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

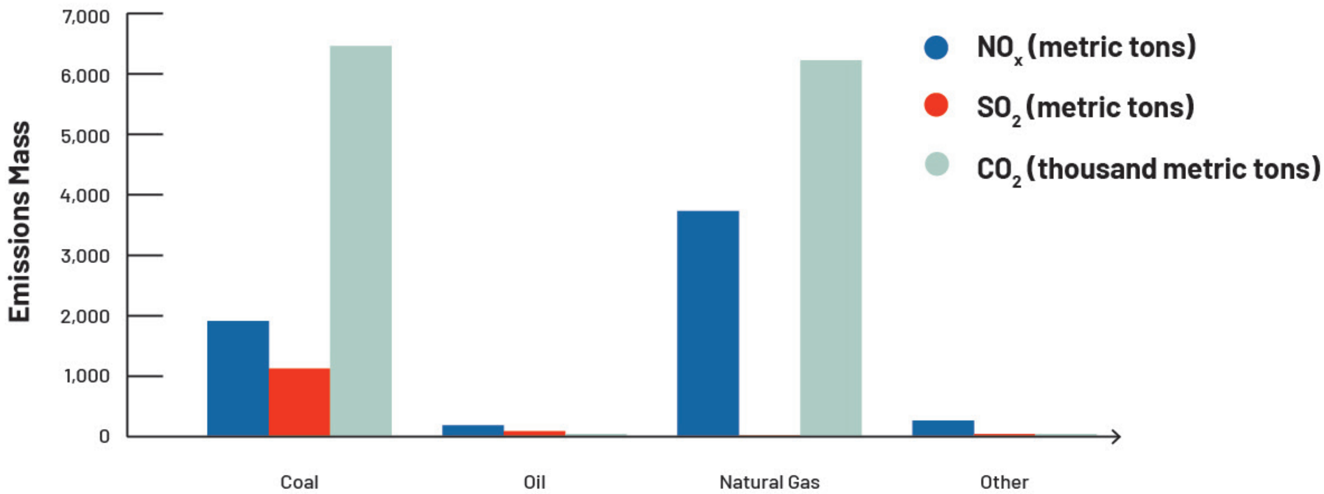

Figure 9.1: Air pollution emissions in New Mexico by energy source in 2023. "Other" includes geothermal, biomass, hydropower, wind, and solar energy. Source: U.S. Energy Information Administration. (2024). *New Mexico electricity profile 2023: Table 1. 2023 summary statistics (New Mexico).* https://www.eia.gov/electricity/state/NewMexico/xls/SEP%20Tables%20for%20NM.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

