Montana Bureau of Mines and Geology

Investigation of Geothermal Energy in the State of Montana for the Purpose of Power Generation

Prepared for: Board of Investments, Helena, Montana

Miscellaneous Contribution 27

October 2026

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https://doi.org/10.59691/RDBK6025



Introduction

Under a Memorandum of Understanding between the Montana Board of Investments (BOI) and Montana Technological University, the Montana Bureau of Mines and Geology (MBMG) conducted a reconnaissance investigation of Montana's geothermal energy potential for power generation. The MBMG compiled and evaluated existing geologic and subsurface data to identify 15 areas of interest for further investigation (fig. 1). Four high-priority areas—Deer Lodge Basin, Big Timber, Poplar Dome, and Colstrip—were selected for detailed assessment of their geothermal resource potential. This report summarizes the findings from these four areas and identifies opportunities for further investigation using conventional geothermal technologies and emerging enhanced geothermal systems (EGS). Detailed technical reports for the four assessment areas are also being prepared. These reports incorporate geophysical and downhole-temperature data to further characterize subsurface conditions and refine conceptual models of geothermal prospectivity.

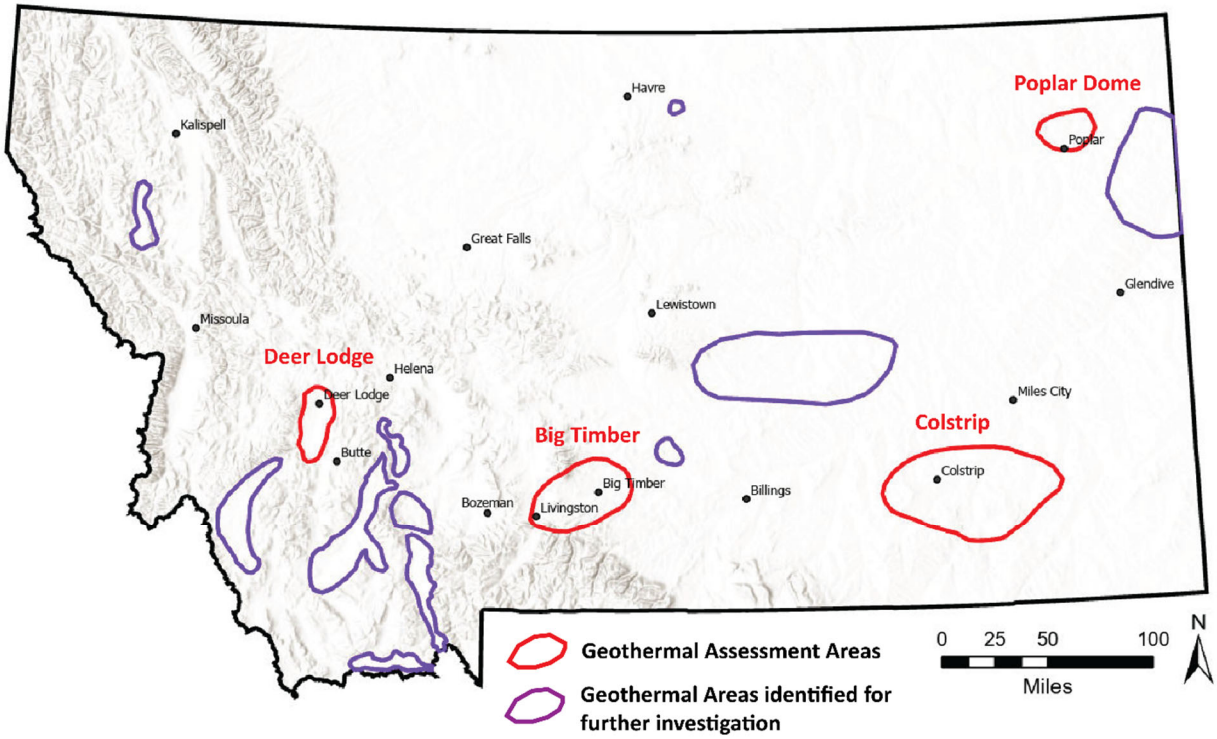


Figure 1. Geothermal assessment areas of interest in Montana. The map shows the 15 areas identified for geothermal investigation and the four areas selected for detailed assessment.

