

Create clear pathways and legal and regulatory certainty for industry

- Clarify heat ownership
- Streamline and simplify legal definitions of *geothermal energy*
- Further enable geothermal reuse of depleted or abandoned oil and gas wells
- Identify priority leasing areas and create geothermal Special Economic Zones at the State Land Office
- Proactively plan for and prepare transmission for geothermal electricity projects
- Produce and maintain a "developer tool kit," a one-stop shop for geothermal project development

Create the conditions that will accelerate geothermal production in New Mexico

- Set a regulatory goal of 5 gigawatts of geothermal energy on the New Mexico grid by 2035
- Work with the federal government to catalyze geothermal deployment on federal lands

Expand state geothermal incentives

- Expand the grant and revolving fund to include commercial and private sector projects on state lands
- Establish targeted grants and loans for geothermal power and industrial process heat
- Incentivize geothermal-powered data centers

Catalyze the development of geothermal heating and cooling

- Allow utilities to build, own, and operate Thermal Energy Networks (TENs)
- Improve utility efficiency with expanded geothermal heating and cooling (GSHP)

Expand educational programs for energy workers and the public

- Expand geothermal-specific apprenticeships and workforce trainings
- Update public education materials and improve outreach for funding opportunities

15 RECOMMENDATIONS TO IMPROVE GEOTHERMAL DEVELOPMENT IN NEW MEXICO

Create Clear Pathways and Legal and Regulatory Certainty for Industry.

1. Clarify heat ownership in the state's legal and regulatory language.
2. Streamline and simplify legal definitions of *geothermal energy.*
3. Further enable geothermal reuse of depleted or abandoned oil and gas wells.
4. Identify priority leasing areas and create geothermal Special Economic Zones at the State Land Office.
5. Proactively plan for and prepare transmission for geothermal electricity projects.
6. Produce and maintain a "developer tool kit," a one-stop shop for geothermal project development.

Create the Conditions That Will Accelerate Geothermal Production in New Mexico.

7. Set a regulatory goal of 5 gigawatts of geothermal energy on the New Mexico grid by 2035.
8. Work with the federal government to catalyze geothermal deployment on federal lands.

Expand State Geothermal Incentives.

9. Expand the grant and revolving fund to include commercial and private sector projects on state lands.
10. Establish targeted grants and loans for geothermal power and industrial process heat.
11. Incentivize geothermal-powered data centers.

Catalyze the Development of Geothermal Heating and Cooling.

12. Allow utilities to build, own, and operate thermal energy networks.
13. Improve utility efficiency with expanded geothermal heating and cooling.

Expand Educational Programs for Energy Workers and the Public.

14. Expand geothermal-specific apprenticeships and workforce training.
15. Update public education materials and improve outreach for funding opportunities.

Some of the recommendations can be undertaken quickly (indeed, two of them dovetail with laws that have recently been passed) by the state or other private entities without waiting for statutory or regulatory processes. Others require government-initiated changes and will take time. All of the recommendations are, nonetheless, important steps to help expand an efficient, productive geothermal industry while also advancing new projects in New Mexico that are clean, always on, and responsive for the benefit of all New Mexicans.

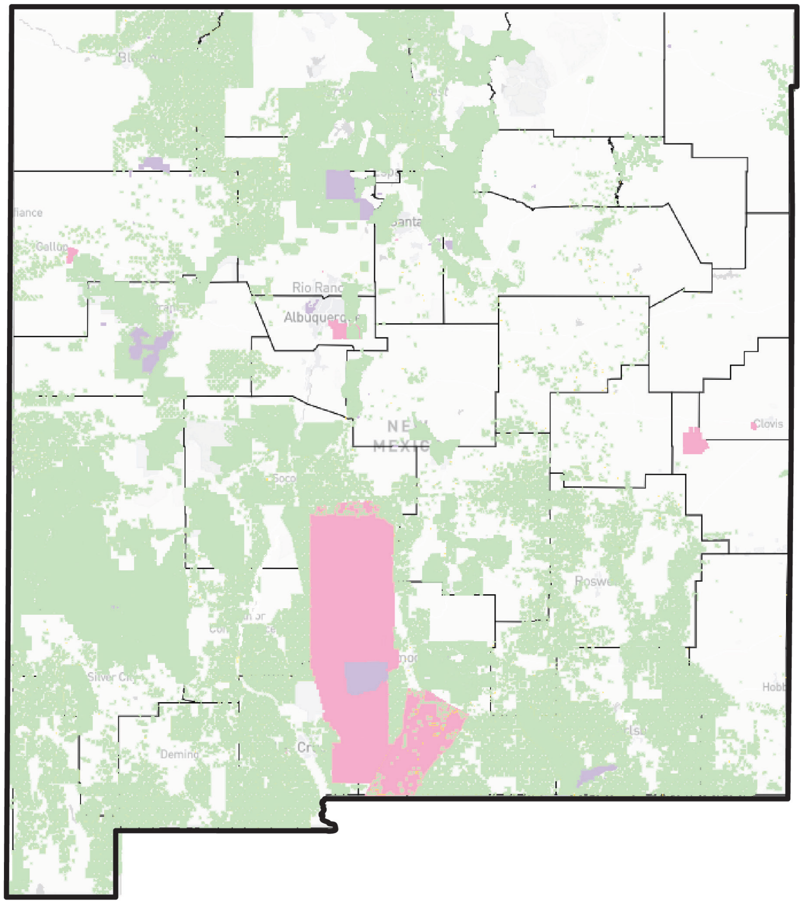
A HISTORY OF GEOTHERMAL ENERGY POLICIES IN NEW MEXICO

As explained in Chapter 6, "Who Owns Heat?" land ownership in New Mexico is mixed, with about 35% owned by the federal government; 12% owned by the 23 sovereign Tribes, Pueblos, and Tribal Nations present in the state; 8% owned by the state itself; and the rest (45%) owned by municipal governments and private individuals.[5] All resource development—whether fossil fuels, water, minerals, or geothermal—is subject to the regulations affiliated with the underlying plot of land. (See **Figure 7.1**.)

The policies discussed in this section include the laws and procedures affecting geothermal development on state and private lands. That said, New Mexico is home to a vast swath of federal land that has some of the state's highest potential geothermal resources. A number of federal facilities, including military bases and research centers, are also located in the state, and these facilities are large and energy intensive. In the first few months of its second term, the Trump administration has made it clear that next-generation geothermal is a priority.[6]

This commitment to next-generation geothermal gives the state the opportunity to partner with the administration to catalyze geothermal on federal lands in New Mexico, including on military bases. In fact, the U.S. Department of Defense (DOD) is currently pursuing geothermal on

FEDERAL LAND OWNERSHIP IN NEW MEXICO



Bureau of Land Management, Fish and Wildlife Service, and Forest Service

Department of Defense

National Park Service

Figure 7.1: Map of federal land ownership in New Mexico. Source: Project InnerSpace. (n.d.). USA Federal Lands (2025) [Data layer]. North America Module. GeoMap. https://geomap.projectinnerspace.org/geomap/

military installations to improve the security, reliability, and resilience of energy consumed on some of the agency's properties.[7] Several of New Mexico's DOD bases have some of the best geothermal potential in the country, including Fort Bliss, White Sands Missile Range, and Kirtland and Holloman Air Force Bases.[8] Additionally, Chapter 8, "New Mexican Stakeholders," explores geothermal development on the vast lands in New Mexico's state borders that belong to Tribes and Pueblos.

CONSTITUTIONAL BACKDROP

In 1978, the New Mexico Legislature passed the Geothermal Resources Development Act. The law has been amended and updated on multiple occasions, including most recently during the 2024 legislative session (House Bill 91).[9] Currently, that act and related New Mexico law define geothermal as "the natural heat of the Earth in excess of 250 degrees Fahrenheit, or the energy, in whatever forms" produced as a result of the Earth's heat.[10] The Energy, Minerals, and Natural Resources Department's (EMNRD's) Energy Conservation and Management Division (ECAM) is tasked with the responsibility to regulate the state's geothermal resources.

Although it is somewhat arbitrary, this 250°F (121°C) threshold is intended to distinguish and establish different regulatory regimes between geothermal for electricity generation (which typically uses subsurface resources above the boiling point of water, 212°F [100°C] at sea level)[11] and geothermal for heating and cooling applications (district heating and ground source heat pumps). See Chapter 1, "Geothermal 101," for more detail on types and temperatures of geothermal electricity generation. Management of New Mexico's geothermal resources at temperatures lower than 250°F (121°C) currently falls under the jurisdiction of several agencies, but primary responsibility falls to the Water Rights division in the Office of the State Engineer.

GEOTHERMAL INCENTIVES AND THE NEW MEXICO RENEWABLE PORTFOLIO STANDARD: HB 252 AND HB 2

HB 252

In 2024, New Mexico passed House Bill (HB) 252 into law, which created and expanded a number of financial incentives for geothermal energy projects. These incentives have the potential to have an impact, but work is needed to improve them.

The bill created a fully refundable tax credit for individuals and businesses that install new ground source heat pumps (GSHPs) to heat and cool their buildings. The credit covers up to 30% of the purchase and installation cost of a system, up to a maximum of $9,000.[12] Although the recipient must still pay for the system up front, the size of the credit goes a long way toward bringing the ultimate capital cost of GSHPs into parity with conventional heating and cooling. In addition, the energy efficiency of GSHPs means that the operating costs and lifetime costs are well below the costs for conventional HVAC systems, with one study estimating that the average New Mexican could save nearly $500 per year with a GSHP.[13] The federal government also currently offers incentives for GSHPs, further reducing costs for homeowners.[14] In 2015, New Mexico also passed HB 263, which allows rural electric co-ops to count energy savings from GSHPs toward their renewable portfolio standard requirements.[15]

HB 252 established a production tax credit of $0.015 per kilowatt-hour for geothermal electricity generation.[16] The sum of the tax credits to all New Mexican geothermal electricity producers available is $5 million per year.[17] Site-specific analysis is required to calculate the potential savings that this credit would provide to a geothermal electricity project developer, but we calculate that the credit could reduce the purchase price of electricity from a hypothetical 130 megawatts at a geothermal power plant near Albuquerque by 15%.[18] If the Federal Production Tax Credit created by the Inflation Reduction Act remains in place, this could also reduce prices up to an additional 18%.[19,20] Recommendation #10 in this chapter highlights how the state tax credit could be improved.

HB 2

In 2024, HB 2 created and appropriated $5 million to the Geothermal Projects Development Fund (GPDF).[21] The GPDF has two pathways to help expedite geothermal development, each of which was originally allocated $2.5 million:

- The first pathway is a grant that provides up to $250,000 to study a proposed geothermal project or to help finance the development of a geothermal project. These grants are limited to public entities (e.g., city, county, or municipal governments; state universities; Nations, Tribes, or Pueblos).[22]

- The second pathway is the Geothermal Projects Revolving Loan Fund (GPRLF), which provides low-interest loans to public, nonprofit, and Tribal entities to apply for financing for a geothermal development project.[23] (As of this writing, staffing constraints and the newness of the grant and loan programs meant EMNRD had not yet released details on these application processes.)

In March 2025, New Mexico passed an updated HB 2 from the House Appropriations and Finance Committee. This bill increased the total funding available for the GPDF program from $5 to $15 million.[24] Increased funding for feasibility studies and for project finance removes much of the initial risk for a project, which should have a positive impact on the number of projects being developed in New Mexico. HB 2 did not specify how the $10 million increase will be divided within the GPDF. Recommendation #9 in this chapter provides suggestions for next steps for this funding.

Along with these policy carrots, New Mexico's renewable portfolio standard (RPS) also provides a stick: It requires a certain amount of the electricity consumed by utility customers to come from renewable energy resources.[25] Investor-owned utilities are required to increase the

POWER GENERATION AND NEW MEXICO'S GRID: ELECTRICITY AND NATURAL GAS UTILITIES

New Mexico's electric grid is powered by a variety of utility providers.

Three main investor-owned electric utilities operate in the state: Public Service Company of New Mexico (PNM), which is part of TXNM Energy; Southwestern Public Service Company (SPS), which is part of Xcel Energy and serves 14 communities and many large industrial consumers in southeastern New Mexico; and El Paso Electric, which is part of the Infrastructure Investments Fund and serves Las Cruces, New Mexico, and surrounding areas. PNM also owns and maintains most of the high-voltage transmission lines in the state.

There are also 16 rural electric cooperatives (co-ops), a number of localities served by municipally owned utilities, and the Navajo Tribal Utility Authority.

As for gas, there are two investor-owned natural gas utilities in New Mexico, New Mexico Gas Company (NMGC) and Zia Natural Gas Company. As this report was being written, NMGC had filed with the New Mexico Public Regulation Commission (NMPRC) to be acquired by Southern Holding Company of Bernhard Capital Partners. Many consumers in New Mexico rely on butane and propane.

With regard to utility oversight, the NMPRC oversees all gas and electric utility matters, including cost of service, service quality and reliability, requirements for interconnection, intrastate transmission and distribution, utility energy efficiency requirements, and net-metering. In addition, SPS and Western Farmers Electric participants are also members of the Southwest Power Pool (a regional transmission organization), connecting them to the eastern interconnection grid of the United States.

Because of the variable nature of electricity consumption patterns, utilities assign a premium to generation resources that can modulate their output to follow the load and resources that can operate on a 24/7 basis, providing always-on power.

In 2007, New Mexico passed the Renewable Energy Transmission Act, which created the New Mexico Renewable Energy Transmission Authority (RETA). RETA facilitates the development of electric transmission projects that can unlock and harvest New Mexico's renewable energy resources in the state—and it isn't subject to NMPRC oversight. RETA's goal is to provide focus and partnership opportunities for transmission projects that carry a minimum 30% of capacity from renewable energy–generating facilities. Although RETA focuses on transmission, its charter includes lower-voltage distribution and battery storage programs.

Sources: New Mexico Gas Company. (n.d.). *Regulatory information*. https://www.nmgco.com/en/Regulatory_Filings; Zia Natural Gas Company. https://www.zngc.com/; New Mexico Legislature. (2021). *Section 62-16-4: Renewable Portfolio Standard*. In *2021 New Mexico Statutes: Chapter 62–Electric, Gas and Water Utilities, Article 16–Renewable Energy Act*. https://www.nmlegis.gov/Sessions/21%20Regular/bills/house/HB0176.HTML; Southwest Power Pool. (2025, March 20). *SPP first RTO to operate in both interconnections with tariff approval*. https://www.spp.org/news-list/spp-first-rto-to-operate-in-both-interconnections-with-tariff-approval/; New Mexico Renewable Energy Transmission Authority. (2024, October 25). *Partnering to make renewable energy a reality: Landowners, developers, and communities working together*. https://www.nmlegis.gov/handouts/WNR%20102824%20Item%2010%20RETA%20Transmission%20Overview.pdf; New Mexico Legislature. (2024). *New Mexico Renewable Energy Transmission Authority Act*, N.M. Stat. Ann. § 62-16A-1 to 62-16A-16. https://law.justia.com/codes/new-mexico/chapter-62/article-16a/

NEW MEXICO RENEWABLE PORTFOLIO STANDARD AND ZERO-CARBON TARGETS

Year	Investor-Owned Utilities (IOUs)	Rural Electric Cooperatives (RECs)
2020	20% renewable energy	10% renewable energy
2025	40% renewable energy	40% renewable energy
2030	50% renewable energy	50% renewable energy
2040	80% renewable energy	
2045	100% renewable energy	
2050		100% zero-carbon resources (80% renewable minimum)

Figure 7.2: Chart summarizing New Mexico's renewable portfolio standard (RPS) and zero-carbon resource standard targets for both investor-owned utilities (IOUs) and rural electric cooperatives (RECs). Source: New Mexico Economic Development Department. *Energy Transition Act awards*, https://edd.newmexico.gov/wp-content/uploads/2024/04/Energy-Transition-Act-Awards-1.pdf

fraction of energy from renewable sources gradually, in steps over time, reaching 100% by 2045. Geothermally produced electricity is an eligible renewable resource. As explained in this report, geothermal only contributes 0.1% of New Mexico's electricity today, whereas wind and solar contribute 41% and 11%, respectively.[26]

Some states have even included mandates for certain technologies in their renewables goals. Having a specific geothermal mandate, as explained in Recommendation #7, would help catalyze the industry in New Mexico. Chapter 3, "Where Is Geothermal in New Mexico?" outlines the massive geothermal potential in New Mexico; expanding the industry could go a long way toward helping the state meet its 100% renewable energy target.

POLICY RECOMMENDATIONS

The current policy environment in New Mexico gives it a foundation for deploying geothermal energy in the state. But more can be done to rapidly accelerate geothermal development—from conventional hydrothermal to next-generation electricity, direct use in manufacturing and industrial processes, and geothermal heating and cooling. The policy actions outlined in this section can position New Mexico to lead a transformative era for geothermal growth across the country.

CREATE CLEAR PATHWAYS AND LEGAL AND REGULATORY CERTAINTY FOR INDUSTRY.

Recommendation #1: Clarify Heat Ownership in the State's Legal and Regulatory Language.

Who Takes Action: State Legislature

One of the most significant legal and regulatory hurdles to advancing geothermal in New Mexico is the lack of clarity about who owns subsurface heat. Unlike for other energy resources such as oil, gas, or minerals, rights to geothermal heat are not clearly defined in state law, which can create uncertainty for landowners, developers, and regulators alike. This lack of definition can also affect lease negotiations, permitting, and investment decisions—particularly when surface and mineral estates have been severed.

To resolve this issue, the Geothermal Resources Development Act would need to be amended to remove or clarify the phrase "minerals in solution"[27] from the statutory definition of *geothermal resources*. This ambiguous language risks conflating geothermal heat with mineral extraction, which can complicate ownership determinations and regulatory processes. Following the model of Texas SB 785, which explicitly excluded minerals from the definition of *geothermal resources*,[28] New Mexico should revise its legal definitions to eliminate confusion and reinforce that geothermal heat is a distinct and nonmineral resource. Such clarification would support a more coherent legal framework and reduce barriers to geothermal leasing and development on both state and private lands.

Additionally, New Mexico should consider adopting a statutory presumption that geothermal heat belongs to the surface estate unless a deed or legal document explicitly states otherwise. This would align with judicial precedent in other western states that apply the "ordinary and natural meaning" test—and it would bring clarity to surface-mineral estate disputes without requiring judicial interpretation in each case. Embedding this presumption into statute would empower surface owners, reduce legal uncertainty, and promote investment in geothermal development by clearly identifying who holds leasing authority in the absence of severed rights. Such a measure would complement existing statutes while addressing one of the core ambiguities slowing geothermal project initiation across New Mexico.

Recommendation #2: Streamline and Simplify Legal Definitions of *Geothermal Energy.*

Who Takes Action: State Legislature and Energy, Minerals, and Natural Resources Department

In the strictest interpretation, the current language in the Geothermal Resources Development Act prohibits new commercial geothermal power plant construction. As written, the act says, "Geothermal resources may be administered as a renewable energy resource, in which case any leases for and regulations of a geothermal resource as a renewable energy resource shall require that the geothermal resource not be diminished beneath applicable natural seasonal fluctuations in the measurable quantity, quality or temperature of any area classified as a known geothermal resources field."[29] Although geothermal heat is renewable and is continually replenished over time, standard operating conditions of commercial geothermal power plants do typically result in small incremental reductions in reservoir temperature over the lifespan of a plant, often approximately 1°C (34°F) per year.[30,31] Thus, the language effectively prohibits commercial-scale geothermal development on New Mexico state land. But geothermal laws in neighboring states do not contain this statutory prohibition, so it is easier to design and develop commercial geothermal projects outside of New Mexico. The law could be amended to simply read, "Geothermal resources may be administered as a renewable energy resource."

State offices are currently attempting to develop work-arounds for this issue; nonetheless, this language should be removed from the statute because it is inconsistent with how renewable geothermal resources are developed—and it puts New Mexico at a disadvantage.

Recommendation #3: Further Enable Geothermal Reuse of Depleted or Abandoned Oil and Gas Wells.