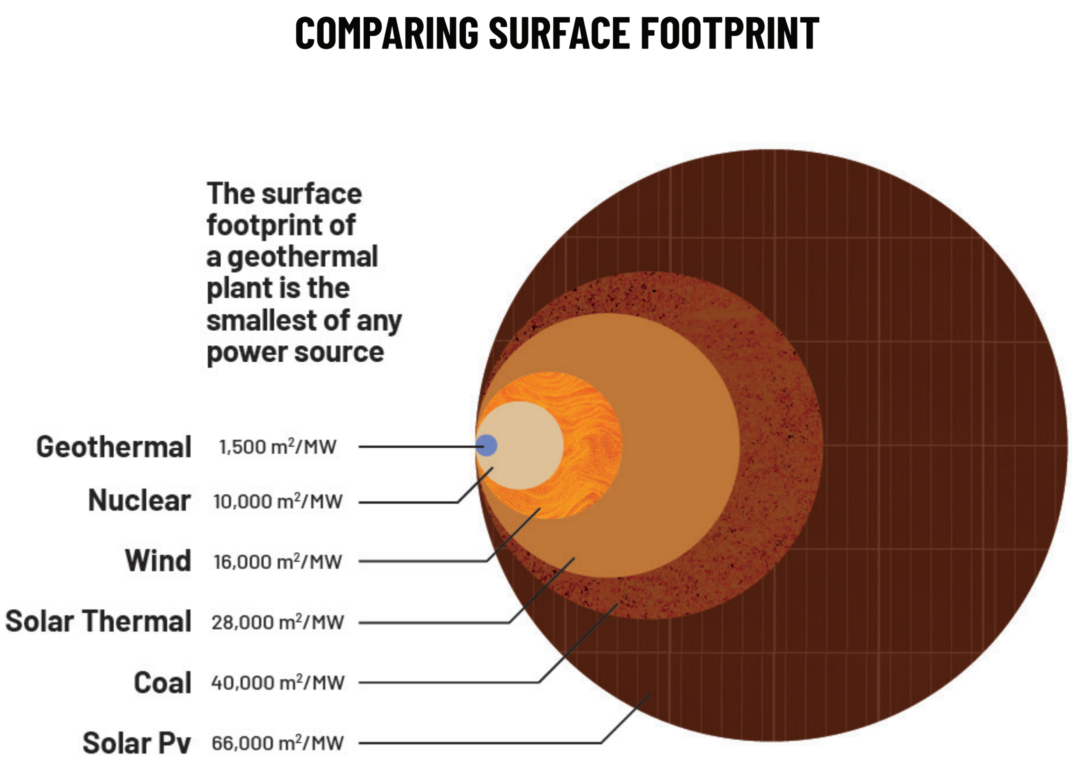

Figure 9.2: The project surface footprint, acre for acre for 1 gigawatt of generating capacity, is smallest for geothermal compared with other renewables and coal. Source: Adapted from Lovering et al., 2022 and NREL.