Enhanced Geothermal Systems (EGS)

Enhanced Geothermal Systems are engineered subsurface reservoirs that produce geothermal energy from hot, dry, impermeable rock where natural hydrothermal resources are absent. EGS adapts oilfield technologies, such as horizontal drilling and hydraulic stimulation, to create or improve pathways through which water can circulate and absorb heat from the surrounding rock

(fig. 2). The heated water is then brought to the surface, where it transfers heat to a separate working fluid in a heat exchanger. The working fluid vaporizes and drives a turbine to generate electricity, while the geothermal water remains in a closed-loop system.

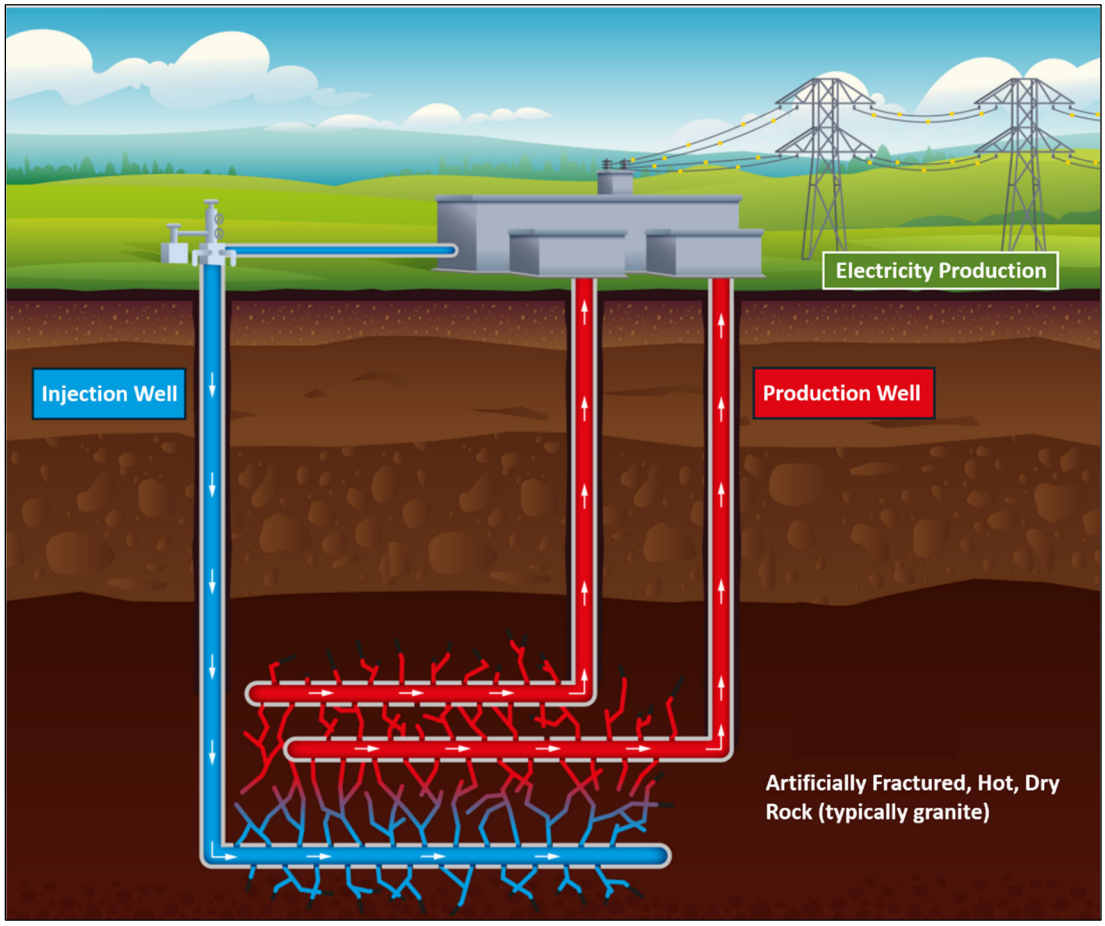


Figure 2. Conceptual illustration of an enhanced geothermal system (EGS), modified from https://www.vallourec.com/news/next-generation-geothermal/.