Who Takes Action: Energy, Minerals, and Natural Resources Department

Before the publication of this report, in March 2025, New Mexico passed HB 361, EMNRD Conversion of Certain Wells. This law authorizes the conversion of depleted oil or gas wells into facilities that provide energy storage or develop geothermal energy.[32] Similar legislation passed in Texas in 2023 permits an operator to claim ownership of an otherwise abandoned oil and gas well for the purposes of generating geothermal electricity.[33] Currently, the Oil Conservation Division of EMNRD is in the process of developing rules for HB 361 and will transfer the management of the program to ECAM.

Here is some background for this recommendation: New Mexico is a significant producer of oil and natural gas, which means the number of wells has proliferated over the years. It is estimated that New Mexico has drilled more than 110,000 wells since 1973.[34] Nearly 53,000 of these wells are still producing,[35] which leaves more than 74,000 wells depleted and or abandoned.[36] When an oil or gas well ceases to produce in economically beneficial quantities, state law requires operators to plug it.[37] Today, a number of studies and pilot projects are exploring the possibility and benefits of reusing hot, depleted oil and gas wells for geothermal uses, including direct-use, power generation, or energy storage, turning these wells into a new asset for the state.

Now that a law has passed in New Mexico to help operators potentially use thermal waste via these wells, the next recommendation is for EMNRD to rapidly adopt regulations implementing the law to ensure safe operations of converted or coproducing wells for geothermal applications.

Recommendation #4: Identify Priority Leasing Areas and Create Geothermal Special Economic Zones at the State Land Office.

Who Takes Action: State Land Office and Economic Development Department

The State Land Office (SLO) should focus on geothermal possibilities by identifying priority lease sites and Special Economic Zones on state-owned land and accelerating the issuance of lease bids, among other actions. If necessary, the SLO should receive additional appropriated funding to do this work.

First, the SLO should create Special Economic Zones geared toward accelerating geothermal growth. Chapter 3, "Where Is Geothermal in New Mexico?" outlines areas in New Mexico that have significant potential for geothermal development. The SLO should refine and prioritize these areas based on criteria such as the quality of the heat resource, proximity to transmission lines, proximity to heat or electricity demand, and any appropriate fiscal incentives (e.g., Inflation Reduction Act tax credits) to create these special zones. These zones should also be chosen with the aim of ensuring minimal environmental impact. The SLO should also create zones for geothermal-powered data centers (see Recommendation #11) and avenues for former coal power plants to transition to geothermal. According to GeoMap, New Mexico is home to two of the nation's four coal plants with the highest subsurface heat potential.[38]

The potential to convert coal plants to geothermal facilities has been investigated around the world, even in regions where geothermal potential is minimal.[39,40,41]

Beyond converting coal plants, the Energy Transition Act (SB 489) mandates that New Mexico's gas plants must take action to decarbonize by 2045.[42] Undertaking these conversion projects in New Mexico would provide an easier connection to the grid, as six of the existing 18 gas plants overlap with areas that have high geothermal potential (see Chapter 3, "Where Is Geothermal in New Mexico?"). Investing in geothermal power generation has the potential to help the state avoid—or at least defer—huge expenditures in building transmission lines for wind from the eastern New Mexico plains to load centers.

The state could accelerate geothermal development in Special Economic Zones through different mechanisms. For instance, permitting and leasing in these zones could be expedited, and wait times to connect to transmission lines could be shortened. Additionally, SLO could streamline right of entry, optioning, and leasing processes. Any of these actions would create incentives for developers. Projects in the zones could also be fast-tracked for financial support from the Geothermal Projects Development Fund. To create additional fiscal incentives, the Economic Development Department could help underwrite the costs of initial exploratory wells in each zone and ensure developers and financial backers have access to that data so they have a better sense of the subsurface heat resource. As needed, the Economic Development Department could also work with other state entities to prioritize these zones for interconnection to the grid (see Recommendation #5).

In fact, geothermal zones could be developed under a similar framework as SB 169, the Strategic Economic Development Site Readiness Act,[43] which helps ready areas in New Mexico for businesses and which the Economic Development Department currently oversees. The state could also create fiscal incentives if certain job or performance thresholds are met, similar to the Inflation Reduction Act's prevailing wage and apprenticeship requirements.[44]

In addition, the website for New Mexico's Office of Renewable Energy (at the SLO) lists geothermal among the state's "abundant renewable resources" that can be developed on state-owned land, but there is no additional information.[45] Building a web page that includes information such as potential geothermal sites, downloadable data for prospective developers, leasing opportunities, and simple instructions on how to apply to the Geothermal Projects Development Fund and the Geothermal Projects Revolving Loan Fund should be a priority (see Recommendation #15). The New Mexico Institute of Mining and Technology would be an excellent in-state partner for developing such a website and to help link technical information to the SLO site.

Recommendation #5: Proactively Plan for and Prepare Transmission for Geothermal Electricity Projects.

Who Takes Action: New Mexico Renewable Energy Transmission Authority

The governor's office, EMNRD, and private developers should engage the New Mexico Renewable Energy Transmission Authority (RETA) to support geothermal electricity production projects. As mentioned earlier, RETA was created to support the transmission of renewable energy in New Mexico. RETA's main focus has been on high-voltage transmission of electrical power produced by wind, solar, and battery storage. Its mission, however, includes lower-voltage transmission, which may be more directly applicable for geothermal power projects because of next-generation geothermal's ability to be located close to the point of demand (enabling local distribution).[46]

As part of its mission, RETA conducts a well-attended energy storage workshop.[47] Geothermal energy storage (see Chapter 1, "Geothermal 101") has advanced significantly over the past few years, and the passage of HB 361, which advances the possibility to reuse abandoned and decommissioned oil and gas wells for geothermal storage and energy, has accelerated these projects.[48] New Mexico could benefit from the potential of pairing longer-term geothermal storage with intermittent renewables. RETA could promote these opportunities at its annual workshop and seek out projects that are baseload and dispatchable and, as appropriate, could advance them to the front of the line for interconnection.

Finally, RETA should play an active role in the creation of geothermal Special Economic Zones. RETA can explore regions of geothermal abundance within the state and map the places where they overlap with transmission development. This approach would create a priority list of service areas where geothermal can quickly and efficiently be added to the grid.

Recommendation #6: Produce and Maintain a "Developer Tool Kit," a One-Stop Shop for Geothermal Project Development.

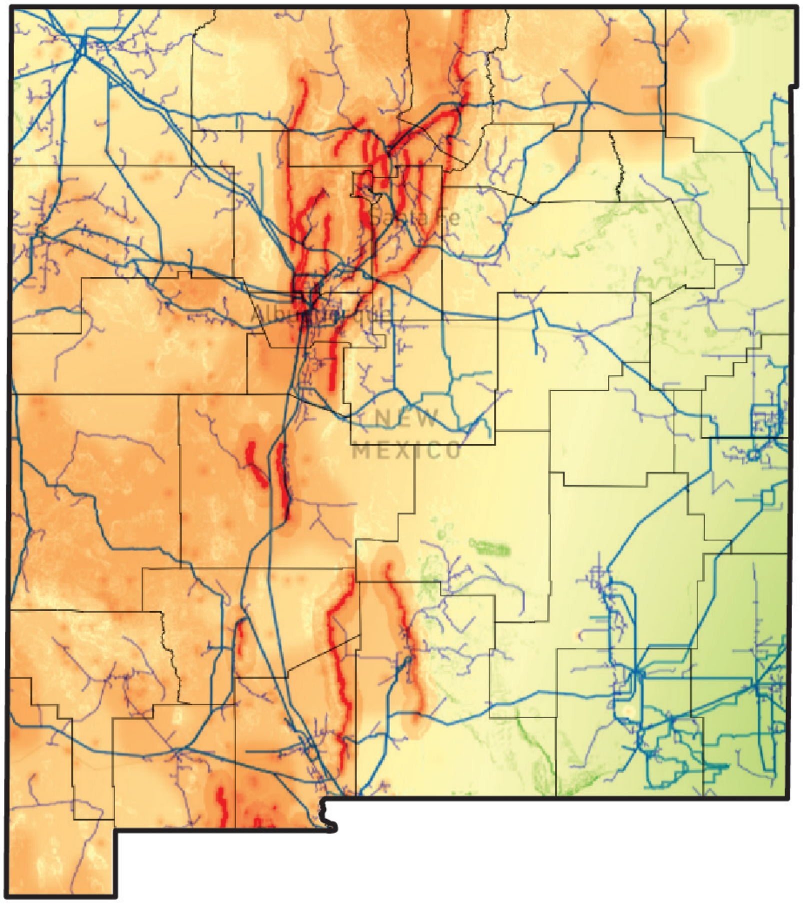
Who Takes Action: Energy, Minerals, and Natural Resources Department

According to the U.S. Department of Energy (DOE), navigating the web of state and federal regulations is a major hurdle for renewable energy developers.[49] Many of the recommendations in this report aim to streamline and reduce the complexity of geothermal development, but a "developer tool kit" could further accelerate the implementation of geothermal projects. New Mexico already has such a tool kit for oil and gas permitting through an e-permitting process[50] via the Oil Conservation Division of EMNRD, and the SLO has its *Oil and Gas Manual*.[51]

Permitting for geothermal should be just as easy as permitting for oil and gas. EMNRD, or any appropriate agency, should develop this "tool kit," which should explain the regulatory processes for all land jurisdictions—federal, state, private, municipal and county, federal, and Native American. The tool kit should also identify the agencies and applicable rules associated with the development of different kinds of geothermal projects (e.g., electricity generation, direct use, heating and cooling) and distinguish whether processes differ for hydrothermal and next-generation projects. The tool kit should be periodically updated as laws, rules, and regulations change.

A model for this idea is the Regulatory and Permitting Information Desktop (RAPID) Toolkit,[52] which was developed by the National Renewable Energy Laboratory (NREL) for Open Energy Information. This NREL tool kit could even serve as a supplement to a New Mexico tool kit.

GEOTHERMAL AND TRANSMISSION IN NEW MEXICO



MV Line

HV Line

Figure 7.3: Geothermal and transmission in New Mexico. Source: OpenStreetMap. (n.d.). *Overlay of transmission lines on geothermal resource map.* Retrieved May 27, 2025, from https://www.openstreetmap.org/#map=7/34.457/-103.151

There also may be funding available for a tool kit through the Geothermal Resources Development Act (see Section 4 of the amended act for more information on funding.)[53]

One critical element in the development of a kit is the potential for the consolidation of permitting rules under a single regulatory authority. A precedent can be found in Texas, which passed legislation in 2023 that expanded the jurisdiction of the Railroad Commission of Texas to include geothermal wells.[54] In New Mexico, the existing oil and gas regulator could also cover geothermal energy production. Of course, adapting the existing requisite oil and gas forms for geothermal projects can be challenging. Care will need to be given to ensure the forms are streamlined, simple, and tailored to focus on risks associated with geothermal versus assuming risks associated with oil and gas apply by default.

CREATE THE CONDITIONS THAT WILL ACCELERATE GEOTHERMAL PRODUCTION IN NEW MEXICO.

Recommendation #7: Set a Regulatory Goal of 5 Gigawatts of Geothermal Energy on the New Mexico Grid by 2035.

Who Takes Action: Energy, Minerals, and Natural Resources Department and State Legislature

New Mexico's renewable portfolio standards require the state to get 80% of its electricity from renewable sources by 2040 and 100% of its electricity from carbon-free power by 2045. Despite these standards, New Mexico's own data shows that it is not currently on track to meet its greenhouse gas reduction targets.[55] Developing 5 gigawatts of geothermal capacity by 2035 would provide clean, firm, dispatchable power—and could help ensure New Mexico meets its greenhouse gas reduction goals. The state is in a position to leverage its massive geothermal potential by using local oil and gas expertise to make those targets real.

Other geothermal producers around the world have developed similar targets and can serve as examples for New Mexico. Kenya set a national target to reach 5 gigawatts of geothermal electricity by 2030.[56] Indonesia established a road map to reach more than 9 gigawatts via geothermal by 2035.[57] In 2023, California passed a law requiring 10.6 gigawatts of energy from generation resources with an 80% capacity factor by 2026,[58] including up to 1 gigawatt of geothermal.

Achieving 5 gigawatts is well within New Mexico's capabilities, given that there are more than 160 gigawatts

TACKLING INCONSISTENT DEFINITIONS

The Geothermal Resources Development Act includes at least three definitions that describe geothermal in slightly different and contradictory ways: *geothermal development project*, *geothermal reservoir*, and *geothermal resource*. The text says the following:

- *Geothermal development project* means "a project using the heat of the Earth above one hundred degrees Fahrenheit to generate electricity or otherwise support industrial, commercial or residential uses." (Note: *Above* as used here means "in excess of.")

- *Geothermal reservoir* means an "underground reservoir containing geothermal resources, whether the fluids in the reservoir are native to the reservoir or flow into or are injected into the reservoir."

- *Geothermal resource* means "the natural heat of the earth in excess of two hundred fifty degrees Fahrenheit, or the energy, in whatever form, below the surface of the earth present in, resulting from, created by or that may be extracted from this natural heat in excess of two hundred fifty degrees Fahrenheit, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas and other hydrocarbon substances and excluding the heating and cooling capacity of the earth not resulting from the natural heat of the earth in excess of two hundred fifty degrees Fahrenheit, as may be used for the heating and cooling of buildings through an on-site geo-exchange heat pump or similar on-site system."

For example, in the definition of *geothermal development project*, a project can use geothermal heat in excess of 100°F (38°C) in whatever form it is manifested. On the other hand, the definition of *geothermal resource* goes into detail and is limited to only geothermal heat in excess of 250°F (121°C). This means that using subsurface heat in excess of 100°F (38°C) but lower than 250°F (121°C) is a geothermal development project but does not technically come from a geothermal resource.

Reducing the ambiguity would help developers more quickly and straightforwardly deploy capital to advance the use of geothermal energy in New Mexico. The Energy, Minerals, and Natural Resources Department should revise these definitions to minimize confusion and potential future litigation. The conflicting legal and regulatory language is explored in more detail in Chapter 6, "Who Owns the Heat?"

Source: New Mexico Legislature. (2024). *House Bill 91: Geothermal Resources Project Funds* [HB 91, 2024 Regular Session]. https://www.nmlegis.gov/Sessions/24%20Regular/bills/house/HB0091.pdf of potential in the state. The state could achieve this goal through several avenues: The EMNRD could petition the New Mexico Public Regulation Commission (NMPRC) to include a target of 5 gigawatts of power produced by geothermal in the renewable portfolio standards by 2035; the legislature can take action to have the NMPRC create this target; or the NMPRC could potentially adopt this goal on its own.

Adopting a goal of 5 gigawatts will yield substantial benefits for New Mexico. Besides generating firm dispatchable electricity, creating geothermal projects, and offering a long-term and sustainable heat supply to agricultural regions and industrial hubs, this approach will help boost both high-skilled and vocational employment. As explained in Chapter 5, a 5 gigawatt goal for New Mexico could create nearly 2,000 construction jobs, 750 indirect jobs, and more than 125 permanent operations and maintenance jobs.

Recommendation #8: Work With the Federal Government to Catalyze Geothermal Deployment on Federal Lands.

Who Takes Action: Governor's Office and Energy, Minerals, and Natural Resources Department

Recent actions by the current administration have elevated geothermal energy as a strategic national priority. The administration has also taken action on expediting permitting processes and expanded leasing opportunities.[59] This shift presents New Mexico with a timely opportunity to unlock its substantial geothermal potential in coordination with federal agencies.

Thirty-five percent of New Mexico's land is federal land, including regions with some of the state's highest geothermal potential. In December 2024, the Bureau of Land Management leased more than 4,000 acres for geothermal development in Doña Ana County, and there is additional interest in areas such as the Santa Fe National Forest.[60] In April 2025, the Department of the Interior announced emergency permitting procedures to accelerate the development of domestic energy resources, including geothermal energy, by reducing approval timelines from years to as little as 28 days.[61] This permitting reform has been a legislative aim of the geothermal industry for years; with one executive order, major barriers to exploration have been removed.

Additionally, in April 2025, DOE announced an effort to co-locate data centers and new energy infrastructure on DOE land.[62] Their list of sites includes two areas in New Mexico that could offer opportunities for geothermal development. If New Mexico adopts Recommendation #4 and develops Special Economic Zones for geothermal energy, developers could work closely with the Bureau of Land Management and the U.S. Forest Service to identify additional leasable acreage, align exploration activities, and streamline the regulatory interface between state and federal agencies.

In many cases there are overlapping regulatory requirements between federal lands and land regulated by New Mexico. EMNRD could eliminate redundant regulatory requirements by coordinating with federal agencies to either assume oversight responsibilities or avoid duplicative regulation of the same processes.

By proactively aligning with federal priorities, New Mexico can position itself as a national leader in next-generation geothermal development. The state should formalize a strategic framework with the Department of the Interior, DOE, and potentially the Department of Defense to coordinate leasing, permitting, and investment efforts.

EXPAND STATE GEOTHERMAL INCENTIVES.

Recommendation #9: Expand the Grant and Revolving Fund to Include Commercial and Private Sector Projects on State Lands.

Who Takes Action: State Legislature

As explained earlier, in its 2025 session—in part due to an early draft of this report—the New Mexico Legislature approved an increase in the Geothermal Projects Development Fund's grant and loan funding for geothermal projects from $5 million to $15 million, which is a great outcome.[63] That said, the GPDF grant funding is currently limited to only supporting public entity projects. If geothermal developers and companies were able to access these funds, it would very likely lead to more projects. Legislation allowing private entities to apply for these funds passed the New Mexico House and received "Do Pass" recommendations from the state's Senate Conservation and Senate Finance Committees, but the proposed bill expired due to lack of time on the last day of the 2025 legislative session. Clarifying that commercial entities could access these funds could help ensure they are used—and help create more geothermal projects in New Mexico.

Additionally, EMNRD should also quickly develop and finalize regulations detailing how entities can tap into that $15 million fund—and work to ensure the funding is spent on projects that will help catalyze geothermal in New Mexico.

Recommendation #10: Establish Targeted Grants and Loans for Geothermal Power and Industrial Process Heat.

Who Takes Action: Energy, Minerals, and Natural Resources Department and State Legislature

Currently, New Mexico offers a utility solar tax credit of between 1.5 cents and 4 cents per kilowatt-hour. The amount changes each year for up to 10 years (it goes up by half a cent for the first six years, then decreases by the same amount). The credit is "limited to the first two hundred thousand megawatt-hours of electricity produced by the qualified energy generator in the taxable year."[64] In other words, a utility-scale solar project can receive a maximum production tax credit of $8 million per year per project. According to data from the U.S. Energy Information Administration, in 2017 (the year before this tax incentive took effect), New Mexico had about 1 million megawatt-hours of utility-scale solar production. By 2024, the figure had grown to 4.3 million megawatt-hours, an increase of more than 200%.[65] Many factors contributed to this growth, but the incentives had their intended impact: A lot of new solar generation came online. In 2024, the New Mexico Legislature created a production tax credit for geothermal electricity generation at a rate of 1.5 cents per kilowatt-hour. That funding is capped at $5 million per year for *all* projects.[66]

A solar project can get more than 1.5 cents per kilowatt-hour in every year except the first year of the solar credit. With such limits in place, the total project credit for *just one* solar project could be higher than the cap for *all* geothermal projects. Increasing the credits available for geothermal power so they could match the available credits for solar could help tap into one of New Mexico's most abundant energy resources—and allow geothermal to scale at a rate similar to solar.

Additionally, by allowing the tax credit to apply to both geothermal power and heat, the state would give parity to direct-use geothermal and vastly increase the chance that direct-use process heat projects are catalyzed throughout the state.