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

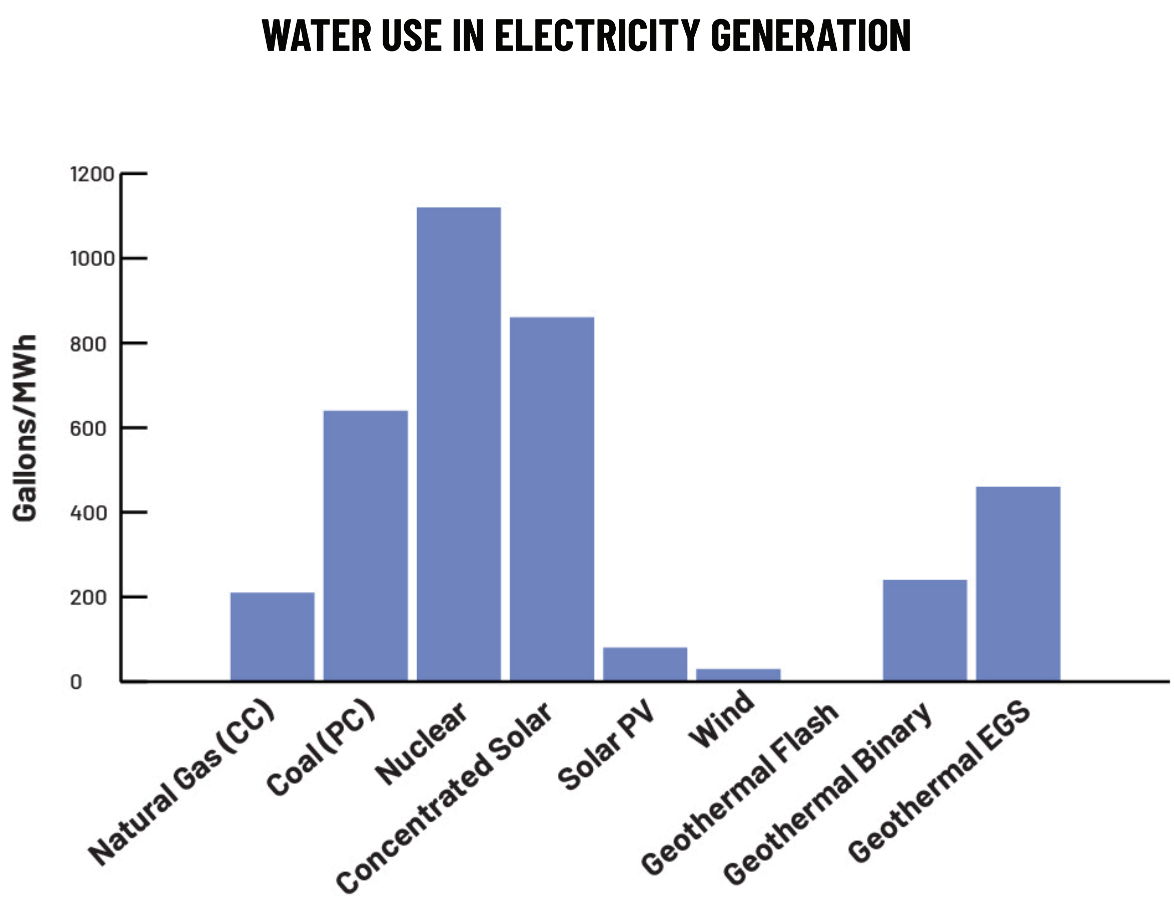

Figure 9.3: Consumptive water use in electricity generation by power plant type. CC = combined cycle; PC = pulverized coal. Source: Meldrum, J., Nettles-Anderson, S., Heath, G., & Macknick, J. (2013). Life cycle water use for electricity generation: A review and harmonization of literature estimates. *Environmental Research Letters*, 8, 015031. https://doi.org/10.1088/1748-9326/8/1/015031