Unlike traditional hydrothermal methods that depend on scarce, naturally occurring, water-rich porous formations, EGS targets dry, hot rock formations, which are far more geographically abundant. Because EGS introduces the working fluid from external sources, it eliminates the need for large volumes of *in situ* formation water, significantly expanding potential power plant locations.

Assessing Montana's Geothermal Potential

Previous geothermal work in the state focused on shallow, hydrothermal systems (Sonderegger and others, 1980; Rautio and Sonderegger, 1980; Smith and Icopini, 2016). There are approximately 120 known hot springs with surface-water temperatures above 68°F, and 170 warm-water wells. Montana has had limited direct-use geothermal development and no geothermal power plants. Surface geothermal features indicate the presence of geothermal heat and circulating groundwater, but they do not fully describe Montana's subsurface resources. In particular, geothermal heat suitable for energy development can exist in areas without hot springs

or other surface expressions. Identifying such resources requires information about subsurface temperatures, rock properties, and geologic structures.

Evaluating this broader geothermal potential requires integrating information from multiple sources. Accordingly, our work followed a three-phase approach: data gathering and integration, favorability analysis and selection of priority areas, and detailed resource assessment of four high-priority areas.

Phase 1—Data Gathering

Phase 1 focused on assembling and integrating existing geological, geophysical, geothermal, and subsurface well data to develop a statewide understanding of Montana's geothermal potential. Because these data were collected for different purposes and vary in coverage and quality, the MBMG drew on multiple complementary sources to characterize subsurface temperatures, geologic structures, basin geometry, and other factors relevant to geothermal resource development. The resulting dataset provided the technical foundation for the Phase 2 favorability analysis and the Phase 3 detailed assessment of four priority areas.

- **Legacy Data and Research:** The MBMG compiled and reviewed existing geological, hydrogeological, and geothermal studies, including regional geologic mapping, subsurface interpretations, known thermal springs, and previous geothermal investigations. These sources provided the regional context for identifying areas with elevated geothermal gradients, favorable geologic structures, and potential heat resources.
- **Oil and Gas Well Analysis:** The MBMG compiled and analyzed records from more than 40,000 historical oil and gas wells across Montana. Well logs, formation tops, lithologic descriptions, drilling records, and other available subsurface information were used to characterize geologic formations, map structural elevations and basin geometry, and assess the depth and distribution of potential geothermal target formations. These data provided critical constraints on subsurface conditions, particularly in central and eastern Montana.
- **Bottom-Hole Temperature Analysis and Geothermal Gradient Modeling:** MBMG staff extracted and evaluated historical bottom-hole temperature (BHT) measurements from oil and gas wells to characterize subsurface temperatures and estimate geothermal gradients. Where appropriate, temperature measurements were corrected for the effects of drilling-related cooling using the Waples–Ramly correction method. Available drill-stem test (DST) temperatures and other subsurface information were used to evaluate and cross-check temperature interpretations. The resulting dataset and models helped identify areas with elevated temperatures and estimate the depths at which potentially useful geothermal temperatures might occur. Temperature estimates were assessed on the basis of data quality, well depth, and local geology.
- **Seismic Data:** The MBMG acquired and interpreted 11 licensed two-dimensional (2D) seismic reflection lines from Seismic Exchange Inc. to improve understanding of subsurface geology in selected areas. Seismic data can image buried geologic formations, faults, and structural relationships that may be difficult to identify from well data alone. These interpretations helped constrain basin geometry, basement depth, and potential

structural pathways relevant to geothermal systems, particularly in areas with limited deep-well control.