Other incentives in New Mexico should apply to direct-use heat. As outlined in Chapter 4, "Geothermal Heating and Cooling," New Mexico is home to a variety of industries that consume thermal energy, including agriculture, oil and gas refining, dairy processing, and more. Specifically naming some of New Mexico's geothermal grants and loan funding for industrial processes—or creating new funding earmarked for direct-use geothermal heat—will also help incentivize the development of clean industrial process heat. As currently drafted, New Mexico's grant and loan programs (GPDF and GPRLF) are permitted to go toward geothermal for electricity or geothermal used in "support [of] industrial, commercial or residential uses." EMNRD should ensure that a portion of the new funding for GPDF and GPRLF is allotted for direct-use geothermal heat projects.

Recommendation #11: Incentivize Geothermal-Powered Data Centers.

Who Takes Action: New Mexico Public Regulation Commission and Energy, Minerals, and Natural Resources Department

Despite New Mexico's abundant oil and gas supply and predictions that natural gas-fired electricity will supply most of the demand for data centers,[67] the state may prove to be an exception to such predictions. In March 2025, the Rhodium Group published a report pointing out that New Mexico's potential for deploying geothermal-powered data centers is one of the highest in the country.[68] New Mexico should use its firm, clean geothermal potential to attract data center development to the state.

As indicated in **Figure 7.3**, there are several hot spots where geothermal potential and fiber nodes overlap, including close to Albuquerque, Santa Fe, Raton, and Las Cruces. Geothermal resources can be used to both generate electricity and provide cooling for data center infrastructure.[69] A targeted business development approach led by the NMPRC, EMNRD, and public utilities for developing these regions for geothermal-powered data centers could result in a significant number of new jobs and revenue for the state.[70] Enabling this development through expedited leasing and permitting can support a strategic New Mexico industry—data centers—while accelerating the development of the state's geothermal energy industry. If Recommendation #10—which would include making tax incentives for geothermal comparable with incentives for solar—moves forward, it could be worth considering whether tax credits could also be eligible for behind-the-meter geothermal projects like data centers.

New Mexico also has a unique incentive that could have an outsize impact in propelling the state into national leadership in geothermal innovation, research, and development. The New Mexico State Investment Council (SIC) currently manages an estimated $32 billion in assets associated with the New Mexico Land Grant Permanent Fund. The state could leverage these funds to provide funding for a portfolio of first-of-their-kind geothermal developments across a variety of applications and use cases, including data centers. See the following page for more information.

CATALYZE THE DEVELOPMENT OF GEOTHERMAL HEATING AND COOLING.

Recommendation #12: Allow Utilities to Build, Own, and Operate Thermal Energy Networks.

Who Takes Action: New Mexico Public Regulation Commission and State Legislature

Geothermal is ideal for climate control in buildings. Relative to the neighboring states of Texas and Arizona, New Mexico's high desert topography means winters—and many nights throughout the year—require far more heating. Thermal energy networks (TENs) provide an efficient and effective way to provide that heating and cooling across city blocks and neighborhoods. Right now, however, it isn't clear whether local utilities can even create these networks. Several states—including California, Colorado, Maryland, Massachusetts, New York, Vermont, and Washington—have already passed legislation allowing gas and, in some cases, other utilities to develop and operate TENs and sell heat as well as gas.[71] In Massachusetts, for example, lawmakers amended statutory definitions to make it clear that gas utilities may distribute "heat" directly to customers—rather than the gas itself—enabling the creation of utility-owned TENs.

New Mexico should adopt statutory or regulatory changes enabling utilities to build, own, and operate TENs, as this approach would create clean, geothermal-based networks across the state, though any TEN should continue to meet service quality standards to protect consumers. In addition, states such as Colorado have gone further by requiring gas utilities to *implement* TEN pilot projects[72] —a model New Mexico could also consider as it works to scale up low-carbon energy solutions.

Additionally, legislators and regulators could consider financial and regulatory streamlining or establishing NMPRC criteria around what constitutes a TEN (e.g., a minimum number of service subscribers). A coalition of communities that want geothermal district heating systems could also craft a community district heating proposal for the state's GPDF and GPRLF programs (see Chapter 4, "Geothermal Heating and Cooling," for more information on geothermal heating and cooling opportunities).

Recommendation #13: Improve Utility Efficiency With Expanded Geothermal Heating and Cooling.

Who Takes Action: Public Regulation Commission

New Mexico recognizes the importance of energy efficiency. The state has set, and updated, goals for energy efficiency that utilities must meet. The current goal states that by 2025, the cumulative amount of electricity saved through energy efficiency measures must equal 5% of the total electricity sold to retail customers.[73]

New targets will be set for 2026 through 2030.[74] As noted previously, New Mexico law allows co-ops to count savings from geothermal heat pumps in their renewable portfolio standards, but that allowance doesn't apply to

THE NEW MEXICO LAND GRANT PERMANENT FUND: A GEOTHERMAL OPPORTUNITY

New Mexico has a unique opportunity to become a national leader in geothermal innovation and development.

The New Mexico State Investment Council currently manages an estimated $58 billion in assets, including $32.6 billion in the New Mexico Land Grant Permanent Fund.[1] This capital could help the state build a portfolio of first-of-a-kind geothermal projects—and therefore create a robust industry—in the Land of Enchantment.

The Land Grant Permanent Fund was established back in 1912, designed to generate revenue from state-owned lands primarily for the benefit of public schools, universities, and other state agencies.[2] Over the decades, especially after the discovery of oil and gas, the fund's assets grew significantly.

Today, despite all the potential of geothermal energy, there's a lack of financial support for infrastructure-level capital needs and risk mitigation for first-of-a-kind projects. This absence of support poses a significant barrier to commercial geothermal development—particularly for next-generation geothermal projects.

The Land Grant Permanent Fund could help fill these funding gaps, possibly through direct funding, public-private partnerships, and partnerships with the federal government to pursue development on federal land in the state. In recent years, the New Mexico State Investment Council has increased its investments in venture capital funds by actively sourcing new technologies, creating new companies, and targeting hard science and emerging technological opportunities often found in the state. Since November 2022, the council has dedicated $774 million across more than 20 venture capital funds.[3]

What's more, in recent years the Investment Council has kept a focus on sustainability. Five years ago, the council developed a strategic plan for renewables, but the plan didn't specifically mention geothermal. In early 2025, the council's board approved changes so that investments in infrastructure now account for between 75% and 95% of the real return portfolio.[4] This structural change gives the council multiple avenues to pursue expansion of New Mexico's geothermal industry, including the following:

- Revise the renewables strategic plan to include a focus on geothermal energy development.
- Develop a geothermal-specific plan leveraging the state's oil and gas industry to support geothermal in New Mexico.
- Establish low-interest loans or bonus payments for geothermal projects that meet certain thresholds in terms of output, performance, and/or jobs.

The Texas House, with only 2 "no" votes, recently approved legislation supporting geothermal deployment in the Texas Energy Fund.[5]

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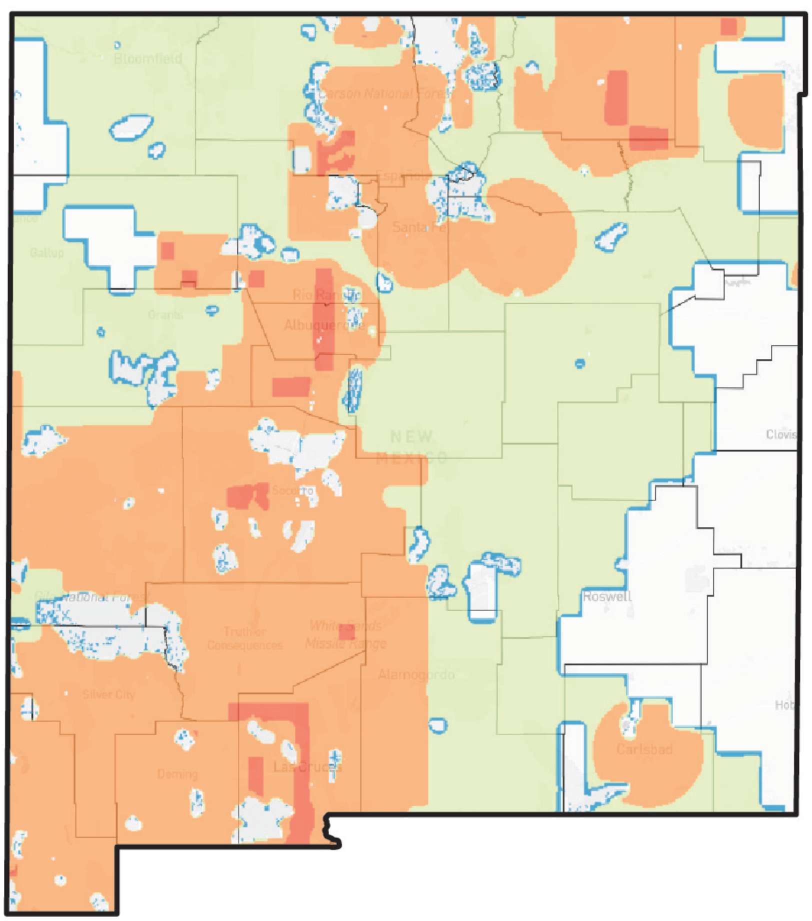
other electricity providers. Ground source heat pumps (GSHPs) could be an important asset to increase the efficiency of the grid, given that GSHPs can be more than two to four times more efficient than traditional HVAC systems.[75] As highlighted in Chapter 2, New Mexico could achieve a 2.96 terawatt-hour (TWh) reduction in primary energy consumption annually by 2050 by increasing its usage of GSHPs.[76]

Encouraging the expanded use of GSHPs would provide significant cost and emissions savings for the grid, including reducing the need for peaker plants, transmission upgrades, and infrastructure upgrades. Those savings could then be used to help consumers adopt more GSHPs or for incentives for gas utilities to develop TENs. The town hall in Española, New Mexico, provides an example. The town hall has had GSHPs in use since 2010, and heating and cooling costs have been reduced by 50% since the pivot to geothermal, saving the city, on average, a reported $42,000 per year.[77]

Stakeholders who could rapidly implement these technologies at scale include hospitals, food sales and service facilities (e.g., restaurants, grocery stores), office buildings (such as other city halls), and educational complexes (e.g., universities, colleges, schools). These four sectors represent the highest energy-intensity consumers for heating and cooling of buildings in the United States.[78] Analysis shows that with current tax credits, GSHPs are cheaper for schools than traditional HVAC systems.[79] Incentivizing the transition from current HVAC systems to GSHPs

NEW MEXICO DATA CENTER FAVORABILITY MAP AT 5,000 METERS



- Exceptional
- High
- Significant
- Promising
- Moderate
- Mild

Figure 7.4: Map showing the cumulative geothermal potential between 0 meters and 5,000 meters across New Mexico, with a 302°F (150°C) temperature cutoff, representing the minimum threshold for power generation. This version of the map excludes areas with slopes exceeding 12 degrees and all globally protected areas to focus on geologically and environmentally viable locations for geothermal development. Additionally, GAP status 1 lands have been screened out, as these areas are designated for strict conservation and typically prohibit industrial activities, including geothermal exploration and drilling. Source: Project InnerSpace. (n.d.). Todays Global Data Center Favorability Map at 5000m [Data layer]. Data Centers Module. GeoMap. https://geomap.projectinnerspace.org/geomap/

in these building sectors could result in a massive decrease in the energy demand on New Mexico's grid.

Additionally, individual homeowners could save money with GSHPs. As mentioned previously, in 2024, HB 252 created a tax credit of up to $9,000 per system for newly installed GSHPs, with a maximum yearly aggregate credit of $4 million. This tax credit lasts until 2034. According to EMNRD, however, very few residents or entities have applied for the credit in the past year.

New Mexico gas and power utilities should analyze the potential benefits they could achieve by broadening the efficiency credit that co-ops receive for GSHPs. NMPRC should also consider how savings to the grid as a result of the increased deployment of geothermal heating and cooling—whether through TENs or GSHPs—could be passed on to consumers (both individuals and companies) to further incentivize the adoption of these solutions. This effort should identify any beneficial legislation, methods for examining and monetizing estimated energy savings, and other possible issues in order to maximize the impact of this approach. NMPRC could also use additional single-purpose funding to carry out this initiative.

EXPAND EDUCATIONAL PROGRAMS FOR ENERGY WORKERS AND THE PUBLIC.

Recommendation #14: Expand Geothermal-Specific Apprenticeships and Workforce Training.

Who Takes Action: Department of Workforce Solutions

New Mexico's Department of Workforce Solutions should develop a geothermal-specific apprenticeship program. A skilled, qualified, and trained workforce is a prerequisite for effective development and will improve project economics because having skilled workers reduces mistakes. Deploying a geothermal apprenticeship program will give New Mexico an edge in the geothermal development ecosystem, making it more cost-competitive for developers to establish projects within the state.

New Mexico has an experienced workforce that is well trained in oil and gas engineering, drilling, and operations (see Chapter 5, "Leveraging Oil and Gas Technologies, Labor, and Workforce to Advance Geothermal in New Mexico"). Several institutions offer degrees and educational courses in oil and gas resources extractions and business management, and these could be quickly expanded for geothermal. In fact, the New Mexico Institute of Mining and Technology (NM Tech) has already launched one of the first graduate certificates for geothermal in the country. The program offers two separate tracks for energy professionals: One targets GSHPs, direct use, and thermal storage, and the second is focused on hydrothermal and enhanced geothermal systems.[80] Similar initiatives should be expanded across the state for both the technical and vocational workforce.

NM Tech recently received an award from DOE for up to $300,000 to advance education and workforce development through immersive virtual reality training in geothermal energy and decarbonization technologies.[81] All of New Mexico's educational institutions should be encouraged and financially supported in their expansion or development of geothermal-specific education programs for power, heat, and residential and commercial heating and cooling. This approach is especially important because the state now provides free education to students enrolled in a postsecondary education institution.[82]

Given New Mexico's significant oil and gas experience, adapting this knowledge to geothermal resources development should not create a significant challenge or financial burden, but rather a golden opportunity to become a pioneer in the cultivation of a workforce for next-generation geothermal.

Additionally, it is worth noting that if geothermal expands as suggested in this report, new regulatory capacity will be needed. New Mexico should ensure that this capacity is met and that newly hired geothermal regulators understand the different risks between oil and gas and geothermal. Initial trainings followed by regular refresher courses for regulators (e.g., perhaps interstate trainings with other state regulators?), would help ensure consistent regulation.

Recommendation #15: Update Public Education Materials and Improve Outreach for Funding Opportunities.

Who Takes Action: Energy, Minerals, and Natural Resources Department

EMNRD should develop an online program outlining New Mexico's geothermal story—one that can be used as an educational tool and for general information. The New Mexico Bureau of Geology and Mineral Resources has a geothermal resources page,[83] but the site needs to be updated and modernized with more contemporary subsurface assessments. The page should also incorporate much of the "developer tool kit" discussed in Recommendation #6 and educate the public on financial mechanisms available to help fund geothermal development, including federal, state, and private grant and tax incentive opportunities for all geothermal applications in New Mexico.

Neither the $9,000 for GSHPs nor the GPDF and GPRLF have received much interest, in part because many people are not aware of these incentives. Increasing public outreach about these funding opportunities at both the community and industry levels, as well as to HVAC installers, would help ensure the funds are used on projects that support the deployment of geothermal. If that outreach is successful and more GSHP projects are implemented, the state should consider increasing the cap beyond the current cap of $4 million per year.

DISCLAIMER

Every attempt was made by the author and contributors to this section to be accurate and current as of early 2025. The author has used public information. The most current information may not be readily available at the time this document was compiled. The author wishes to thank the many people in the New Mexico state government and the private sector who provided guidance and information.

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Part IV

Stakeholder and Environmental Impacts

Chapter 8

New Mexican Stakeholders: Opportunities and Implications for Geothermal Growth and Development

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Travis Broadhurst, University of New Mexico

New Mexico is a diverse state, especially when viewed through a demographic lens. As of 2025, the state has the largest Hispanic[1] and the third-largest Native American population in the United States.[2] The state's 23 federally recognized Tribes contribute to a rich cultural landscape.[3] With regard to energy issues, New Mexico has myriad stakeholders, from ranchers and farmers in rural communities who have been in the state for generations to government agencies, research facilities, and one of the largest oil and gas industries in the nation. For geothermal energy to advance in New Mexico, proponents must engage several—if not all—of these stakeholders.

Several state agencies are involved in royalty management and geothermal energy regulation. Tribal and Pueblo leaders, whose land often overlaps with potential geothermal areas, are interested in the economic, environmental, and social impacts on their local communities. Other key stakeholders include the Department of Defense, labor unions, and even industries such as agriculture[4] and the film industry,[5] which can be affected and deserve consideration.

Other parties are interested in education, research, and technological developments related to geothermal energy, including the National Laboratories in New Mexico and state research institutions. This chapter discusses relevant constituencies that should be involved in the expansion of geothermal energy in New Mexico. We elaborate on the benefits to and effects on each of these constituencies and provide recommendations for how to engage them in the future. By involving these groups in a respectful way, developers can foster a collaborative environment in which citizens and the state benefit tremendously from this renewable resource.

PRIMARY ROYALTY RECIPIENTS

New Mexico has only a few active geothermal projects that generate revenue for the state and federal governments. Currently, only two projects on federal land are operational and contribute to the state's income.[6] The financial benefits from oil and gas extraction and mining, of course, have proven to be much more profitable. Examining these benefits can provide insight into potential future royalties stemming from geothermal energy development.