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

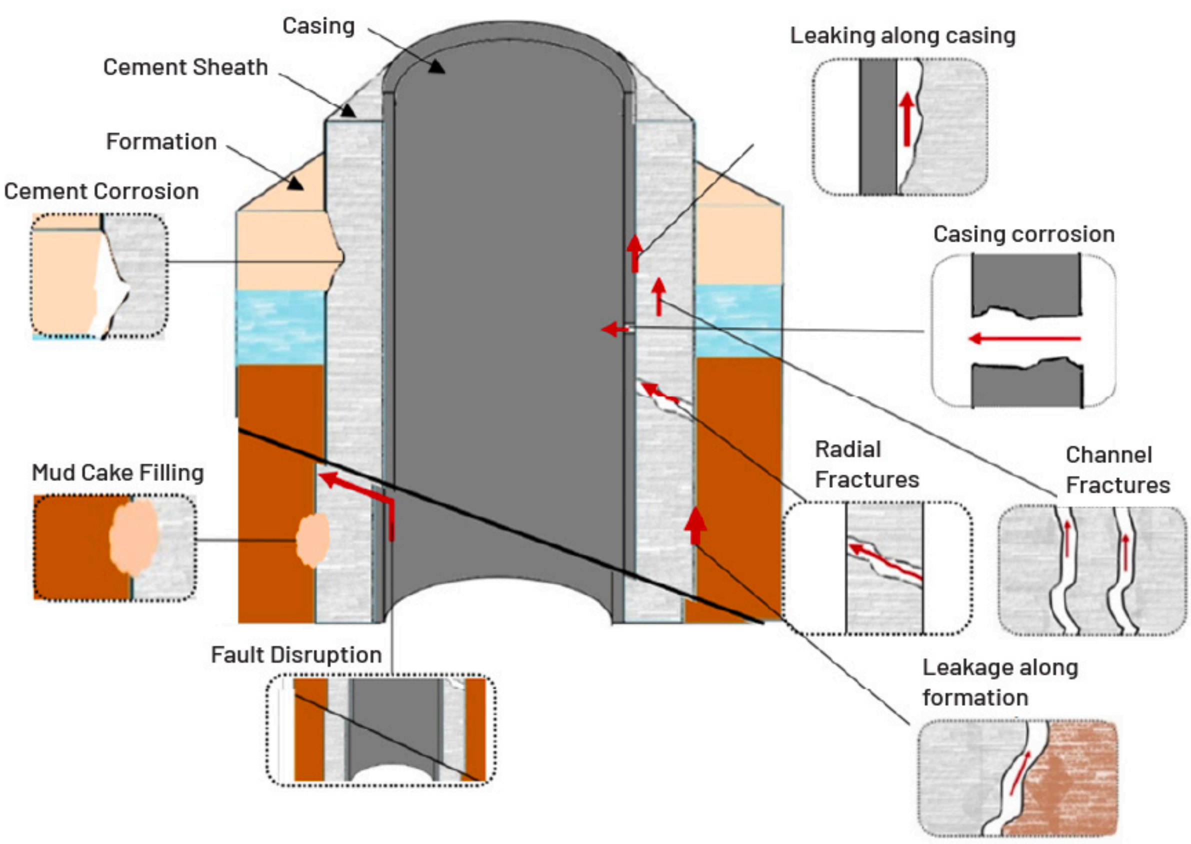

Figure 9.4: Common leakage pathways and cement failures in subsurface wellbores . Modified from Wu, B., Arjomand, E., Tian, W., Dao, B., & Yan, S. (2020). *Sealant technologies for remediating cement-related oil and gas well leakage: A state-of-the-art literature review*. Commonwealth Scientific and 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

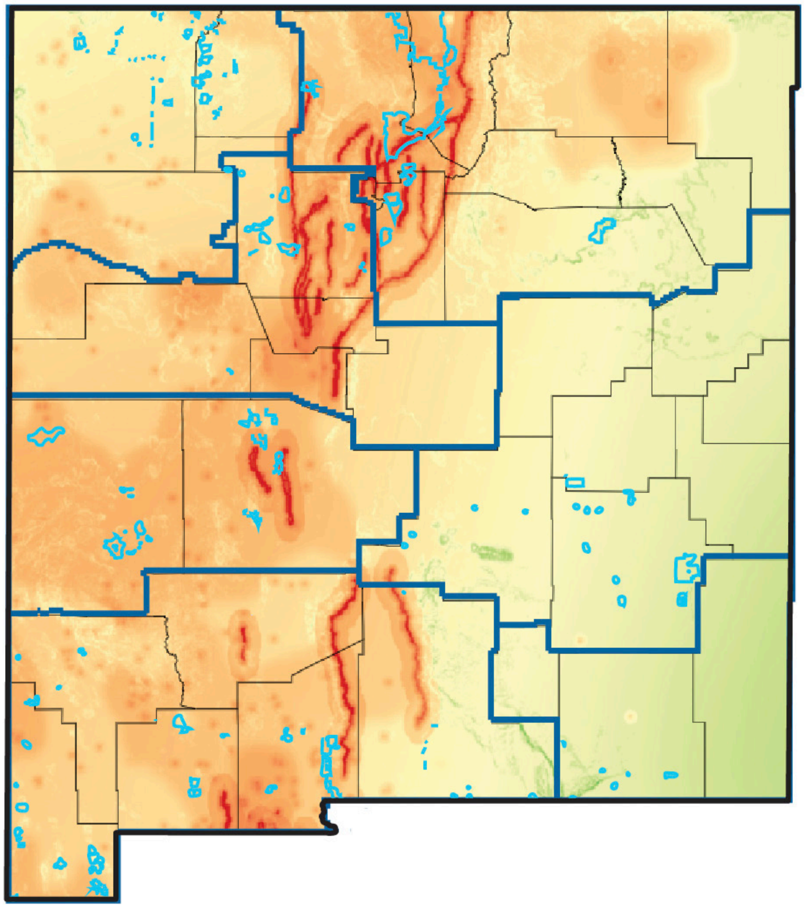

Figure 9.5: Map of Bureau of Land Management (BLM)-identified Areas of Critical Environmental Concern (ACECs) in New Mexico and geothermal potential. ACECs are outlined in green, with blue lines indicating boundaries of BLM management districts. Source: Bureau of Land Management. (n.d.). *New Mexico 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