- **Other Geophysical Data:** MBMG staff integrated available airborne magnetic, radiometric, and ground-based gravity data to improve interpretations of subsurface geology. Magnetic data helped characterize variations in crystalline basement rocks and identify major geologic boundaries, while gravity data provided information about subsurface density variations that can help constrain basin geometry and buried structures. Together with geologic mapping, well records, and seismic interpretations, these datasets strengthened the understanding of the geologic framework underlying potential geothermal areas.
- **GIS Data Hub:** The MBMG organized and compiled geological, geophysical, geothermal, well, and infrastructure information into a centralized geographic information system (GIS) data platform. The GIS Data Hub provides a framework for visualizing and comparing datasets, identifying potential geothermal areas, and supporting subsequent resource assessments. By bringing previously dispersed information together, the platform improves access to relevant subsurface data and provides a foundation for future geothermal exploration and evaluation.

Phase 2—Favorability Analysis

The MBMG integrated Phase 1 data and identified AOIs where elevated subsurface temperatures, favorable geologic conditions, and opportunities for geothermal power generation coincided. We focused on estimated temperatures, sedimentary-basin and crystalline-basement geometry, mapped and interpreted faults and other structural features, and the availability of subsurface data to characterize potential geothermal targets. The evaluation also considered existing energy infrastructure and potential opportunities to support future power generation.

The availability and quality of supporting data varied across the state, influencing both the interpretation of geothermal potential and the feasibility of conducting more detailed assessments. From an initial set of 15 areas of interest, MBMG staff selected four areas—Deer Lodge Basin, Big Timber, Poplar Dome, and Colstrip—for more comprehensive evaluation. Colstrip was included in part because the planned decommissioning of its coal-fired power plant created an opportunity to investigate whether geothermal energy could eventually use existing electrical transmission infrastructure.

Phase 3—Resource Assessment of Priority Areas

In Phase 3, the MBMG conducted a more detailed assessment of the four selected AOIs to evaluate their potential for geothermal electricity generation. Using the data and interpretations assembled in Phase 1 and evaluated during Phase 2, MBMG staff developed conceptual models of subsurface conditions, assessed estimated temperatures and the depths at which potentially useful geothermal resources may occur, and examined the geologic characteristics relevant to geothermal development. The evaluation used a minimum target temperature of about 300°F and considered uncertainty in temperature estimates and the extent of supporting subsurface data.

The assessments identify the evidence supporting each area's potential, key uncertainties and data gaps, and opportunities for additional investigation.

Three of the initial target areas (Deer Lodge, Big Timber, and Poplar Dome) show favorable temperatures at depths of approximately 7,300 to more than 10,000 feet. Targeted characterization work will refine temperature estimates, characterize potential reservoirs, and determine whether these resources could support geothermal power generation.

Deer Lodge Basin—Southwest Montana

The Deer Lodge Basin (fig. 3) is a promising geothermal prospect where elevated subsurface temperatures appear to be associated with radiogenic heat from crystalline rocks of the nearby Boulder Batholith and with faults that influence the basin's geologic structure. Temperature data from eight oil and gas exploration wells indicate higher than average geothermal gradients, reaching 300°F at depths of approximately 10,000 feet in the central part of the basin. The basin also contains known hydrothermal features, such as Warm Springs and Fairmont Hot Springs in the southern region. While higher temperature gradients may exist in this southern area, further investigation is needed to characterize the location and extent of the thermal anomaly, as well as the relationship between faults and heat distribution. To better define the geothermal target and guide future exploration, the MBMG recommends refining the three-dimensional structural model and conducting magnetotelluric surveys.