Taxes, royalties, and other land income from oil and gas operations in New Mexico amounted to more than $15 billion combined in fiscal year (FY) 2023. Of this revenue, $1 billion went to local governments, $2.7 billion went to the federal government, and the remaining nearly $11.5 billion was divided among several state budgets (see **Figure 8.1**).[7] The funds are of particular interest to New Mexicans, as they provide millions each year to public schools, universities, health care programs, infrastructure, and more.[8]

Taxes on oil and gas (such as production, income, property, and gross receipts taxes) amounted to $6.6 billion in FY 2023.[9] Receipts from renewable energy in New Mexico, including geothermal energy, pale in comparison; for instance, the State Land Office received only $4.4 million from wind and solar

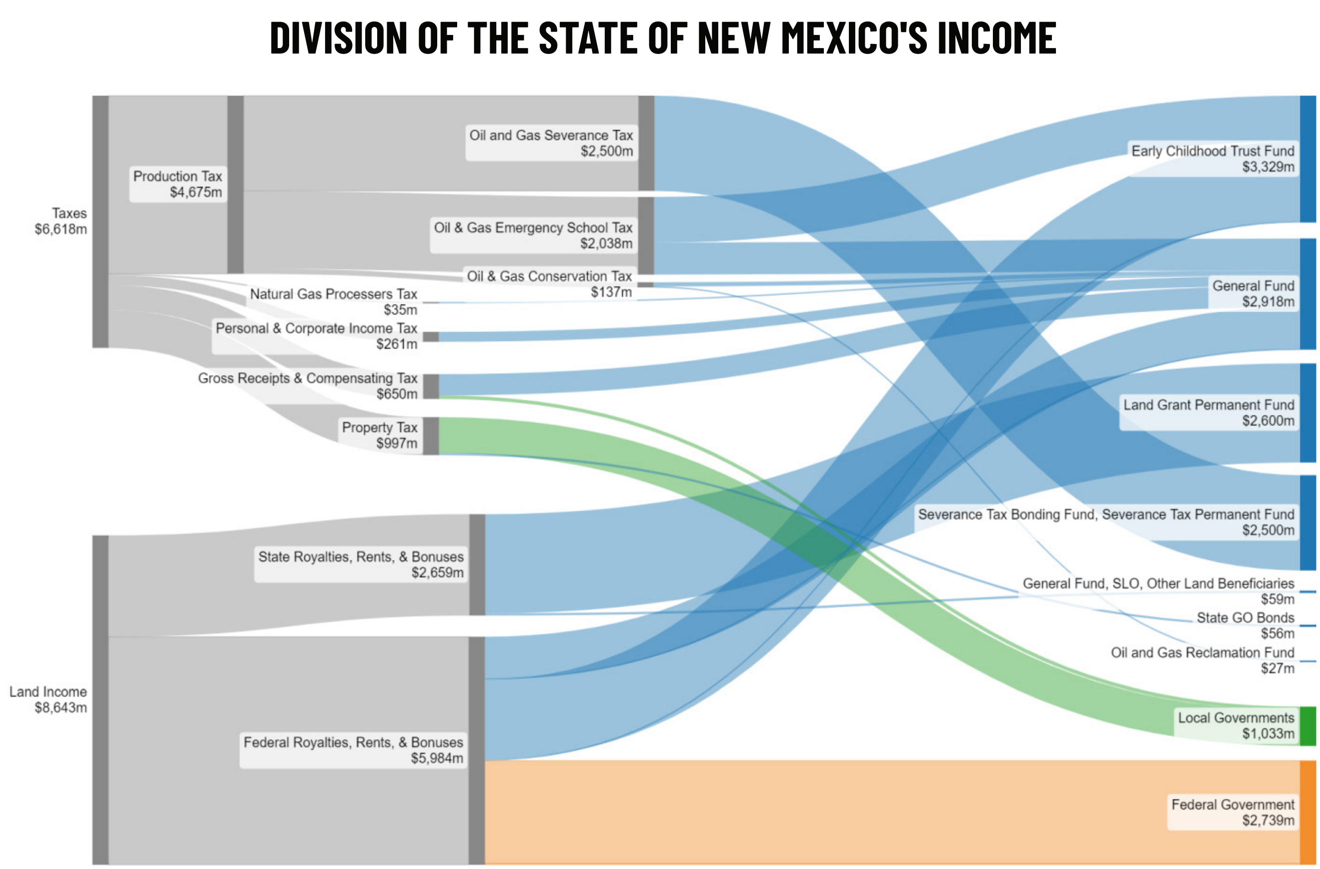

Figure 8.1: Schematic of funding sources (in gray) and sinks to federal (orange), local (green), and state governments (blue) from oil and gas revenues in New Mexico in FY2023. *Source:* Faubion, J. (2024, June 11). *Oil and gas revenue to the State of New Mexico* [Staff presentation]. New Mexico Legislative Finance Committee. https://www.nmlegis.gov/Handouts/ALFC%2006112 4%20Item%204%20Oil%20and%20Gas%20Revenue%20to%20the%20State%20of%20NM.pdf

in 2023.[10] Geothermal is currently only levied as a 0.19% conservation tax on the taxable value, which is calculated after royalties have been paid to the state, Tribes, and the federal government.[11] Geothermal land leases provide a bit more funding: On federal land, 50% of lease funds are distributed to the state, 25% to local counties, and 25% to the U.S. Department of the Treasury.[12] That said, in 2019, federal revenue from geothermal in New Mexico was only $122,000.[13] This amount is similar to the revenue from other renewable energy sectors. Funds collected from solar and wind, for instance, contributed slightly more than 1% to state revenue in 2023.[14]

According to New Mexico's Geothermal Resources Act, geothermal leases in New Mexico must provide "a royalty or percentage … from the production, sale, or use of geothermal resources."[15] Given that the act does not specify the amount or percentage, it is difficult to estimate the financial contribution that geothermal royalties could make to the state. In California, geothermal energy royalty rates can range from 10% to 12.5% of the calculated product of gross value of electric power and a 42% set estimate of steam content.[16]

Federal royalties from oil and gas in 2023 amounted to $5.98 billion, of which more than half—$3.28 billion—stayed in New Mexico.[17] Royalties from operations on state lands contributed an additional $2.66 billion. (Royalty rates from oil and gas on federal lands in New Mexico were 18.75% in 2022 and 16.67% in 2023. Royalties on state lands can range from 12.5% to 20%.)[18]

Public data is not available on private landowner royalties from oil and gas in New Mexico. The royalty rates are negotiated on a case-by-case basis and can vary based on production level, resource quality, location, and market conditions. As of 2023, 11% of oil production and 15% of gas production occurred on private or Tribal lands.[19] Royalties from this land use can have an enormous impact on local and rural communities that otherwise might lack access to higher-paying jobs.

It is important to note that the major constituency of oil and gas stakeholders in New Mexico is locally owned, private businesses. These businesses make up 44% of identified entities (see Chapter 5) and have operated in the state for decades; they are used to a landscape dominated by subsurface energy. These landowners and small businesses could be major catalysts in the geothermal transition, especially when they consider the finite nature of fossil fuel extraction.[20]

MAJOR STAKEHOLDERS AND IMPACTED COMMUNITIES

Pueblos, Nations, and Tribal Communities

For the purposes of this chapter, the terms *Tribe* and *Tribes* are used inclusively to refer to Pueblos, Tribes, and Nations, all of which can be found across 7.8 million acres in New Mexico (see **Figure 8.2**).[21]

Native American Tribes are significant landholders in New Mexico and essential stakeholders in the development of energy resources, including geothermal. Developing geothermal energy could offer Tribes new revenue streams through royalties, land leases, and generated electricity for Native-owned utilities.[22,23] It could also offer employment opportunities during the exploration, construction, and operation phases of a project[24,25,26] and enhanced energy sovereignty from external generating stations and utilities.[27]

As an example of how geothermal could support Tribes, several of New Zealand's geothermal hubs have strong Tribal links. Māori communities play significant roles in the ownership, development, and cultural stewardship of these resources.[28,29] In some cases, industrial heat users are located close by so they can benefit from the geothermal heat. The Miraka and Waiū dairies are both partially owned by Tribes and use geothermal heat to process their milk.[30,31]

The development of geothermal projects on Tribal lands is both feasible and worthy of consideration. However, it must be approached with the recognition that each Tribe may pose a distinct set of questions and offer unique perspectives on energy development, reflecting these communities' cultural, historical, and political heterogeneity.[32]

Each Tribe in New Mexico is a sovereign Nation with its own government and legal system.[33] When engaging with Tribes, it is necessary to be familiar with their governance structures. A Tribe's leadership is determined by either elections or appointments conducted by the Tribal council or traditional leaders or both. The authority to adopt such governing frameworks was granted under the Indian Reorganization Act (IRA) of 1934, which encouraged federally recognized Tribes to develop formalized systems of self-governance.[34] Since this act, many Tribes have ratified constitutions and bylaws that define the structure of their governments, delineate officials' powers and duties, and articulate their citizens' rights and responsibilities. These documents serve as the foundational legal instruments for contemporary Tribal governance.

Each Tribe has its own unique government setup, often split into three branches:

- Governors serve as the executive in Pueblos. Tribal presidents or chairpersons can be found in other Tribal governance structures. The Navajo Nation, for example, has a president.

- Tribal councils serve as the legislative branch of Tribal governments and are composed of elected or appointed bodies, in accordance with each Tribe's established governance structure. In some cases,

TRIBAL AREAS WITHIN NEW MEXICO, 2021

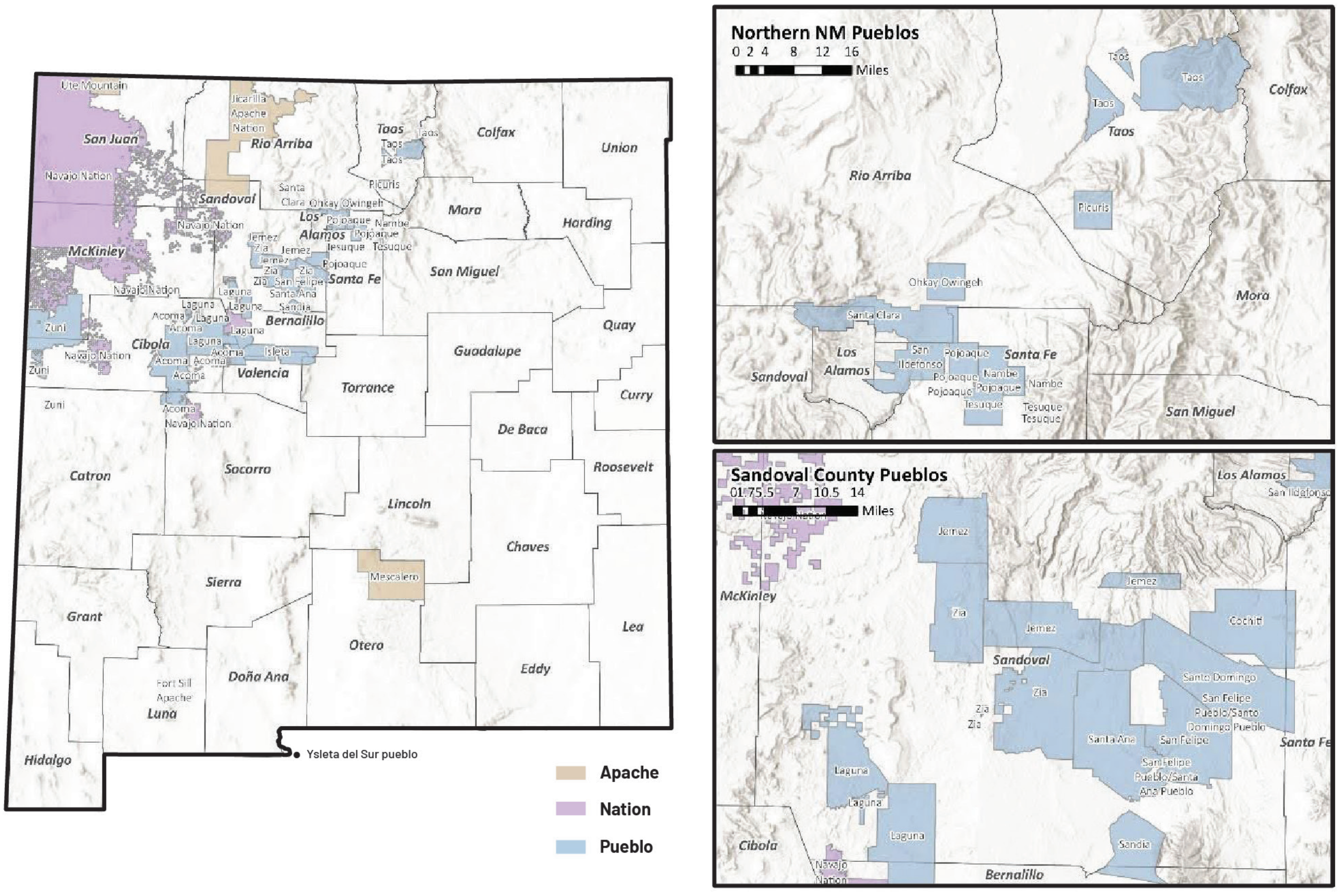

Figure 8.2: Tribal areas in New Mexico, 2021. Source: New Mexico Office of Information Technology. Map produced by Earth Data Analysis Center; Data Sources: US Census, RGIS; Base map: "World Topographic Map" and "World Hillshade" by Esri, NASA, NGA, USGS, New Mexico State University, Texas Parks & Wildlife, HERE, Garmin, SafeGraph, METI/NASA, Bureau of Land Management, EPA, NPS, USDA. https://www.doit.nm.gov/wp-content/uploads/sites/4/2021/12/NM_Tribal_Areas_2021.pdf

AN OVERLAP OF TRIBAL LANDS AND GEOTHERMAL RESOURCES

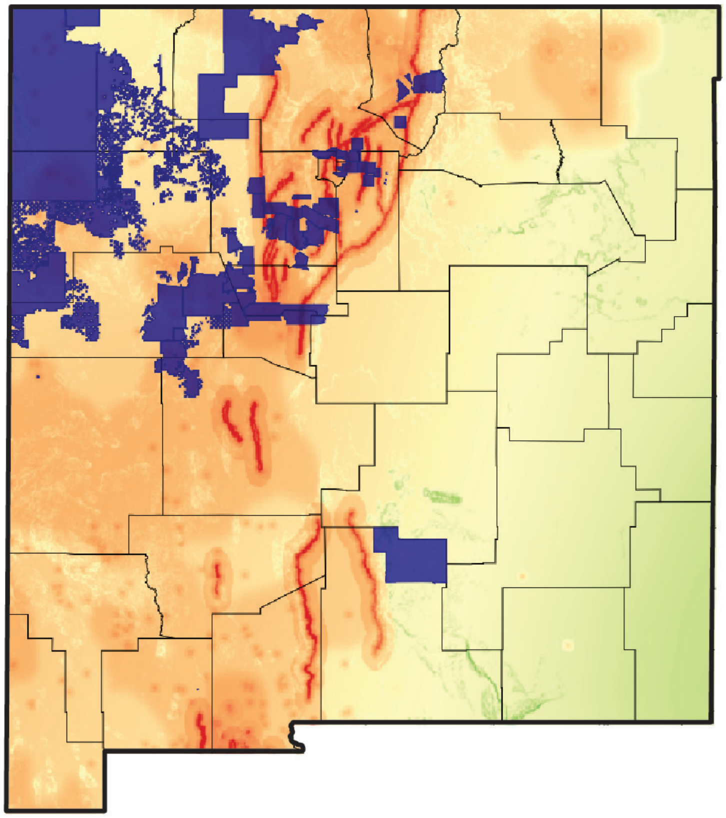

Figure 8.3. Map of known Tribal areas in New Mexico, including 19 Pueblos, 3 Apache Tribes, and part of the Navajo Nation. Source GeoMap.

councils may include former governors or other Tribal leaders. Tribal councils meet with frequencies established in their governing documents.

- Tribal courts serve as the judicial systems that oversee law and dispute resolution on Tribal lands.

Tribal governments have two additional unique aspects:

- Traditional leaders in some Pueblos are called *war chiefs* or *church helpers*. These leaders are separate from the elected or appointed executive leaders.

- Tribal administrators are employed at the discretion of the executive leader. This position will likely be the point of contact for a Tribe about projects. The individual in this position can remain over the years, while executive leadership may change according to appointments or elections.

Geothermal technology may not be on the radar of some Tribal leaders. Many Tribes do not have the in-house technical resources needed to effectively engage in these discussions.[35] In addition to these resource limitations, mistrust generated by past experiences with developers involving things such as housing, solar, and infrastructure development has made Tribes cautious. Fortunately, there are Tribal organizations working to demonstrate the potential benefits of using solar energy as a pathway to Tribal energy sovereignty. One such organization undertaking this effort is Sovereign Energy, whose executive director and founder, Mayane Chavez Barudin, was instrumental in working with the Tribes and bringing their concerns to the table during the development of the Community Solar Act in 2021.[36] A similar collaborative approach must be established for geothermal energy, and some initiatives are already underway. The Santa Fe-based company EnviTrace, for example, is actively developing a database of information about geothermal energy specific for Tribes. The company's Tribal outreach has resulted in discussions with some Pueblos to provide technical assistance on the potential development of geothermal projects.[37]

TRIBAL INTEREST IN GEOTHERMAL ENERGY

There are no current geothermal projects on Tribal lands in New Mexico, but several Tribes and Pueblos have expressed interest and have taken steps forward on geothermal energy exploration and development:

- The Jicarilla Apache Nation is taking part in ongoing geothermal feasibility studies.[38]
- The Navajo Nation, which also has oil and gas leases on its land, is consulting with developers for geothermal energy production on its lands in neighboring Arizona and Utah and is in discussions about expanding the idea to New Mexico.[39]
- The Jemez Pueblo conducted a feasibility study with the U.S. Department of Energy that found multiple sites with geothermal potential. [40]
- The Zia Pueblo, with the Department of Energy, conducted a feasibility study in the early 2010s to assess the viability of geothermal resources and identified a promising opportunity for sustainable energy development.[41]
- The Acoma Pueblo have had favorable heat characteristics for low-temperature geothermal found on their lands west of Albuquerque. [42]
- The Ohkay Owingeh submitted a funding application to the Department of Energy for a geothermal feasibility study in 2025.[43]

The impacts on the communities near geothermal project sites are most likely to be influenced by geothermal siting, design, and operations. Tribes may have several considerations for geothermal energy projects, including economic factors, effects on the community, and long-term environmental implications.[44,45]

Economically, unemployment rates are higher than average on Tribal lands, and limited revenue opportunities make potential job creation and royalties appealing.[46] Geothermal development can help resolve some of these issues through access to higher wages, more local employment, energy independence, and long-term resilience. In some cases, if a holistic approach is used when considering a geothermal project, the project could also address food security. Heat pumps in greenhouses, for example, could be functional year-round and provide high-quality locally grown food, which could then be used for health programs, senior centers, schools, clinics, and hospitals. Economic development could also be bolstered through year-round farming operations, trade jobs in operations and maintenance at geothermal installations, and the sale of power to the local utility company. If geothermal technology is used in residential homes and Tribal businesses, the associated utility bills would be lower, which would benefit both household and business budgets.

Early and transparent communication with local stakeholders, coupled with clear communications about the benefits to communities, can improve social and political acceptance of geothermal development. Politically speaking, sovereignty and Tribal decision-making authority are critical, and negative experiences with previous development projects can foster mistrust among community members.[47] A 2021 white paper submitted to the Planetary Science and Astrobiology Decadal Survey[48] emphasizes that "relationship building with the communities is first and foremost the foundation upon which all collaborations should be centered." Additionally, patience and two-way cultural training are imperative, as communication styles and internal difficulties can delay Tribal decision-making.[49] Social apprehensions include cultural preservation, respect for sacred sites, and community well-being. Developers should create a community engagement program to promote mutual respect, foster collaboration, and ensure Tribes can trust that their concerns will be addressed throughout the process.

The environmental concerns associated with energy development are deeply rooted in cultural beliefs and respect for the land. Some risks that the Tribe will likely consider are environmental degradation, water contamination, ecological disruption to cultural heritage sites, and perceived loss of control in preservation and conservation. The use of water and land disturbance are primary concerns, especially given the climate in New Mexico. Clear communication about the environmental benefits of geothermal—including improved air quality, reduced pollution risk, and minimized land footprint—will be critical. Developers will need to have a systematic environmental impact analysis completed and presented to Tribes to ensure their concerns are proactively addressed.

Rural and Low-Income Communities

Rural and low-income communities are often sensitive to economic changes because they have fewer industries and a small workforce, especially in New Mexico. Eddy and Lea counties, for example, are heavily dependent on oil and gas production. Others, such as Doña Ana and Hidalgo counties, depend on farming and ranching.[50] Geothermal energy can offer economic diversification in the form of local jobs that can last for decades.[51] Furthermore, a 2014 feasibility study indicated that geothermal energy development in rural areas could provide power to settlements up to 25 miles (40 kilometers) from a plant site.[52] Rural and low-income communities would likely see substantial economic benefits from geothermal energy and thus would be keen on its development.

Direct-use systems for local communities are also promising, as these have a relatively low initial cost and are a versatile option that has been applied to projects ranging from thermal energy networks to agri-processing to drying wastewater sludge.[53] In New Mexico, direct-use geothermal meets up to 93% of the thermal energy needs of the Masson Farms greenhouse, the second-largest greenhouse in the United States and an employer of 200 people in Doña Ana County.[54] In the city of Española, the geothermally heated City Hall has saved the city nearly $42,000 per year in heating and cooling costs.[55] And one year, during an intense cold weather pattern, the City Hall was the only public building in town that remained heated.

In the city of Española, the City Hall, which is heated by geothermal, saved the city nearly $42,000 per year in heating and cooling costs. And one year, during an intense cold weather pattern, the City Hall was the only public building in town that remained heated.