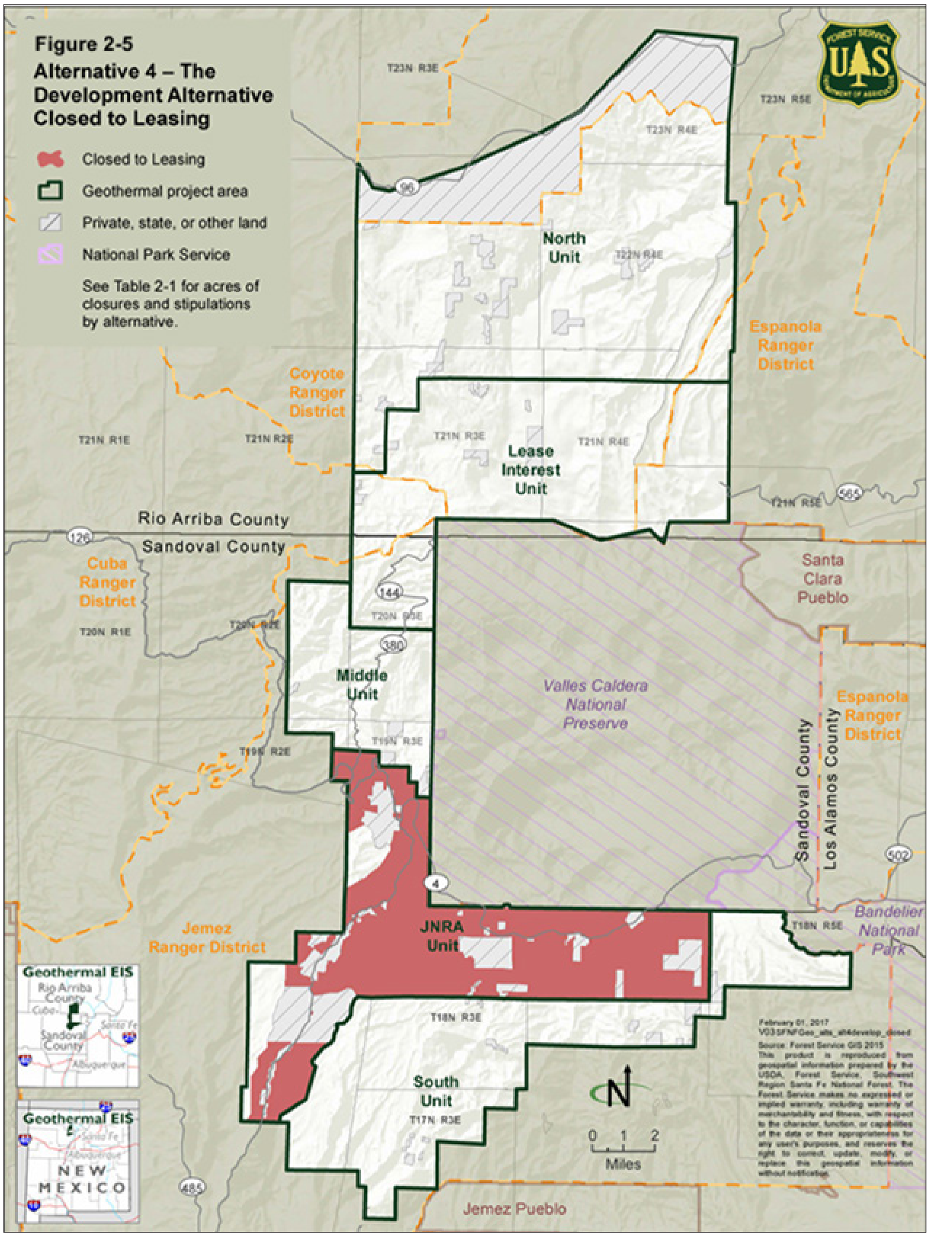

Figure 9.6: Map showing area of Environmental Impact Assessment for Santa Fe National Forest with lease areas for consideration outlined in green and the area deemed closed to leasing in red. Source: U.S. Department of Agriculture. (2017). *Santa Fe National Forest geothermal leasing: Final environmental 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