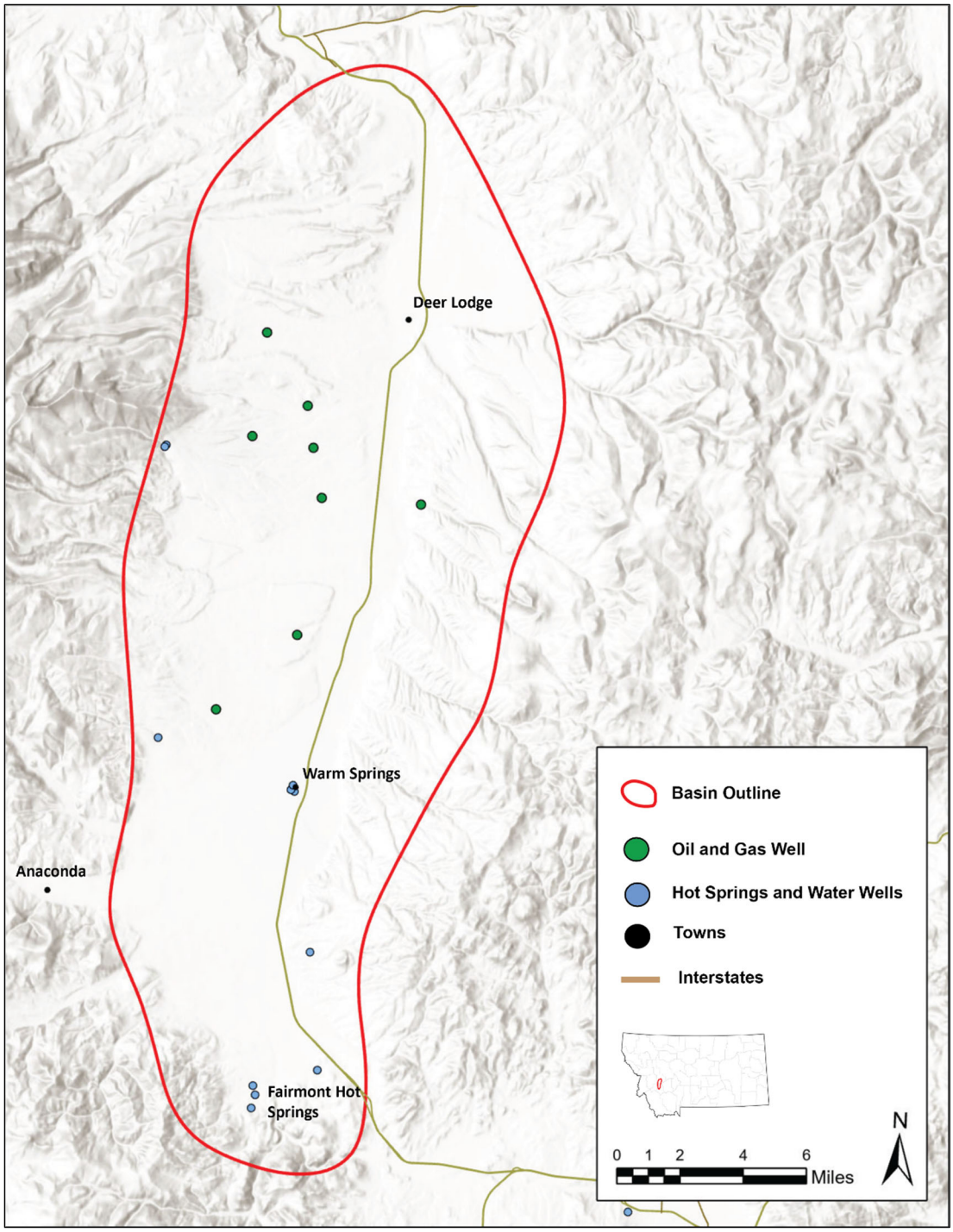


Figure 3. Deer Lodge Basin geothermal assessment area and available well data.

Big Timber—South-Central Montana

The Big Timber area (fig. 4) has several independent indicators of a potentially significant geothermal system, including Hunter's Hot Springs, which discharges water at approximately 140°F at a reported rate exceeding 1,000 gallons per minute, and elevated temperatures recorded in deep oil and gas wells. Most notably, DST from the Burns 1 well recorded temperatures of

approximately 384–392°F at depths below 10,500 feet, indicating a substantial thermal anomaly. Seismic interpretations identify a complex fault system in the underlying basement that may influence heat and fluid movement. However, the relationship between the deep temperature anomaly and the surface hot springs remains uncertain. Further geophysical surveys and structural analysis are needed to identify the most promising target and assess EGS potential.