Geothermal offers environmental benefits to local communities as well, including improved air quality, low land footprint, and little to no environmental pollution.[56] Each factor contributes to better public health as well. In fact, a 2020 study found that the main risk to public health from geothermal energy in local communities is exposure to hydrogen sulfide gas.[57] However, emissions of this gas are reduced by 99.9% with modern abatement systems in traditional binary and flash power plants.[58]

It is worth noting that proper education will be paramount for ensuring geothermal is viewed positively in local communities and is part of geothermal operators' corporate social responsibility initiatives. A 2016 study found that, when properly applied, robust local programs such as new business opportunities, additional training, and contributions to existing infrastructure are highly regarded by local communities.[59]

Oil and Gas, Mining, and Other Workforce Groups

Although New Mexico's oil and gas industry ranks high nationally and added $16.1 billion to the state's gross domestic product in 2022, it only employs 8.5% of New Mexicans.[60] This is still a sizable population of workers who have direct knowledge of subsurface resources, drilling, engineering, and geology that can be applied to geothermal. In fact, a 2024 survey found that the vast majority (95.5%) of the oil and gas workforce in the Permian Basin of southeastern New Mexico would participate in additional training if the training was free and convenient.[61] Though the survey did not specify geothermal energy training, we could assume that additional energy jobs, and the training for them, would be of significant interest since nearly 60% of the same surveyed group reported being concerned that clean energy jobs would not be available in New Mexico and 65% feeling concerned they would need to move as a result.[62]

BUREAU OF LAND MANAGEMENT GRAZING ALLOTMENTS

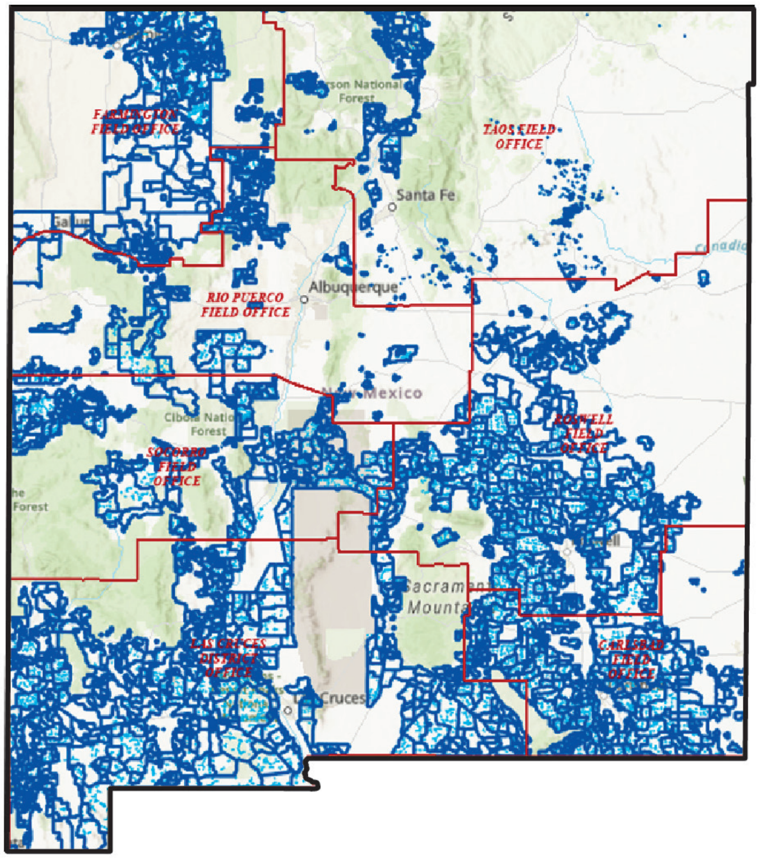

Figure 8.4: Bureau of Land Management grazing allotments in New Mexico as of 2023. *Source*: Bureau of Land Management. *BLM New Mexico statewide spatial data*. U.S. Department of the Interior. https://blm-egis.maps.arcgis.com/apps/webappviewer/index.html?id=dea6e3c9f3734e55be5a047f834b9c9d

Nearly half of the oil and gas workforce in the state is Latino, with a sizable portion being immigrant workers and approximately 20% making less than $25,000 annually.[63] These workers will be crucial to the development of geothermal energy in the state.

Other workforce groups will become more interested as the geothermal employment base grows. Labor unions, for example, are a prominent force in several industries. Of the 199 labor unions present in the state, the largest include mining and electrical engineering,[64] both of which are fields with direct crossovers to roles in a geothermal power plant. The Bureau of Labor Statistics and the Geothermal Energy Association estimate that a 50 megawatt geothermal power plant would need between 697 and 862 workers to be completed.[65,66] While the majority of these jobs are time limited during the various phases of development (i.e., exploration, drilling, plant design, and construction), if the state achieves the goal outlined in this report of developing 5 gigawatts of geothermal electricity, these jobs could be permanent, distributed across approximately 100 development projects over many years.[67] Union membership across these phases ranges from 4.9% (oil and gas sector average) to 20.8% (utility sector average).[68,69]

If the state were to adopt thermal energy networks, potentially more union jobs would be created. Utility workers, who have high levels of union membership, will also have a vested interest in geothermal development because they can stay employed while working on the transmission and distribution of electricity.

Other workforce groups could turn their attention toward geothermal energy, including agriculture, mining, and rural industries in regions with geothermal potential. Chapter 5, "Leveraging Oil and Gas Technologies, Labor, and Workforce to Advance Geothermal in New Mexico," shows that the overlap of mining resources with geothermal potential is substantial, especially in the Rio Grande rift and in the southwestern part of the state. There is also a lot of overlap in direct-use geothermal resources (as discussed in Chapter 4) in the Rio Grande Valley[70] for agriculture and the farmland (see **Figure 8.4**). This overlap means ranchers and farmers will have an active interest in the geothermal development that could occur on their land.

Environmental interest and advocacy groups will also be a crucial part of the geothermal energy development process given the significant potential and benefits of geothermal energy in New Mexico. Environmental advocates will be needed to help advance more geothermal policies while also ensuring that frameworks are in place to mitigate any negative impacts.

Department of Defense

The Department of Defense is a potential early adopter of geothermal, as the agency has high energy demands, is in several remote locations, and has substantial capital to pursue new technologies (see **Figure 8.5**).[71] New Mexico is home to Kirtland and Holloman Air Force Bases. Major installations such as White Sands Missile Range[72] and Fort Bliss (partially in Texas)[73] —in the top five largest military sites in the United States by square miles—have garnered attention as possible development sites.[74,75] A 2017 Play Fairway Analysis examined the Tularosa Basin, a 100-mile-long geologic feature in southern New Mexico, for its geothermal energy potential.[76] The study identified 12 potential geothermal areas, with the most promising areas to the west of White Sands and in the northeast corner of Fort Bliss—where four slimholes were drilled by Sandia National Laboratories in the 1990s that reached

MAP OF MILITARY INSTALLATIONS AND GEOTHERMAL POTENTIAL

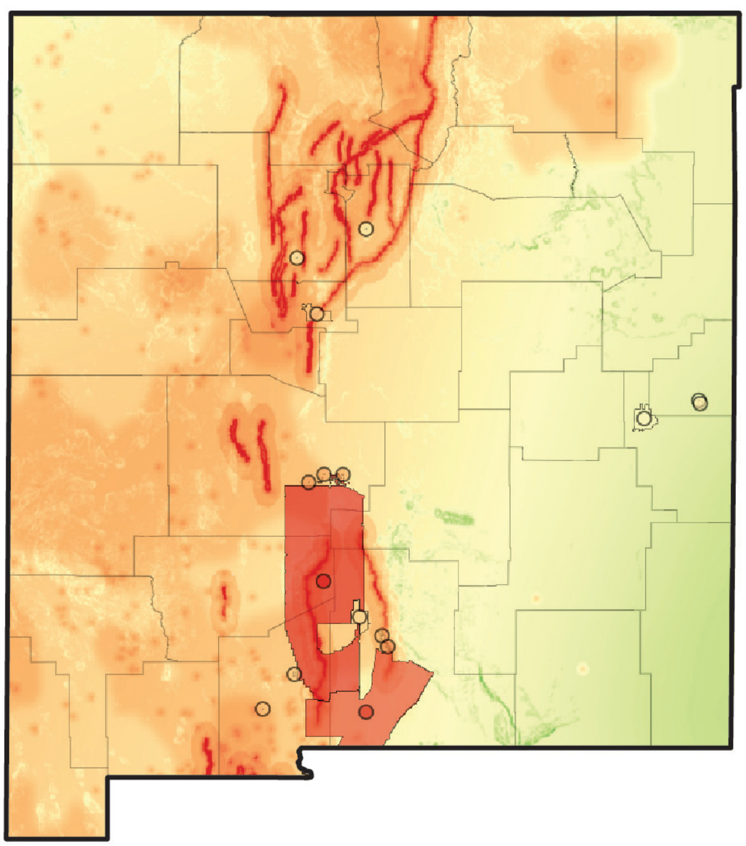

Figure 8.5: Note the large military installations in south central New Mexico directly above temperatures of at least 300°F (150°C). *Source*: Anderson, K. (2011). *Broad overview of energy efficiency and renewable energy opportunities for Department of Defense installations*. National Renewable Energy Laboratory.

close to 180°F (80°C–85°C).[77] An additional well was drilled in 2013 and reached 200°F (93°C) at 3,000 feet (900 meters) deep.[78] The site was determined to be suitable for a 20 megawatt power plant that could contribute 425 gigawatt hours of energy per year—roughly 10% of Fort Bliss's demand.[79]

Additional geothermal technologies, including ground source heat pumps, could be applied at White Sands and have been in use at Fort Johnson in Louisiana for more than a decade.[80,81] Though harnessing heat from coproduced water in oil and gas has never been done at a military site, it is done at oil and gas facilities out of state and is a viable option in southeastern New Mexico.[82,83] (In fact, a 1981 study argued for a high-temperature hydrothermal system beneath Kirtland Air Force Base near Albuquerque based on the intersections of faults, the presence of surface mineral deposits, and inferred high subsurface temperatures.[84]) Given the numerous potential geothermal applications, high electricity demand, and prominent socioeconomic position in New Mexico, Department of Defense installations should be a target stakeholder for future development.

State Agencies

Several state agencies help monitor geothermal energy development and are active stakeholders:

- The **Royalty Management Division** within the State Land Office processes royalty revenue from oil, gas, and geothermal operations.[85]

- The **Energy Conservation and Management Division** of the Energy, Minerals, and Natural Resources Department regulates exploration, development, and production of high-temperature geothermal resources in New Mexico.[86]

- The **Energy, Minerals, and Natural Resources Department** is also now responsible for the management of repurposing abandoned oil and gas wells for geothermal energy.[87,88]

- The **Ground Water Quality Bureau** within the New Mexico Environment Department oversees low-temperature resources.

- The **New Mexico Environment Department** oversees air permitting for potential gaseous emissions from geothermal operations.[89]

- The **Office of the State Engineer** supervises the appropriation and distribution of all surface water and groundwater in New Mexico, which is applicable because surface waters are used in geothermal drilling, construction, and operations.[90]

INNOVATION STAKEHOLDERS

Public and Private Universities

Academic institutions have a strong interest in participating in data-sharing initiatives—and often are required to do so. Plans at the New Mexico Institute of Mining and Technology to compile and share geothermal research findings through a centralized database reflect a commitment to collaboration. In addition, New Mexico's academic institutions are at the forefront of geothermal research and development.

- **University of New Mexico (UNM):** UNM researchers are exploring more efficient and sustainable materials for extracting geothermal energy, including high-temperature cement blends and specialized polymers.[91] In 2021, the Department of Energy awarded UNM a $2 million grant to develop technologies for enhanced geothermal systems focused on overcoming challenges such as thermal short-circuiting.[92] UNM has also considered updating its own independent utility system with a district heating geothermal system with wells drilled adjacent to campus.[93]

- **New Mexico Institute of Mining and Technology (NMT):** NMT's Bureau of Geology and Mineral Resources has been instrumental in geothermal exploration, resource assessments, heat flow mapping, and engagement in other geothermal research for more than 20 years.[94] NMT's Petroleum Recovery Research Center has expertise in related fields that is widely applicable to the geothermal industry.[95] Additionally, NMT houses GO-TECH, a historical database of oil and gas data that can be used in future research on coproduced geothermal or in adapting abandoned wells for geothermal

NEW MEXICO'S GEOTHERMAL DATA CENTER POTENTIAL

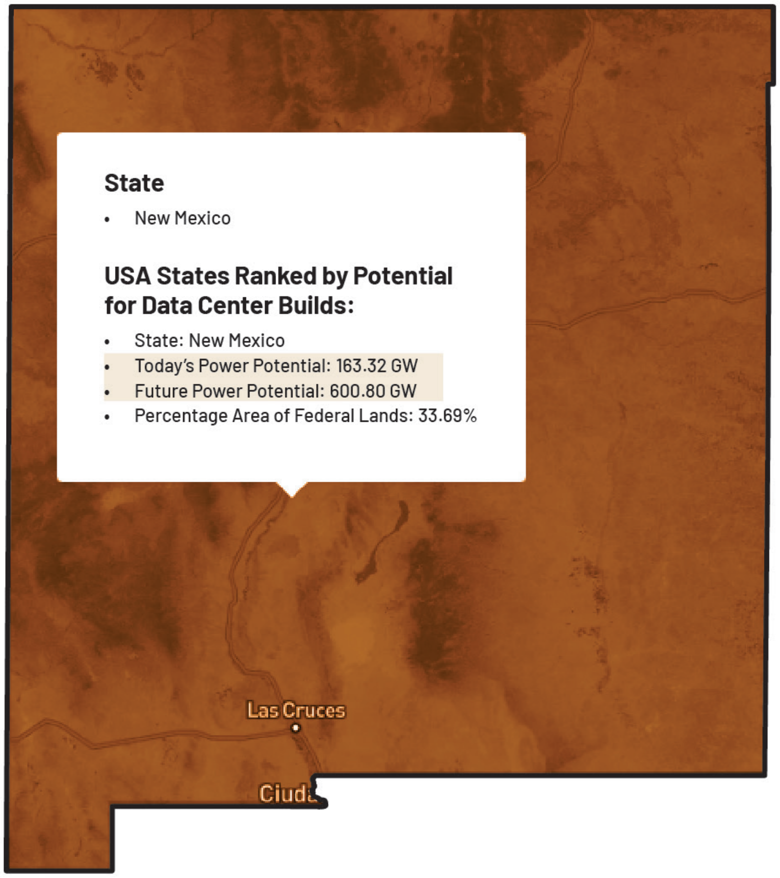

Figure 8.6: According to data from GeoMap, New Mexico is one of the top states for geothermal data center potential, with 163 gigawatts of power potential down to 5,000 meters. Source: GeoMap

purposes.[96] Finally, NMT has recently announced that the first geothermal training program in the state—with courses on well completion, advanced thermodynamics, advanced production design, and more—is slated to start in fall 2025.[97]

- **New Mexico State University (NMSU):** NMSU has been central to the state's geothermal research, notably through the 12,000 square foot (1,100 square meters) Geothermal Greenhouse Facility.[98] This facility served as a testing ground for commercial growers considering operations in southern New Mexico. The facility was heated via a district heating system that was active from 1979 through 2015.[99]

Department of Energy National Laboratories

New Mexico is fortunate to be one of only three states with multiple National Laboratories, both of which have a history of research into geothermal energy. In fact, New Mexico has 20 federal, state, and private laboratories,[100] all with robust supercomputing power to help solve the most challenging technical issues.[101] National Labs can play a role in policy initiatives, spark entrepreneurial growth in local areas, and inspire collaboration on both domestic and international scales.[102]

- **Sandia National Laboratories:** Sandia National Laboratories support advanced geothermal research focusing on drilling technologies, wellbore integrity, and high-temperature tool development, particularly for enhanced geothermal systems.[103] Previous work has improved polycrystalline diamond drill bits, which drill three times faster than standard bits.[104] Sandia National Laboratories are also known for high-resolution, high-fidelity microseismic monitoring.[105]

- **Los Alamos National Laboratory (LANL):** Building on a lengthy history of hot dry rock projects,[106] LANL conducts studies on thermodynamics, advanced

UTILITY COVERAGE IN NEW MEXICO

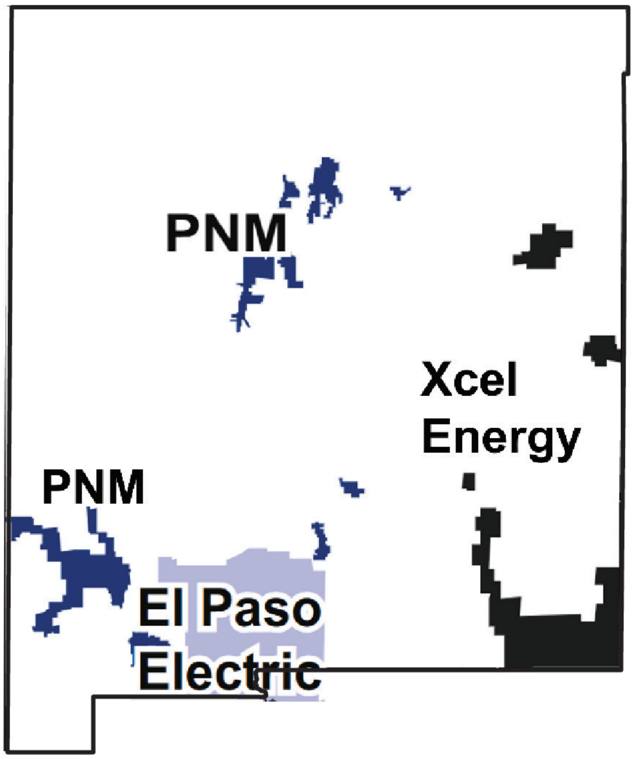

Figure 8.7: Map of major electric utility coverage areas in New Mexico. *Source*: Edison Electric Institute. (2024). *EEI U.S. member company service territories* [Map]. https://www.eei.org/-/media/Project/EEI/Documents/About/EEI-Member-Map.pdf

materials, and how to understand heat transfer efficiency in porous media for potential applications to geothermal systems through advanced computing in the geosciences.[107] LANL also hosted the first demonstration project of enhanced geothermal system technology in the 1970s in an early effort to demonstrate the feasibility of this technology. [108]

Data Centers

The introduction of artificial intelligence (AI) has created a need for more data centers, which are predicted to demand immense amounts of energy—as much as 9% of total U.S. demand by 2030.[109] Geothermal energy and related technologies can help satisfy some of this demand and have several benefits, including a high capacity factor, wide geographic availability, and a large volume of subsurface mass from which to harness or store heat.[110]

A 2025 study found that almost two-thirds of the growth in data center energy demand could be met in a cost-effective way by geothermal energy and that 13 of the 15 largest data center markets in the United States could meet 100% of their power needs via geothermal.[111] Analysis shows that New Mexico is ranked as one of the best states for geothermal data centers, with a potential for 163 gigawatts of energy (see Figure 8.6). The state offers several advantages, such as a central location between major markets in the Pacific, Mountain, and Central regions of the United States; competitive electricity costs; and a low risk of natural disasters.[112,113,114]

The Trump administration recently issued a Request for Information regarding building AI infrastructure on Department of Energy land, including at Los Alamos and Sandia National Laboratories.[115] In response, Project InnerSpace collected data that shows that the subsurface in those locations offers a significant opportunity for developing geothermal-powered data centers. These centers would leverage domestic, abundant, secure, baseload electricity—and support energy resilience and U.S. leadership in innovation and advanced drilling and completion technologies.

A current project by the National Renewable Energy Laboratory aims to use underground thermal energy storage to help cool data centers.[116] More advanced research will be needed to fully realize all applications of geothermal energy for data centers, but the data centers are nevertheless an important future stakeholder in New Mexico, especially considering societal reliance on AI.

Industry and Utility Companies

A final stakeholder group in geothermal development includes private companies. Some, such as utilities, are inevitably intertwined with energy development, as most geothermal operators are not also involved with the transmission and distribution of electricity. The main electric utilities in New Mexico, with some also having customers in west Texas, are El Paso Electric, Public Service Company of New Mexico (PNM), and Xcel Energy.[117] Although PNM is the only purchaser of geothermal power from the Lightning Dock Geothermal Facility,[118] Xcel Energy and El Paso Electric currently serve customers in eastern New Mexico and southern New Mexico and west Texas (**Figure 8.7**), respectively. These companies would benefit from additional geothermal energy in New Mexico's energy portfolio.[119]

Other private companies are potential geothermal operators in New Mexico and are making strides in development. Zanskar Geothermal and Minerals, the current operator at Lightning Dock, recently drilled one of the most productive pumped geothermal wells in the world.[120] At the same location in 2022, Eavor Technologies drilled the deepest and hottest geothermal well in New Mexico, which reached around 480°F (250°C) at 18,000 feet (5,500 meters) and demonstrated the success of several new drilling technologies.[121] Additionally, several companies—including TLS Geothermics, XGS Energy, and Sage Geosystems—were designated as "awardable" by the Department of Defense for geothermal projects on U.S. Air Force bases, including bases in New Mexico.[122] Private companies also have opportunities to take on direct-use projects. As mentioned in Chapter 4, these can include agriculture, farming, greenhouse operations, and even oil and gas companies. Add to all those, potential district heating networks at places like the hot springs resorts in Mesa del Sol, a neighborhood in Bernalillo County, New Mexico.[123] Regardless of the application, private companies will be pivotal in expanding geothermal energy in New Mexico and are arguably the stakeholders with the most to gain, as they can serve as a launchpad to propel development forward.