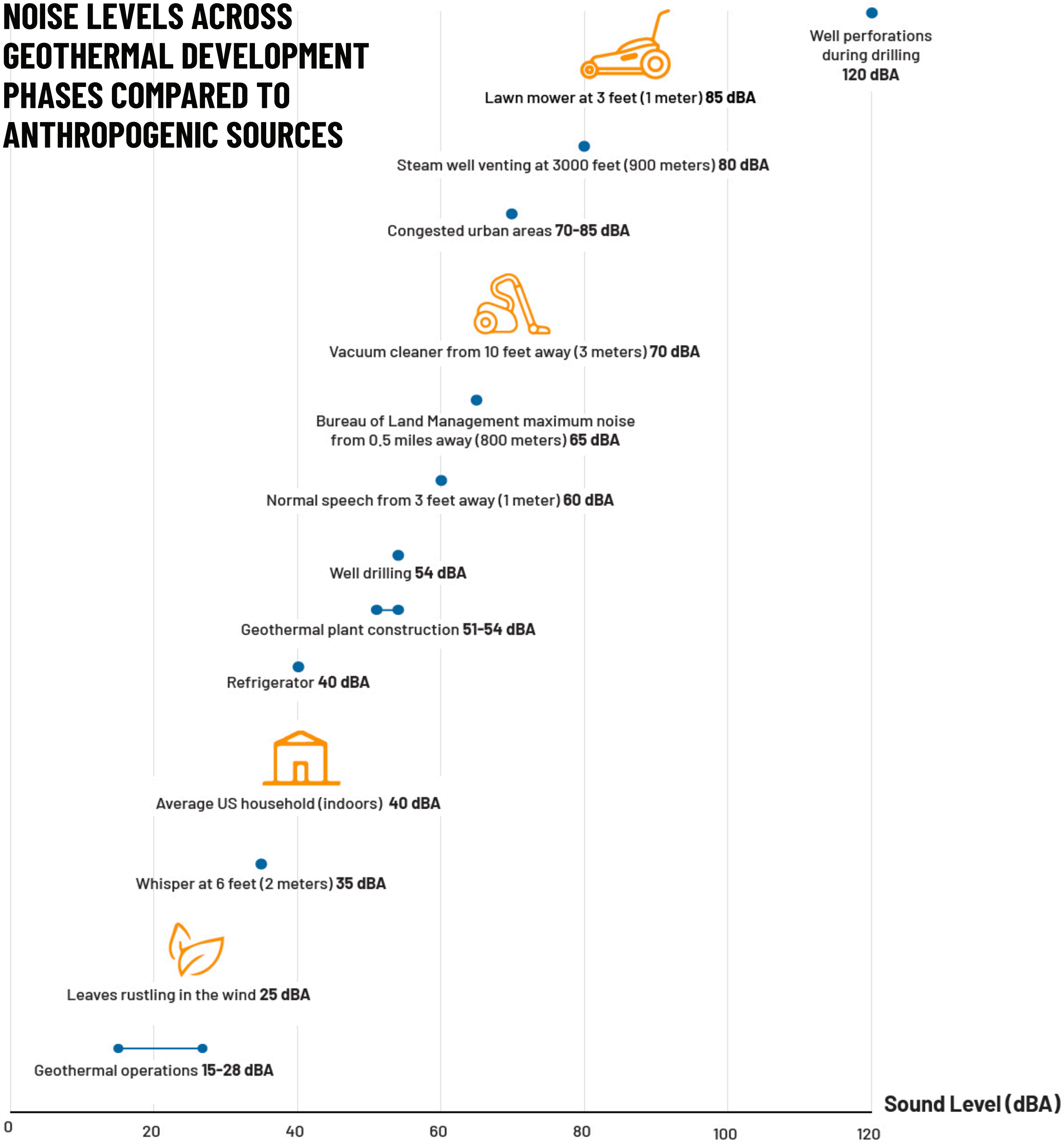

Figure 9.7: Noise levels across geothermal development phases compared to anthropogenic sources. Sources: Kagel, A., Bates, D., & Gawell, K. (2005, April 22). *A guide to geothermal energy and the environment*. Geothermal Energy Association. https://doi.org/10.2172/897425; Massachusetts Institute of 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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