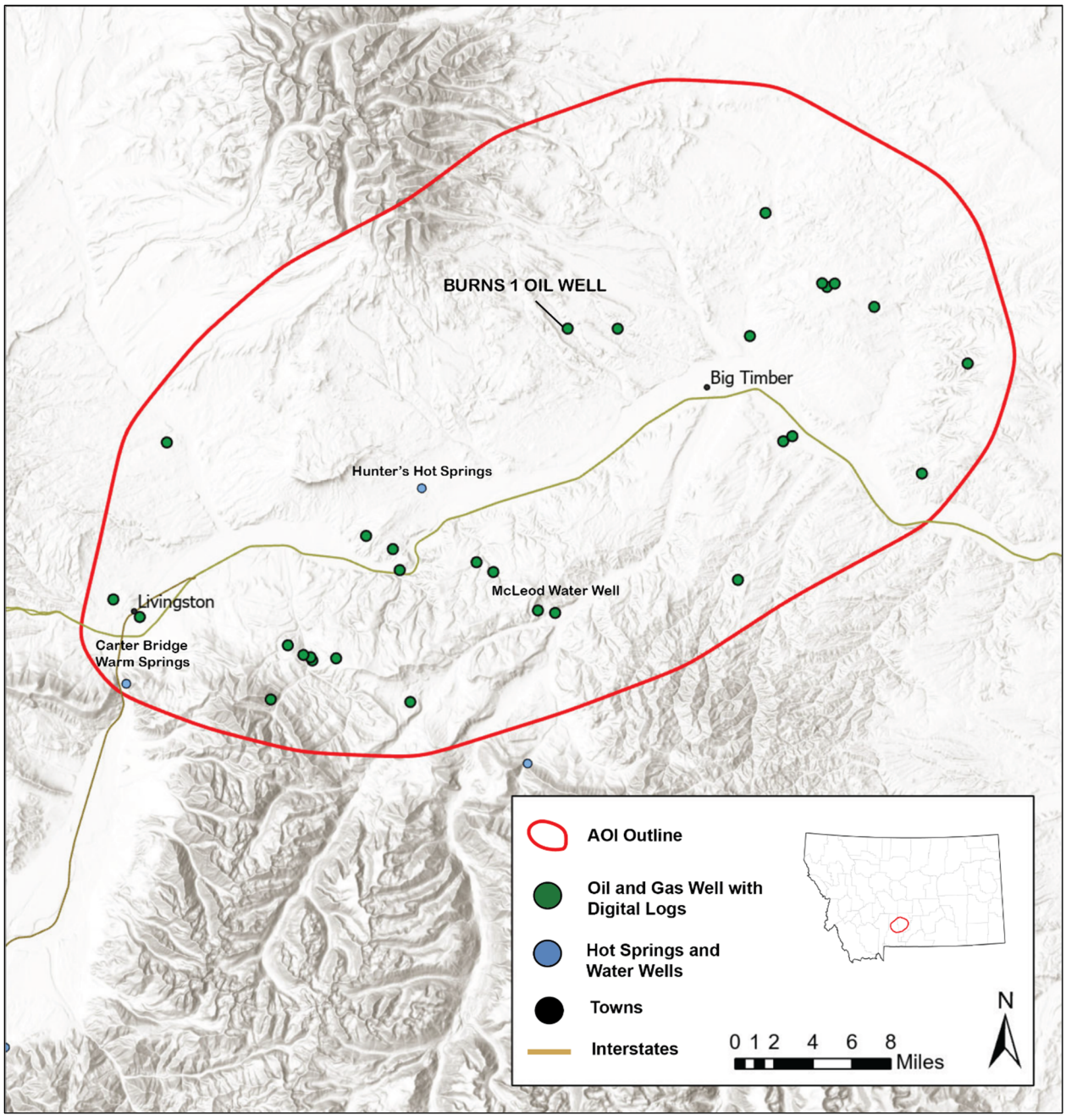


Figure 4. Big Timber geothermal assessment area and available well data.

Poplar Dome—Northeastern Montana

Poplar Dome (fig. 5) stands out because bottom-hole temperature data indicate a geothermal gradient substantially higher than the Montana average. Modeling suggests temperatures near 300°F may occur at depths of about 7,300 feet in some areas, while a conservative temperature model projects the top of the Precambrian crystalline basement to reach about 358°F at about 9,800 feet. Although some existing oil wells produce hot water, using these fluids (from aging petroleum infrastructure) for geothermal energy production could introduce operational challenges. The assessment instead identifies the deeper crystalline basement as a potential EGS target, where engineered permeability would allow heat extraction from hot rock. The recommended next step is to drill a dedicated geothermal science well to verify temperatures, characterize the basement rock, and determine whether suitable fractures and other conditions exist to support a viable geothermal reservoir.