CONCLUSION

A 2022 study noted that New Mexicans want an energy transition done *with* them, not *to* them.[124] Engaging all stakeholders is paramount to fostering involvement and collaboration so that every group feels included and valued. A single fracturing of stakeholder relationships during the development of any project could be destructive for all future projects. In this spirit, we propose the following recommendations to encourage positive interactions among all groups:

1. Strengthen collaboration and promote mutual understanding between state agencies, private developers, and Tribal governments. Tribal leadership is encouraged to view geothermal as part of a diversified economic strategy that aligns with both cultural values and long-term energy sovereignty.

2. Respect Tribal sovereignty and ensure Free, Prior, and Informed Consent (FPIC) processes are upheld. Support Tribal access to feasibility studies, technical assistance, and grant writing early and often in the project development process. Assist Tribes with locating funding sources for future projects.

3. Labor unions in New Mexico can benefit substantially from increased geothermal development and will likely express clear interest, with indications that even conservative geothermal growth would result in increased union membership in the state.

4. The Department of Defense has demonstrated interest in geothermal, and several installations have favorable conditions for power installation. As an entity with high capital and high need, these sites should be examined early for new projects.

5. Data centers pose a new, politically favorable application of geothermal energy with direct relevance to New Mexico. These opportunities should not be overlooked.

6. Environmental interest and advocacy groups are a crucial part of the geothermal energy development process in New Mexico. Engaging with environmental advocates is key to advancing geothermal policies while also ensuring that frameworks are in place to mitigate any negative impacts.

7. Innovative partnerships will be critical to solve the technical, economic, and social challenges of geothermal energy in the state. With an extensive network of universities, national labs, and private companies, new collaborations should be encouraged.

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Chapter 9

Environmental Considerations in New Mexico: Assuring Responsible Growth of the Geothermal Sector

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The fifth-largest state by area, New Mexico is so geographically diverse that it has six different ecosystems.[1] These fragile regions depend on New Mexico's limited water supply to maintain their beauty and biodiversity, but the limited water supply isn't the only environmental concern: air quality, land disturbance, water quality, habitat availability, and waste disposal all affect the state's biotic and abiotic communities.

Humans have always been deeply tied to the environment in New Mexico, and sacred sites are revered for their cultural and religious significance. Hot springs, fumaroles, rivers, wetlands, acequias, gypsum deserts, alpine regions, waterfalls, caves, and other sensitive environmental areas hold irreplaceable value to the people of New Mexico.

This chapter identifies **the environmental benefits, considerations, and potential impacts of increased geothermal energy use in the state. It shows that the benefits outweigh the risks.** The following pages include an investigation of potential impacts that should be considered in geothermal project development. Though not meant to be exhaustive, the chapter covers:

- Surface land effects
- Surface water effects
- Gaseous emissions
- Liquid emissions
- Induced seismicity
- Groundwater effects
- Ecosystem disturbance
- Noise pollution
- Solid waste generation

ENVIRONMENTAL BENEFITS OF GEOTHERMAL IN NEW MEXICO

Reduced CO_2 Emissions

Perhaps the most obvious environmental benefit of increasing geothermal energy in any area is a significant decrease in carbon dioxide (CO_2) emissions.

As mentioned in Chapter 4, "Geothermal Heating and Cooling," the largest industry in New Mexico is the oil and gas sector. The state's reliance on oil and gas for heating and industrial processes produces significant CO_2 equivalent (CO_2e) emissions.[2,3] The San Juan Basin has the largest concentration of methane emissions in the United States.[4] The process of extracting and burning oil and gas also releases other pollutants, which contribute to smog and health risks, particularly for individuals with respiratory conditions.[5] The impacts are most pronounced in the San Juan Basin[6] and the Permian Basin.[7] **The benefits of geothermal energy are critical to New Mexico's clean energy strategy. The use of geothermal resources would not only support the state's climate goals but do so in a way using expertise and know-how the state already has.**

The only geothermal power project in New Mexico at the moment—Lightning Dock—has no CO_2 emissions, as it is a pumped binary system in which dissolved gases are entrained in the geothermal fluid and reinjected into the subsurface.[8] Total CO_2 emissions from the Geysers, a geothermal power plant in California, reached 0.26 million metric tons in 2014.[9,10] According to data from the same year, CO_2 emissions among 1,544 power stations across the country averaged 1.35 million metric tons, putting emissions of the Geysers at 80% below the national average.[11] Particulates and pollutants such as nitrous oxides and sulfur oxides are also significantly reduced at geothermal power plants compared to nonrenewable energy plants in New Mexico (**Figure 9.1**).[12] For example, the Four Corners coal plant in New Mexico emitted 25.6 times more CO_2; 11,430 times more sulfur dioxide; and 4,667 times more nitrous oxides than average geothermal power emissions.[13,14] (These numbers have been adjusted to reflect emissions per megawatt-hour [MWh].)

New Mexico's electricity sector produced an estimated 10.3 million metric tons of CO_2 emissions (MMT CO_2e) in 2021.[15] In order to meet its 45% reduction target by 2030, New Mexico's emissions need to be 53.1 MMT CO_2e. However, state data shows that with current policies, New Mexico is on track to emit 65.8 MMTCO_2e in 2030, which would put the state at 12 MMTCO_2 over its goal.[16] Thus, meeting the 5-gigawatt geothermal target described in this report could offset roughly 12 million metric tons of CO_2 annually, depending on the energy displaced. This change would enable the state to meet its 2030 climate goals.

Reduced Emissions in Other Sectors

If geothermal plays a significant role in direct-use heat for the industrial and agricultural sectors and the building sector (see Chapter 4), these reductions in emissions can be even larger. CO_2 from oil and gas is projected to make up about 27% of New Mexico's emissions in 2025, with agriculture emissions representing 15% and buildings and industrial at 12%; these areas combined would contribute 54% of the state's total emissions. Even if geothermal meets only 10% of that projection, it would still reduce total oil and gas emissions in the state by an additional 5%—roughly the same impact as removing all the emissions from New Mexico's buildings.

Geothermal and New Mexico's Targets for Reducing Emissions

New Mexico has set a goal of reducing its greenhouse gas emissions by 45% by 2030, though data shows the state is not on track to meet that target.[17] Current projections indicate that the state can reduce emissions by 31% by 2030 without additional policy changes.[18] According to initial estimates, if New Mexico achieves the 5-gigawatt geothermal target outlined in Chapter 2, "The Geothermal Opportunity in New Mexico," it could apply geothermal technologies across important sectors (such as agriculture, buildings, and industry) to reduce emissions enough to meet its goal. In other words, going big on geothermal creates a climate buffer: The state would continue to benefit from the economic contributions of the oil and gas sector—including jobs and tax revenues—while staying on track to meet its climate goals. This balance would enable sustainable growth without forcing zero-sum trade-offs between economic vitality and emissions reductions.

AIR POLLUTION EMISSIONS IN NEW MEXICO, 2023

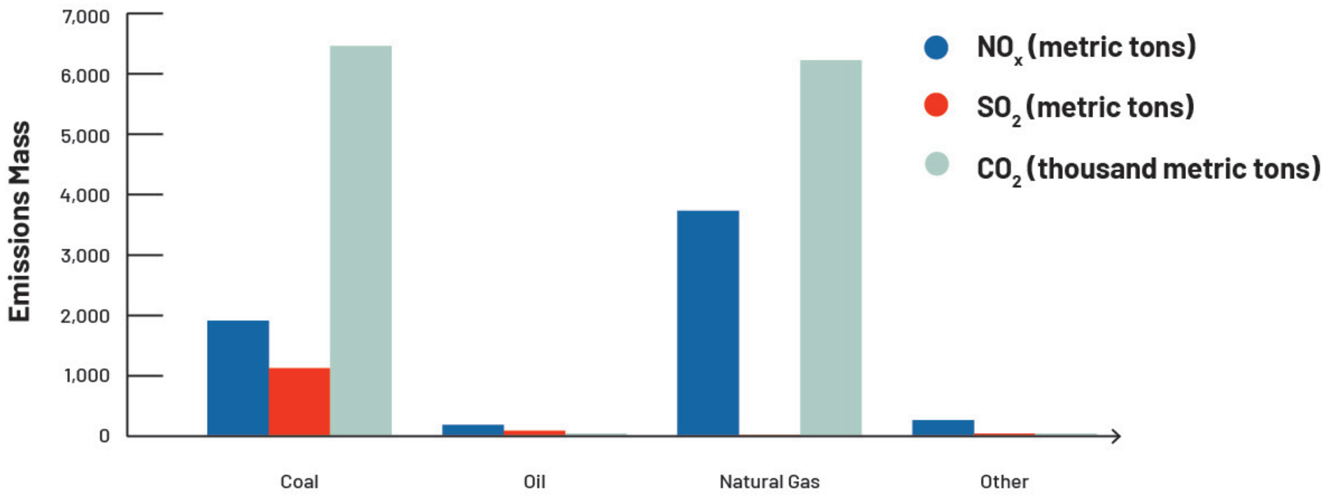

Figure 9.1: Air pollution emissions in New Mexico by energy source in 2023. "Other" includes geothermal, biomass, hydropower, wind, and solar energy. Source: U.S. Energy Information Administration. (2024). *New Mexico electricity profile 2023: Table 1. 2023 summary statistics (New Mexico).* https://www.eia.gov/electricity/state/NewMexico/xls/SEP%20Tables%20for%20NM.xlsx

Saving Water

Geothermal power plants use far less water than most other sources, largely because most are required (and all are recommended) to reinject geothermal fluid into the reservoir.[19] This approach not only limits water use but also helps ensure the reservoir's longevity. For example, Masson Farms in Radium Springs reinjects geothermal fluid to heat several greenhouses.[20] (This process also prevents thermal pollution in the nearby Rio Grande, eliminates subsurface contamination in shallow aquifers, and avoids contamination of surface waters.)

Direct-use applications use similarly low amounts of water when tapping into shallow aquifers. Even when water must be taken from surface sources to start a direct-use operation, and the water is kept in a closed-loop system, virtually none is lost.[21] Closed-loop technologies for electricity generation, such as an advanced geothermal system (AGS), use similarly low quantities of water. An enhanced or engineered geothermal system (EGS) is an exception; hydraulic fracturing and potential downhole losses during development and operation can use large volumes of water.[22,23,24] That said, data from the U.S. Department of Energy and Fervo Energy shows that an EGS can have a water recovery rate of 90%.[25]

In New Mexico, water use in geothermal energy activities is governed by three separate legislative acts: the New Mexico Oil and Gas Act (1935), the New Mexico Water Quality Act (1967), and the Geothermal Resources Act (1975).[26] The Geothermal Resources Act gives state regulatory agencies jurisdiction over geothermal activities; if geothermal development increases in New Mexico, this legislation helps ensure proper water use and waste management. Given that New Mexicans recently rated water scarcity as the fourth most important environmental issue, saving water is a major benefit of geothermal energy production. [27]

Another consideration related to fluid is that power plants are a major contributor to thermal pollution, or the discharge of water that is often hotter than ambient temperatures even when it is treated. Today, more than half of New Mexico's rivers have thermal pollution.[28] While geothermal energy produces immense amounts of heat waste—up to nine times that of other power plants[29]—that heat is expelled to the atmosphere as mostly water vapor from cooling towers or is captured entirely in a next-generation system. Little to no thermal energy is directly expelled to surface waters. The common practice of reinjecting geothermal fluid means most of the heat is retained and returned to the reservoir where it existed naturally.[30]

Local Energy Sourcing and Knowledge Gained

Another major benefit of geothermal energy is its local, homegrown nature. As an indigenous source of energy, geothermal is available in New Mexico and can stay in New Mexico. There is no need to mine, transport, or process the resource, all of which contribute to CO_2 emissions and generate waste.[31]

Exploring, drilling, and operating a geothermal power plant offers up valuable subsurface knowledge—information that can improve our understanding of subsurface seismicity, ancient faults, landslide risk, aquifer stability, and contaminant transport. For example, a study from 2021 used data from drill cores and well injection tests in the Permian Basin of Texas and New Mexico to estimate seismic hazards caused by future oil and gas activity.[32] In addition, **geothermal wells drilled through shallow aquifers for use in agriculture, manufacturing, or drinking water can help the state determine the extent, thickness, and hydrogeology of these aquifers. Such information is critical when 78% of New Mexicans rely on groundwater to meet their needs**.[33] Furthermore, monitoring wells that are commonly drilled near geothermal sites can help scientists track potential subsurface contaminant leaks in groundwater.[34]

More Local Agriculture

Additional geothermally heated and cooled greenhouses and aquaculture farms would reduce the state's reliance on transporting crops from neighboring states.[35] These new farms and greenhouses would use far less water from New Mexico's surface water bodies or water pumped from interstate aquifers compared with traditional agriculture. (See Chapter 4 "Geothermal Heating and Cooling," for more.) In 2006, geothermal greenhouses were among the largest employers in Hidalgo and Doña Ana counties.[36]

Additional Wildlife Habitats

Finally, in some areas, geothermal power plants **have created additional habitats for wildlife, such as migratory bird nesting ponds in arid areas near Cerro Prieto in Mexico and the Salton Sea in California**.[37] Wetlands near holding ponds have also spurred plant growth and served as new habitats for large mammals in more humid areas.[38] As a mostly arid state with high biodiversity and few wetlands, New Mexico could see similar benefits for its wildlife with more geothermal development. A model to consider would be the Abandoned Mine Land Program and the Mining Act Reclamation Program. But instead of waiting to revegetate or recontour a geothermal site into a self-sustaining ecosystem after a power plant's operational life cycle,[39] habitat restoration could begin soon after power is being generated from a geothermal plant.[40,41]

All this said, while geothermal contributes to improved air quality and lower emissions, the variety of environmental features, biomes, and biota throughout New Mexico means that each region presents a different environmental challenge. Several stakeholders are involved in the state's environmental well-being, including ranchers and farmers, Indigenous tribes, activist organizations, for-profit companies, researchers, and hundreds of thousands of citizens. (See Chapter 8, "New Mexican Stakeholders: Opportunities and Implications for Geothermal Growth and Development.")

ENVIRONMENTAL CONSIDERATIONS AND CONCERNS

The first stage in the development of any geothermal resource is geological exploration to find and characterize a resource. Once a resource has been identified, wells can be drilled and cemented and infrastructure put in place to channel geothermal fluid to its destination. Next, there are ongoing operations. Each stage involves specific environmental considerations, including land use, water, gaseous emissions, and liquid emissions that need to be taken into account to ensure that geothermal's benefits far outweigh its concerns.

GEOLOGICAL EXPLORATION

Land Use

Many exploration techniques are largely noninvasive and observational. For example, sampling methods can involve the need to access sensitive areas, but impacts from these activities are largely trivial. Some exploration methods, however, do have a larger effect.[42]

Seismic exploration involves generating seismic waves at the surface through rapid ground displacement. Active seismic surveys often compress soil or rock at the surface with an air gun or a seismic vibrator.[43] Though this method creates noise and disturbs soil and wildlife, it is temporary and usually doesn't require excavation or result in any lasting impacts. **Most surveys use existing road and infrastructure networks to save costs, resulting in little habitat loss or vegetation removal.** In cases where the survey does have these effects, reclamation is often mandated by law, though it can take decades for the environment to return to its natural state.[44]

Magnetotellurics, which is used to get an understanding of resisitivity in the subsurface, involves digging shallow holes (less than 5 feet deep) in soil to install large magnetometers.[45] Special care must be taken during these operations so as not to disturb local soil columns or accidentally excavate historic Indigenous sites. Strict regulations control these activities and seismic surveys can take place on public lands. Maintaining oversight and proper planning are key to preventing damage.

Surface Water

Geothermal exploration activities have minimal effects on surface water. Although geochemical methods involve sampling from thermal springs and fumaroles, which displaces some water, the sampled quantities pale in comparison to the overall flow of these features.

Gaseous Emissions

The only gaseous emissions produced during exploration activities are emissions from vehicles accessing data collection sites. In a typical geothermal power plant, any emissions associated with exploration account for only 1% of total life cycle emissions.[46]

DRILLING

Land Use

Large, commercial drilling operations cause pervasive surface land effects, starting with clearing the land of any vegetation and compacting uneven soil,[47,48] for the placement of drilling equipment. Companies also build roads to access the site, often through difficult terrain that can involve deforestation and soil disturbance. The removal of vegetation increases erosion from wind and rain. Destroying soil crusts that form in arid areas makes soil layers more susceptible to evapotranspiration, drying the soil and limiting water available for plants.[49]

Though the land area affected during commercial drilling operations is small compared to the land disturbed by other energy sources,[50] it isn't negligible. Drilling operations have affected lands in locations other than the actual wellpads. Oil and gas drilling in New Mexico, Utah, Wyoming, and Colorado has contributed to increased erosion and increased sediment loads in the Upper Colorado River Basin. The sediment loads increased turbidity, salinity, and total dissolved solids (TDS) in surface waters, threatening aquatic life.[51] Disturbance from oil and gas drilling as indicated by the level of dissolved solids in streams, while present, does not appear to be significant.[52]

These findings offer positive news for geothermal drilling, as an increase in activities may not harm water quality. In addition, the Bureau of Land Management's (BLM's) Gold Book provides outlines for drill pad and road construction to mitigate erosion and land impacts.[53] Suggestions include not building near narrow ridges, within 500 feet of riparian zones, and more.[54] Directional drilling makes it easier than ever to build drill pads in environmentally secure areas while directing the well to reach the desired resource. Additionally, multiwell drill pads, which reduce the need for more land and more roads, are becoming more prevalent.[55]

Surface Water

The largest effect on surface waters from drilling is caused by the use of drilling fluid. Even when drilling fluid is not water based, some amount of water is still needed. Shallow exploration and monitoring wells, which typically do not exceed 1,500 feet (450 meters) in depth, can require between 13,200 gallons and 22,500 gallons (50 kL–85 kL) of water.[56] This amount is nontrivial considering most projects involve more than one exploration or monitoring well.

EGS drilling, which consists of one injection well and a production wells drilled to reservoir depths of between 9,900 feet and 16,500 feet (3,000 meters–5,000 meters), can require 235 gal/MWh to 4,210 gal/MWh.[57] This is not a trivial amount of water, but Fervo has said the drilling does not use potable water.[58] Best practices for EGS, particularly in arid parts of the West, will include using brackish water or water with high TDS levels from underground sources where potable water is not sourced. New Mexico already struggles with drought, as the past five years were drier than the previous 15.[59] The importance of conserving water resources in the state cannot be overstated.

Another solution in drilling operations has been to reuse produced drilling fluids, which is already being done with geothermal wells. Used drilling fluid from geothermal operations could also be disposed of into existing oil and gas reservoirs in New Mexico.[60,61,62] The reuse of drilling fluids would alleviate water stress in future geothermal development and leave more water for agricultural use.[63] Though some additional infrastructure is required to use produced water (such as holding tanks, injection pumps, and trucks to transport the fluid), these elements would also be needed if another water source was used. Add to all that: disposing of used geothermal drilling fluid through large holding ponds or with desalination is difficult and costly. Holding ponds produce large amounts of solid evaporite waste that must be disposed of in a responsible way. (They may also, however, hold high enough concentrations of critical minerals to be economical, as is the case with lithium in geothermal power development in California.[64])

Estimates for desalination of drilling fluid can range from $5.53 to $50 per cubic meter, depending on water quality. That could mean up to $14 million per EGS module.[65] With a demonstrated history of success, and if state environmental agencies enforce safe practices, the reuse of coproduced water for drilling and for disposing of used drilling fluid in existing oil and gas reservoirs should not be overlooked.

Gaseous Emissions

Emissions during drilling operations come largely from the equipment itself, although the exact amount is hard to quantify. Commercial drilling equipment is almost entirely operated with fuels (including gas-powered rotary drill rigs and diesel-powered generators) and a connection to the overall power grid, which primarily relies on oil and gas in New Mexico.[66] While drilling operations will continue to produce some emissions, the use of geothermal can mitigate the lower heat-source spectrum of this CO_2 output. (See Chapter 4.)

Though emissions will vary based on the type of well, depth, and machinery used, **a 2022 study cites a low end of 6 kg of CO_2 per foot of drilling, which equates to 60 metric tons of CO_2 for a 10,000-foot-deep (3,000 meter) well.[67] These emissions roughly equate to the amount emitted by 13 passenger cars in the United States in a single year.[68]** Other gaseous emissions come from the geothermal reservoir itself when the drill bit reaches a certain depth, as gases in a geothermal reservoir can travel up the wellbore and reach the surface. In most cases, drilling operators mitigate these emissions with proper valves and seals.[69]

Liquid Emissions

Liquid emissions from the drilling process itself are minimal because the drilling fluids that circulate in the wellbore are reused. In New Mexico, significant effort is invested to limit spills so costs can be kept low.[70] If spills do occur, however, heavy metals from geothermal brine, including carcinogenic arsenic, could pollute shallow subsurface aquifers,[71] though this has not yet happened in the United States.[72,73] Similarly, any liquid that might escape as a drill bit reaches a reservoir is also contained to follow regulations and maintain safety. (**See Figure 9.4**.)

OPERATIONS

Land Use

Along with wells, geothermal operators must install pipelines, transmission lines, cooling towers, heat exchangers, turbines, and more. Roads also have to be built to get equipment to a site. These operations must be done with careful consideration of a site's environmental zone. The good news is that geothermal facilities mostly require far less infrastructure than other energy sources, with a typical geothermal energy power plant occupying just 1,500 m2/MWh (0.37 acres/MWh) compared to 40,000 m2/MWh (9.9 acres/MWh) for a coal-fired power plant (see **Figure 9.2**).[74] **Emerging next-generation geothermal technologies require even less space, such as a single, shallow groundwater circulation well for direct use or a geothermal doublet well for electricity production.[75]**

Subsidence

In a traditional geothermal operation, a developer must consider land subsidence. When pore fluid is removed from the subsurface without reinjection, the effective stress between soil and rock grains is decreased and the overlying mass compresses deeper layers. Subsidence often takes place over decades, but it has been seen in multiple geothermal projects, most commonly in porous or pyroclastic reservoirs.[76] Subsidence as high as 6.8 inches per year (17 centimeters) has been seen at Ohaaki Power Station in New Zealand; another site in New Zealand, Wairakei Power Station, has seen 46 feet (15 meters) of total subsidence over 50 years of operations.[77,78] Subsidence can be mitigated or eliminated by reinjecting fluid into the reservoir.[79] Nearly all geothermal power plants use reinjection, resulting in very few cases of extreme subsidence.[80] This is less of a concern for next-generation geothermal.

Surface Water

Water use during geothermal operations can vary depending on the type of plant and technology used. As mentioned, EGS technology requires the most water (500 gallons per MWh) to maintain reservoir pressure

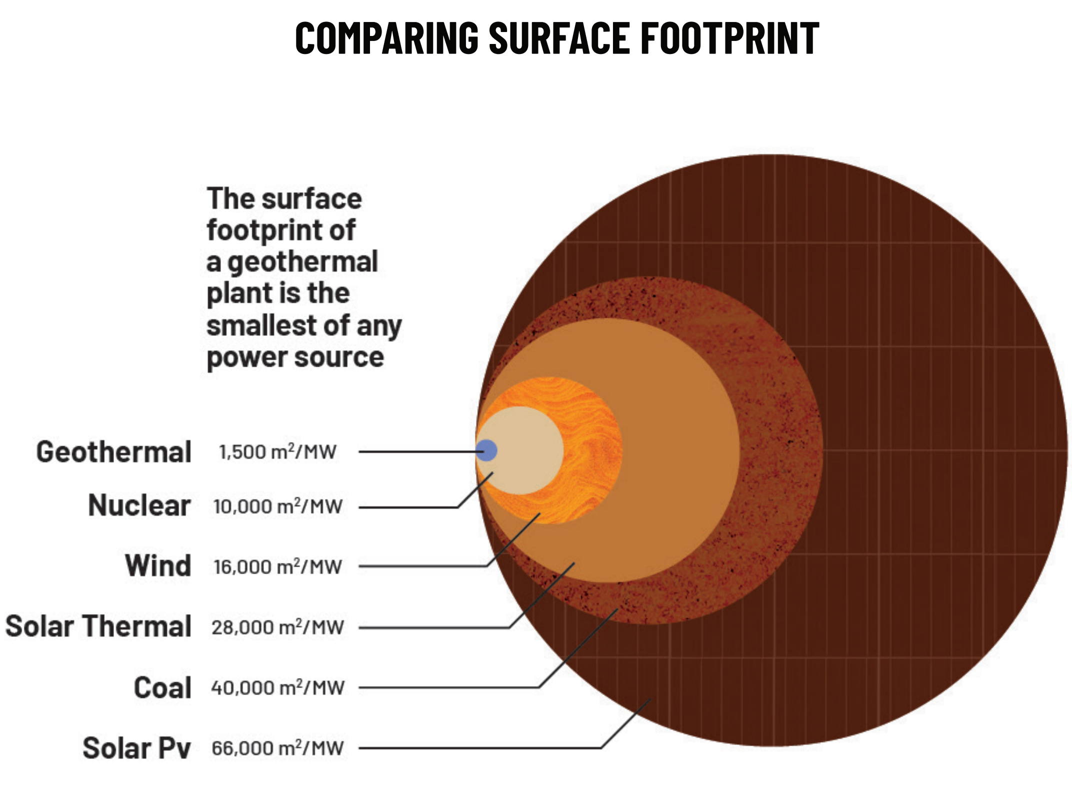

Figure 9.2: The project surface footprint, acre for acre for 1 gigawatt of generating capacity, is smallest for geothermal compared with other renewables and coal. Source: Adapted from Lovering et al., 2022 and NREL.

and keep fractures open amid losses to the reservoir rock.[81,82,83] Geothermal uses similar amounts of water as natural gas and far less than coal, nuclear, and concentrated solar power (**Figure 9.3.**)

Gaseous Emissions

During power plant and commercial operations, most gaseous emissions are made up of harmless water vapor from cooling towers. Next-generation geothermal systems, particularly AGS, do not typically produce ongoing gaseous emissions from the reservoir itself, so volatile gases such as CO_2, hydrogen sulfide (H_2S), or methane that might be present in traditional hydrothermal reservoirs do not escape to the surface. Other emissions sources include gas-powered pumps, emergency generators, heavy equipment used during maintenance, and other routine small emitters.[84] Noncondensable gases (NCGs) are present in every geothermal reservoir but often amount to less than 5% of the geothermal fluid by weight.

In an estimate of a proposed geothermal power station in the Jemez Mountains, the geothermal fluid was only 2.64% NCGs by weight with 28,250 ppm CO_2, 204 ppm H_2S, 56 ppm N_2, 2 ppm H_2, and 2 ppm CH_4.[85] H_2S is a toxic, hazardous gas that forms sulfuric acid when mixed with liquid water. If this gas is not reinjected into the reservoir, abatement systems are routinely installed that can reduce emissions of it by up to 99.9%.[86] N_2 and

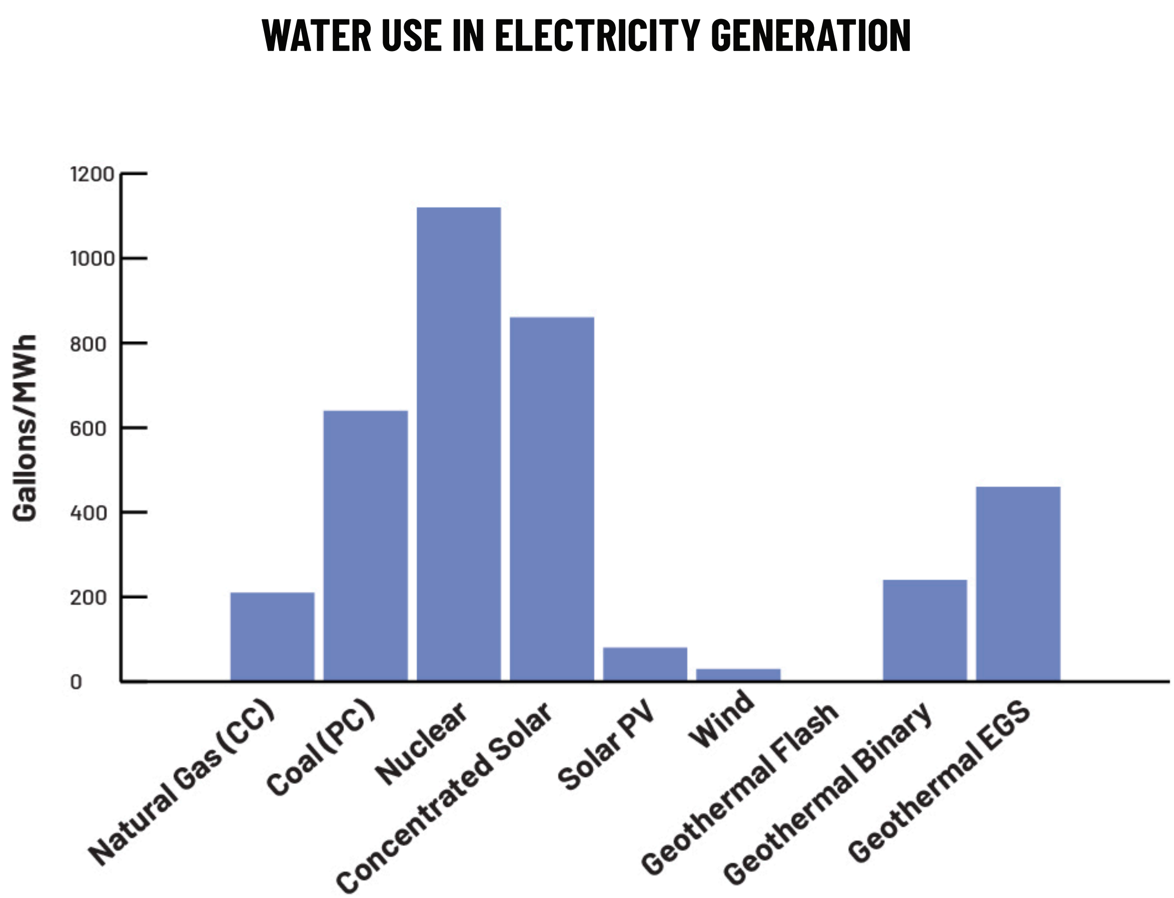

Figure 9.3: Consumptive water use in electricity generation by power plant type. CC = combined cycle; PC = pulverized coal. Source: Meldrum, J., Nettles-Anderson, S., Heath, G., & Macknick, J. (2013). Life cycle water use for electricity generation: A review and harmonization of literature estimates. *Environmental Research Letters*, 8, 015031. https://doi.org/10.1088/1748-9326/8/1/015031

N_2 and H_2 (nitrogen and hydrogen, respectively) are harmless and naturally occurring in the atmosphere. Although CH_4 (methane) is a potent greenhouse gas, it is emitted in small enough quantities in geothermal systems that it is not even included in the U.S. Environmental Protection Agency's (EPA's) inventory of methane emissions.[87]

CO_2 (carbon dioxide) is the most common NCG in geothermal systems.[88] Some geothermal systems naturally emit some CO_2, which must be considered when estimating CO_2 emissions. One 2021 study examined CO_2 emissions at the Wairakei Geothermal Field in New Zealand and found that even though geothermal operations increased CO_2 emissions above ambient levels when operations began, the emissions trailed off over time to reach less-than-ambient levels.[89] When viewed over 300-year time scales—not unheard of considering some geothermal power plants have been in operation for more than 100 years[90]—the CO_2 emissions from geothermal development match what would have been emitted through natural processes.[91]

The most effective method to prevent emissions is to reinject NCGs back into the reservoir with the rest of the fluid. Existing and new geothermal operations, particularly binary power plants and AGS that already keep the fluid contained, can easily incorporate this method into the plant design and keep geothermal emissions far lower than other energy sources.[92]

Liquid Emissions

Liquid emissions during operations can include minor spills of fuels, lubricants, and accessory chemicals. These emissions can generally be prevented through proper employee training and operational practices, but larger accidental spills can occur due to a mechanical failure of the plumbing infrastructure transporting the geothermal fluid. This has happened at Raft River, Idaho, and in Mexico at Los Azufres. Though monitoring confirmed no contamination of shallow aquifers from the surface spill in Idaho,[93] an 18-month monitoring project in Mexico detected significant amounts of boron, arsenic, and other contaminants in surface waters and shallow aquifers from geothermal activities.[94] In addition, the spill left behind solid evaporites that can increase salinity and kill vegetation.[95] Ultimately, the spill was determined to have been caused by leaking pipelines, wellheads, and mufflers that were not properly engineered.[96] Luckily, no such contamination has been seen in geothermal operations in the United States,[97,98] and EPA policies currently mandate that containment systems must be built to hold 150% of potential spill volumes.[99]

OVERLAPPING ENVIRONMENTAL CONSIDERATIONS

Induced Seismicity

Reinjection of fluids is recommended for sustaining reservoir fluid levels, maintaining pore pressure, and disposing of potentially harmful geothermal fluids, but it is known to change the state of stress in the subsurface. When the change in stress occurs, fractures can form (hydraulic fracturing), or existing fractures can reopen and displace (hydroshearing),[100] causing small earthquakes that can be felt at the surface. Since this impact does not occur naturally, it is referred to as *induced seismicity*. In an EGS, higher-pressure injection can also create new fractures, lengthen existing fractures, or supply enough pressure to reopen old fractures and allow movement along their rough surface.[101] In all types of systems, chemical dissolution from injecting foreign fluids into the reservoir fluid can also change stress regimes.[102]

Not all geothermal operations have induced seismicity, especially direct-use projects that have shallower injection depths, lower injection pressures, and smaller differences in fluid and rock temperatures. Stakeholders should investigate where and how induced seismicity might occur in New Mexico.

A 2000 report found that 20% of U.S. geothermal fields experience some impact of reinjection.[103] Though this finding represents a minority of geothermal fields, induced seismicity could eventually lead to larger earthquakes. In 2006, seismicity events from early EGS operations, with magnitudes as large as 3.4, were reported in Basel, Switzerland.[104] In New Mexico, events with magnitudes of 5.4 have also been noted in the Permian Basin, caused by wastewater reinjection in oil and gas operations.[105]

Microseismicity is difficult to predict and has been the topic of geothermal research for decades.[106,107] Our understanding of this issue is improving, but the best methods for prevention currently include matching injection and production volumes during operation, minimizing injection flow rates, monitoring pressure at depth in the wellbore, and monitoring earthquakes during drilling and operations.[108] A detailed understanding of a site's reservoir and fracture network can also help ensure that wells are located in stable areas and optimize injection practices.[109] If geothermal is developed on federal land, seismic monitoring is required and the data will be made public.[110] Several geothermal operations in the United States, such as the Frontier Observatory for Research in Geothermal Energy (FORGE) site and the Geysers geothermal field, have their own seismic monitoring networks in addition to U.S. Geological Survey stations.[111,112]

As noted, New Mexico has fewer issues with induced seismicity than other states. Subsurface conditions in Texas mean that nearly an order of magnitude less pressure is needed to induce seismicity than would cause it in New Mexico.[113]

Induced seismicity can generally be mitigated through careful site characterization (particularly by avoiding development in tectonically active areas), thoughtful design of fluid circulation systems, and controlled injection rates during operations.

SUBSURFACE WELLBORE STABILITY

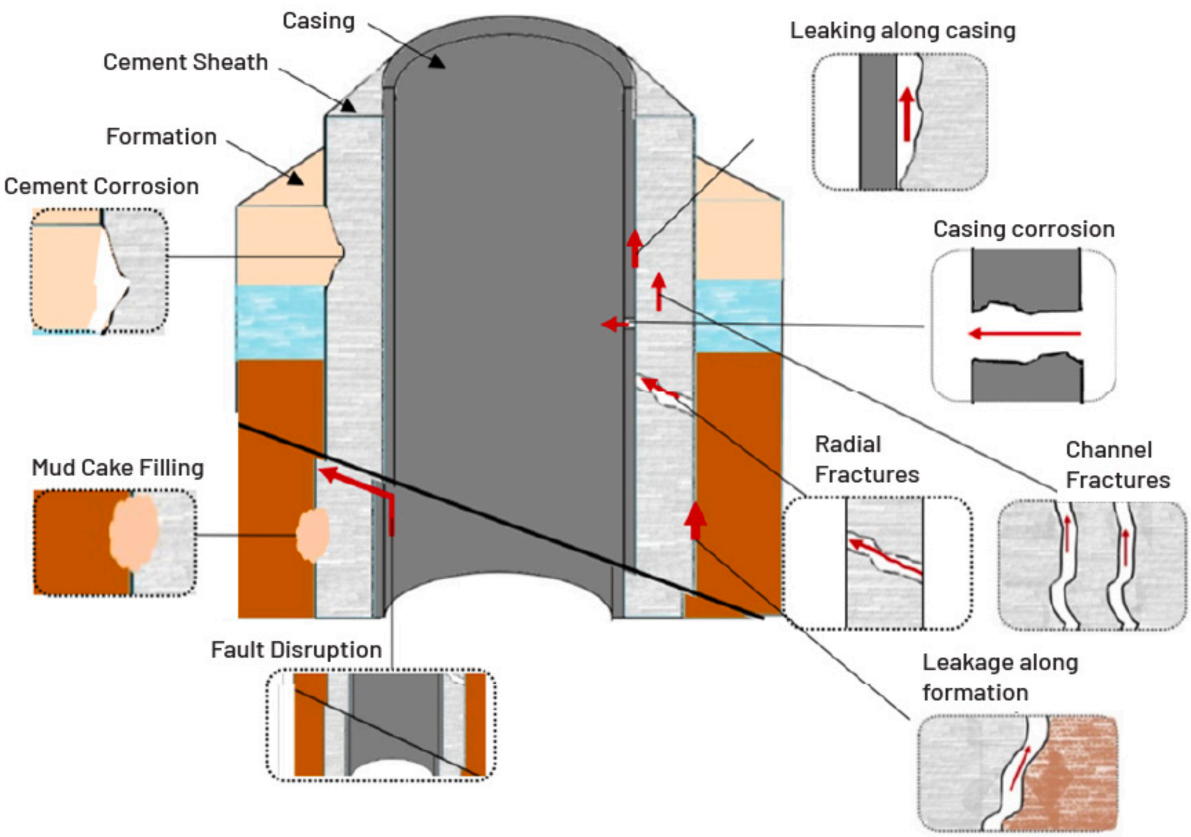

Figure 9.4: Common leakage pathways and cement failures in subsurface wellbores . Modified from Wu, B., Arjomand, E., Tian, W., Dao, B., & Yan, S. (2020). *Sealant technologies for remediating cement-related oil and gas well leakage: A state-of-the-art literature review*. Commonwealth Scientific and Industrial Research Organization of Australia.

For wastewater disposal wells, limiting both injection pressures and flow rates is key. The EPA's Underground Injection Control program plays a central role in regulating these activities, setting site-specific limits on injection pressures and rates based on the geology and formation characteristics of each well. Given that New Mexico's geology is more resistant to induced seismicity and the protocols being developed in shale basins across the country, induced seismicity should pose little risk.