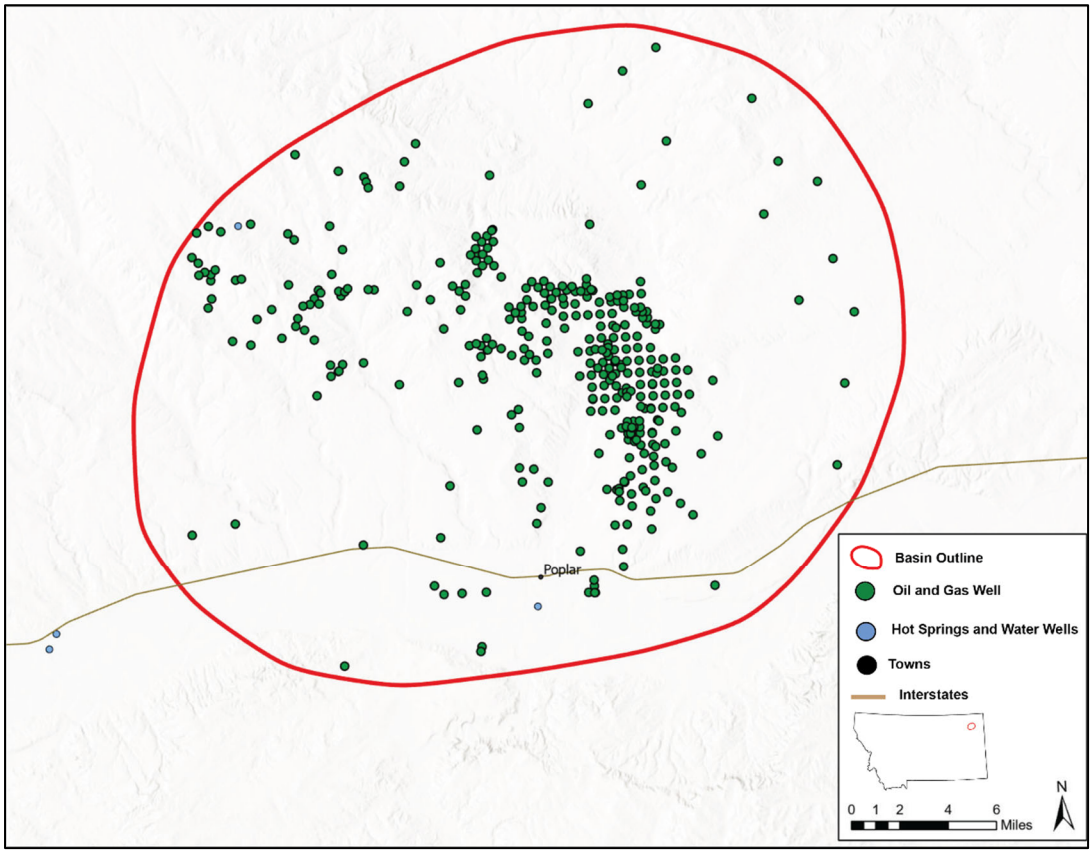


Figure 5. Poplar Dome geothermal assessment area and available well data.

Colstrip—Southeastern Montana

Colstrip (fig. 6) was evaluated for geothermal potential because existing power-generation and transmission infrastructure could offer a strategic opportunity if we can identify a geothermal resource. However, the available subsurface data indicate a geothermal gradient of approximately 1.9°F per 100 feet (the Montana average), and the area lacks known thermal springs or other clear surface evidence of a hot geothermal system. Based on this gradient, we

estimate that reaching 300°F would require drilling to approximately 13,425 feet—substantially deeper than the available temperature-control data. Based on the current evidence, Colstrip has very low geothermal potential relative to the other three areas, and major exploration is not recommended unless new data or a compelling development partnership justifies further investigation.