Groundwater Contamination

There have been no documented examples of groundwater contamination from geothermal activities in the United States, but groundwater contamination remains a significant concern, so regulations should be put in place to ensure wells are properly cemented and designed.[114,115,116] A 2021 study attributes this success to EPA, BLM, and state requirements for geothermal projects coupled with industry efforts to properly isolate geothermal wells and avoid drilling across active faults.[117] Potential contamination is also heavily monitored through regular sampling of shallow wells around geothermal sites for fluid chemistry, water levels, fluid temperature, and pressure.[118] Extensive monitoring has also provided insight into local hydrogeology.

The Lightning Dock Geothermal power plant in Hidalgo County has received some public backlash for affecting nearby aquaculture farms and groundwater wells.[119] Cyrq Energy, the former operators, dismissed these claims and asserted that there has been no groundwater contamination or disruption of local businesses due to their operation.[120]

Groundwater monitoring will be crucial in New Mexico because water resources and thermal features are critical to not only environmental cycles and wildlife but also residents. Many Indigenous tribes hold hot springs and fumaroles as sacred sites. Concern over the loss of these sites impeded geothermal development in the state in the past. To ensure a geothermal site causes little to no effects on surface thermal features and effectively sustains a geothermal reservoir in a near-natural state,[121] developers, regulatory agencies, and local communities should collaborate on their approaches and processes.

Ecosystem Disturbance

Given that geothermal opportunities in New Mexico exist largely in rural, undeveloped areas, wildlife considerations are essential. One consideration is the loss of habitat for wild species and of grazing land for domesticated animals. Geothermal operations occupy less land area per megawatt than most other energy sources (**Figure 9.2**), but some displacement does occur. In central Nevada, for example, the habitat loss of an endangered species, the Dixie Valley toad,[122] has halted development of the Dixie Meadows Geothermal power plant. **The good news: In New Mexico, BLM areas of critical environmental concern don't overlap much with areas of high geothermal potential (Figure 9.5).123**

In addition to habitat loss, another important consideration is the potential effect on sacred Tribal lands, essential ecosystems, and protected federal lands.[124,125,126] The disturbance of cultural or archaeological resources is also regulated. Geothermal activity must pause for investigation if any discovery is made during plant construction.[127] Environmental Impact Assessments (EIAs) must be completed before any geothermal development on land managed by the BLM or the U.S. Forest Service, but permitting reform is an ongoing discussion at the federal level at this time.

A 2017 EIA in Santa Fe National Forest examined potential geothermal leases around the Valles Caldera National Preserve and found that "tribes consider the disturbance of the land or use of geothermal resources as an adverse impact that could not be avoided or minimized."[128] This finding was in part why geothermal permitting was not allowed in the general area of Jemez Springs and Jemez Pueblo (**Figure 9.6**). Other areas that didn't allow permitting included areas around streams, lakes, and acequias; a radius zone of 1 mile (1.6 kilometers) around any thermal feature; areas of cultural, Indigenous, or religious significance; and any area that could potentially be a source of public drinking water.[129] The EIA also included plans to allow for discretionary closures and stipulations during future geothermal development to prevent unforeseen environmental impacts. Such assessments must be undertaken for any project on public lands.

New Mexico is well known as the Land of Enchantment. Preserving the state's beauty is a priority, and there

AREAS OF CRITICAL ENVIRONMENTAL CONCERN AND GEOTHERMAL OVERLAP

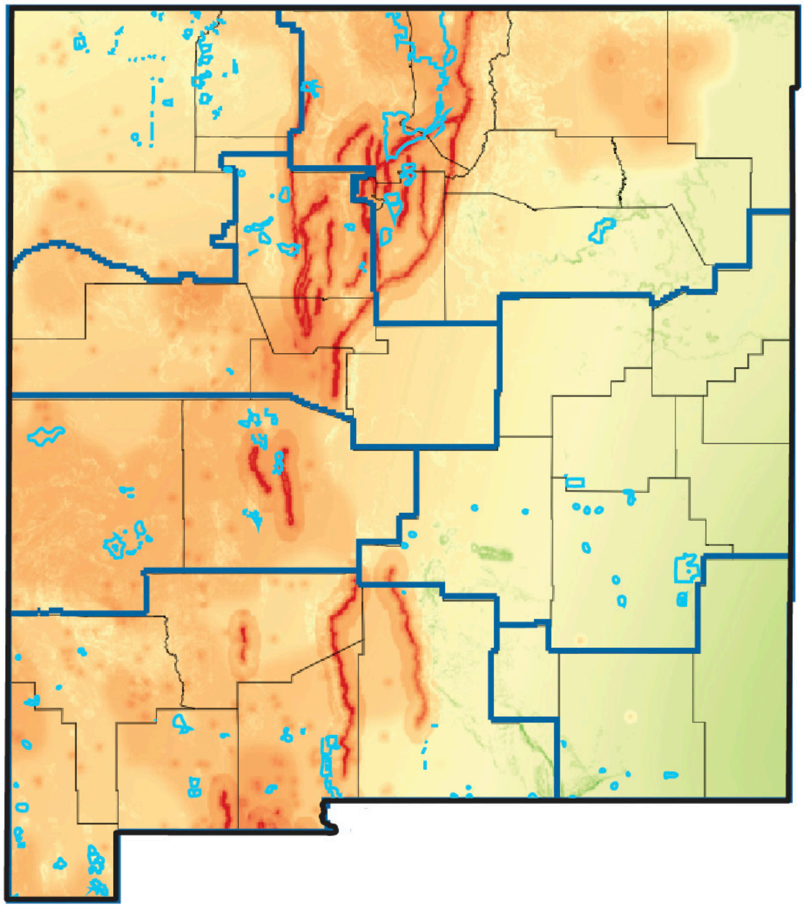

Figure 9.5: Map of Bureau of Land Management (BLM)-identified Areas of Critical Environmental Concern (ACECs) in New Mexico and geothermal potential. ACECs are outlined in green, with blue lines indicating boundaries of BLM management districts. Source: Bureau of Land Management. (n.d.). *New Mexico geospatial data*. Retrieved December 12, 2024, from https://gbp-blm-egis.hub.arcgis.com/pages/newmexico

are ways to meet this need while also developing geothermal power infrastructure. Some power plants and direct-use facilities incorporate building materials with colors that fit in well with the environment.[130] Geothermal operators also often insulate hot materials and surround plant areas with a barrier to prevent exposure to wildlife and people.[131] The use of air-cooled condenser systems instead of water-cooled systems can reduce plumes of steam, thus protecting the viewshed. Although the air-cooled systems can be inefficient in hot areas and often produce noise, they also[132] use less water—a key resource in New Mexico. Another concern is deforestation during plant and road construction. While some sites have planted trees as a reclamation action,[133] some deforestation near a plant site is not necessarily a bad thing, as it can remove potential wildfire fuel.

Noise Pollution

In exploration activities, noise pollution is negligible. And while noise isn't a huge problem in geothermal activities, it does occur during drilling and operations, so addressing it is important. Most geothermal sites are far from human populations, but noise levels can be as high as 120 dBA when field workers are perforating a well during drilling.[134] This noise is only temporary, and from 900 meters away, it decreases to match ambient noise levels in urban areas (71 dBA–83 dBA). During normal operations, noise levels drop to between 15 dBA and 28 dBA, which matches the average background noise in wilderness areas (20 dBA–30 dBA).[135] The BLM mandates that noise at a half-mile distance (about 1 kilometer) must be 65 dBA or less.[136] Many geothermal operations employ muffling techniques such as noise

AREA OF ENVIRONMENTAL IMPACT ASSESSMENT FOR SANTA FE NATIONAL FOREST

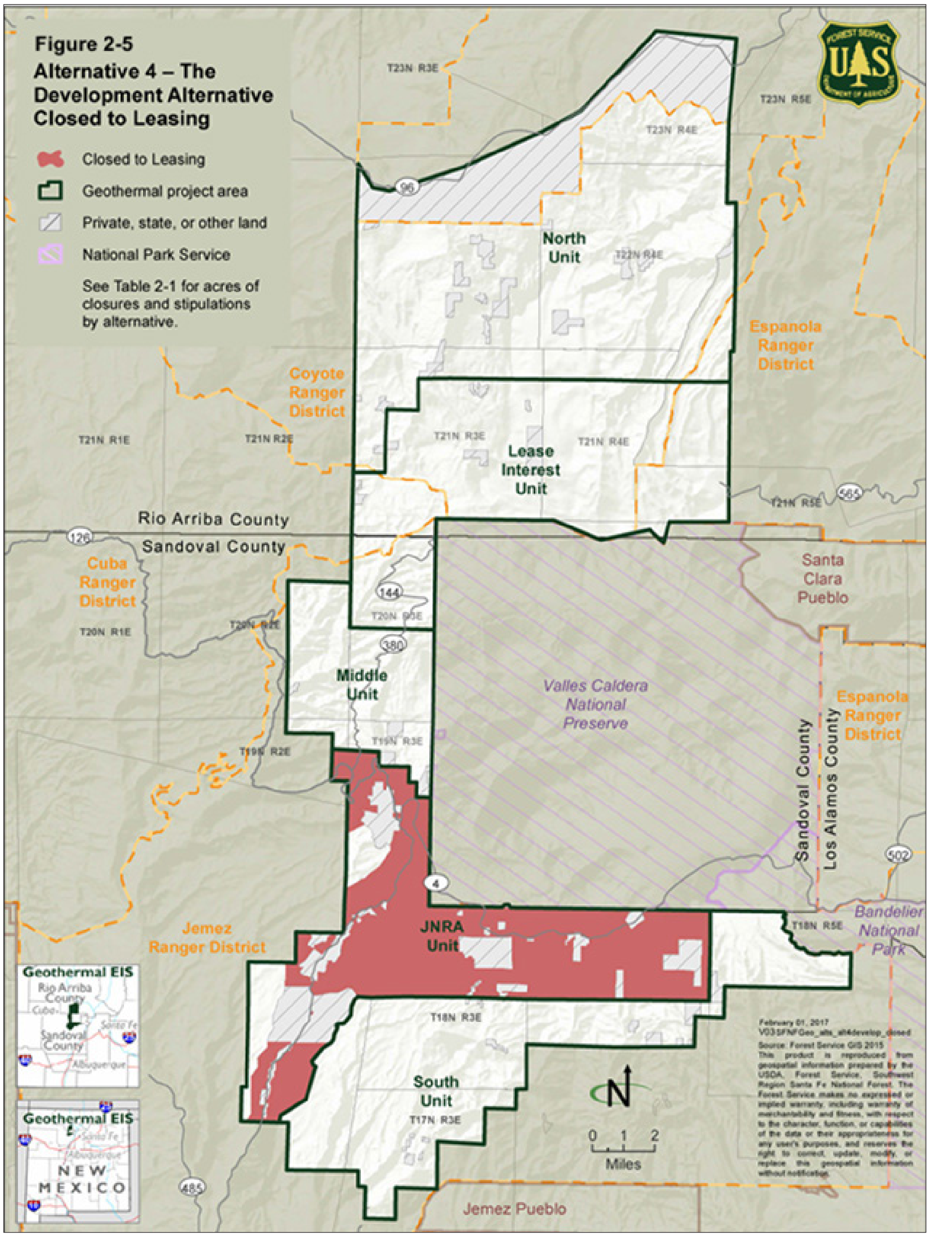

Figure 9.6: Map showing area of Environmental Impact Assessment for Santa Fe National Forest with lease areas for consideration outlined in green and the area deemed closed to leasing in red. Source: U.S. Department of Agriculture. (2017). *Santa Fe National Forest geothermal leasing: Final environmental impact statement*. Forest Service, U.S. Department of Agriculture. https://www.govinfo.gov/content/pkg/GOVPUB-A13-PURL-gpo105526/pdf/GOVPUB-A13-PURL-gpo105526.pdf

shields, exhaust mufflers, and acoustic insulation to reduce noise by up to 40%.[137] **Figure 9.7** shows reported values for various noise sources for comparison.

Solid Waste Generation

Geothermal operations produce solid waste through multiple waste streams. Maintenance and construction debris, dried drilling-mud residue, obsolete machinery, damaged piping and flow elements, and drilling cement waste often end up in nearby landfills or sit idle at the geothermal site.[138] When properly disposed of, this waste poses little threat to the environment. Some waste, however—including drilling circulation chemicals, fuels, lubricants, asbestos, and other hazardous materials—must be handled properly and disposed of through more regulated waste streams involving chemical treatment. Volumes of waste produced can be significant, with as much as 79,000 gallons (300,000 liters) of fuel waste and 790 gallons (3,000 liters) of lubricant waste generated from a single well.[139]

NOISE LEVELS ACROSS GEOTHERMAL DEVELOPMENT PHASES COMPARED TO ANTHROPOGENIC SOURCES

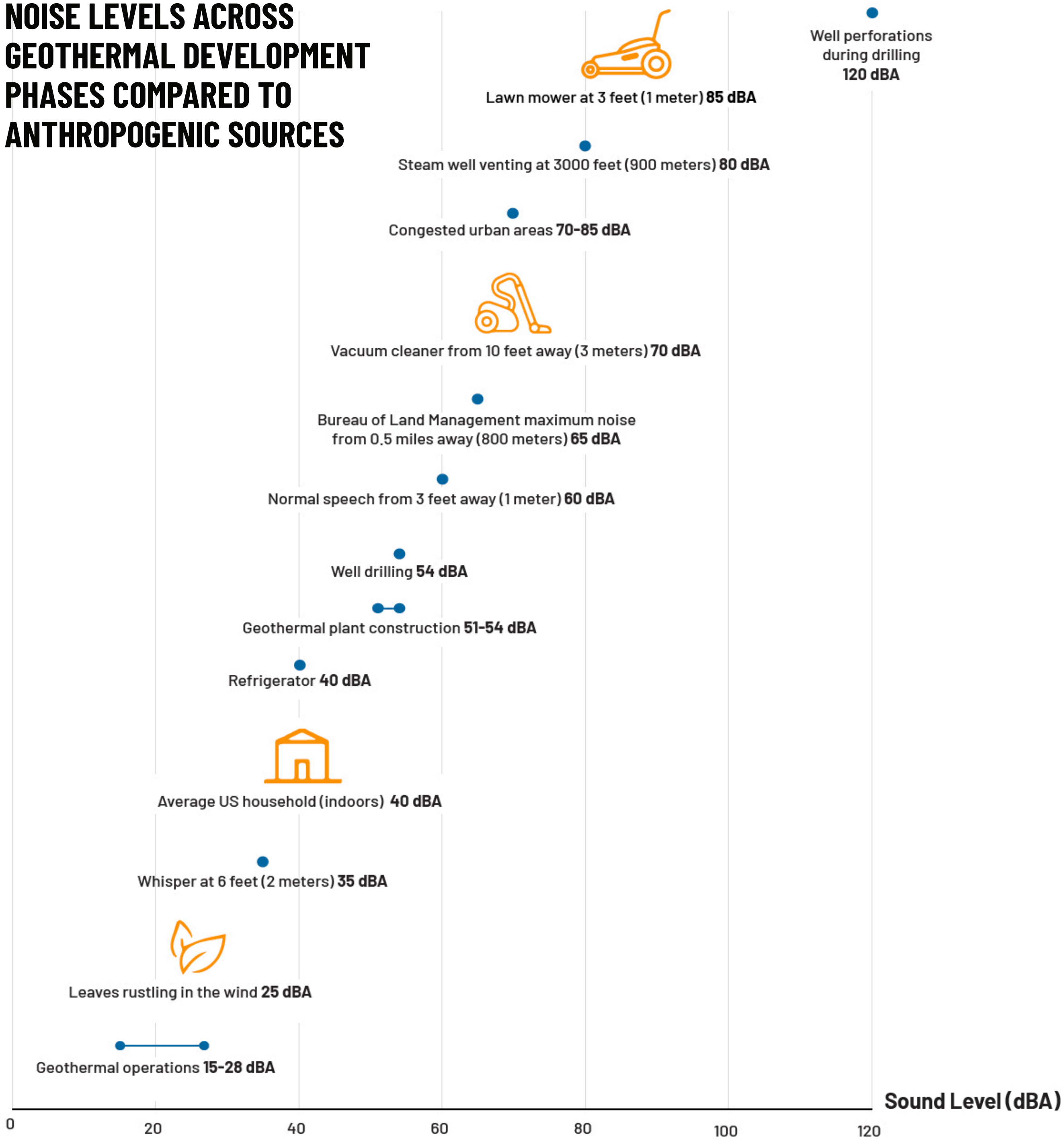

Figure 9.7: Noise levels across geothermal development phases compared to anthropogenic sources. Sources: Kagel, A., Bates, D., & Gawell, K. (2005, April 22). *A guide to geothermal energy and the environment*. Geothermal Energy Association. https://doi.org/10.2172/897425; Massachusetts Institute of Technology (MIT). (2006). Environmental impacts, attributes, and feasibility criteria. In MIT (Ed.), *The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century*. (pp. 8-1–8-20). Massachusetts Institute of Technology. https://www1.eere.energy.gov/geothermal/pdfs/egs_chapter_8.pdf; Bryant, M., Starkey, A. H., & Dick-Peddie, W. A. (1980). *Environmental overview for the development of geothermal resources in the State of New Mexico*. New Mexico Department of Energy. https://doi.org/10.2172/6725435; Birkle, P., & Merkel, B. (2000). Environmental impact by spill of geothermal fluids at the geothermal field of Los Azufres, Michoacán, Mexico. *Water, Air, and Soil Pollution*, 124, 371–410. https://doi.org/10.1023/A:1005242824628

Another form of solid waste generated by geothermal operations is geothermal scale, a solid substance that forms from cooling or depressurizing a geothermal fluid. Though not significant in most geothermal operations, scale formed from fluids with high total dissolved solids can be on the order of several metric tons per hour. The good news is that scale can be used for other purposes. One study showed that scale, when mostly silica, can be used as an additive in construction when combined with cement, asphalt, lime, and other common building materials.[140] Other sites, such as geothermal power plants in California, extract valuable lithium from geothermal scale for use in the battery industry.[141] When not used in other applications, solid scale must be transported and disposed of properly.

CONCLUSION AND RECOMMENDATIONS

In the Land of Enchantment, the Oil Conservation Division within the Energy, Mineral and Natural Resources Department (EMNRD) regulates oil, gas and geothermal activities in the state, including permitting new wells, enforcing regulations, and ensuring responsible land restoration and water protection.[142,143,144] Though regulatory environments change frequently, these safeguards help ensure that environmental impacts from geothermal energy are mitigated, environmental risk is reduced, any environmental damage is rectified, and the state can take advantage of the myriad environmental benefits of geothermal energy.

There are clear advantages to New Mexico's pursuit of additional geothermal, and implementing these recommendations will help maximize positive benefits while reducing potential negative impacts associated with geothermal water usage, wastewater disposal, and induced seismicity.

Taking these steps will help New Mexico achieve its climate goals, reduce air emissions, and prevent as many surface impacts as could be caused by other energy solutions.

There are several recommendations for how to support responsible, ethical geothermal development given New Mexico's unique environment:

- Environmental Impact Assessments should be undertaken prior to any geothermal development in New Mexico, especially on lands near historic or Indigenous sites and near areas of critical environmental concern.
- Geothermal development must include all stakeholders, including other representatives of industries, state agencies, private landowners, and Indigenous tribes.
- Reinjection of geothermal fluid should be incorporated into any geothermal operation to sustain the reservoir and protect surface thermal features.
- Wastewater produced by drilling should either be reinjected into the reservoir or reinjected with existing oil and gas infrastructure to prevent contamination. Similarly, to save on water resources, produced water from oil and gas should be considered an option for geothermal drilling fluid.
- Land subsidence and microseismicity must be mitigated with proper reinjection strategies and should be monitored.
- Groundwater contamination must be avoided through the use of proper well drilling and cementing procedures and monitored with several shallow monitoring wells.

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