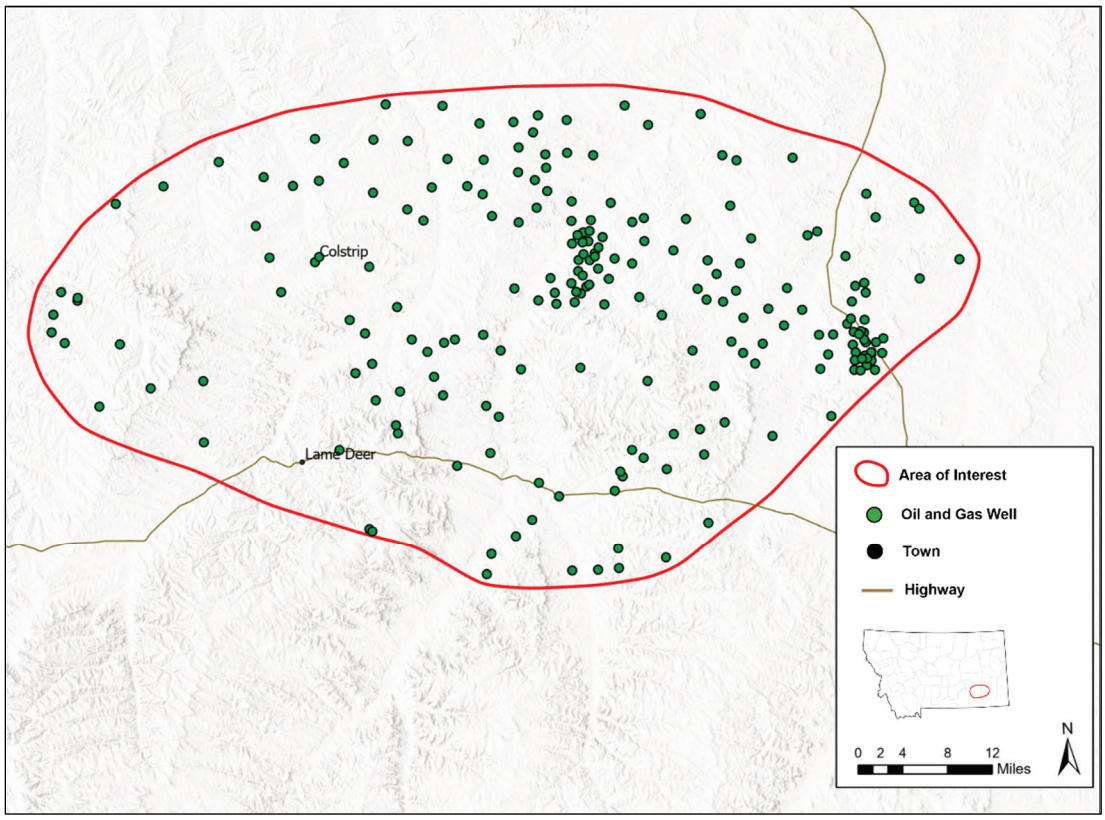


Figure 6. Colstrip geothermal assessment area and available well data.

Summary

The preliminary assessments indicate that the Deer Lodge Basin, Big Timber, and Poplar Dome warrant further investigation, although each presents different opportunities and uncertainties (table 1). The Deer Lodge Basin has elevated geothermal gradients that may reflect favorable heat sources and structural controls. Big Timber has reported high temperatures in deep wells, indicating a substantial thermal anomaly. At Poplar Dome, temperature modeling based on downhole temperature data suggests potentially useful heat at relatively accessible depths of approximately 10,000 feet. In contrast, Colstrip appears less promising because reaching target temperatures would likely require substantially deeper drilling, with additional uncertainty about reservoir properties.

Table 1. Summary of geothermal resource potential and recommended next steps.

Area of Interest (AOI)	Subsurface Temperature & Depth	Preliminary Geothermal Potential	Strategic Takeaway & Action Plan
Deer Lodge Basin	~300°F estimated near 10,000 ft in parts of the basin; higher temperatures indicated at greater depths.	**High**	Refine the 3D structural model and conduct MT surveys to delineate the thermal anomaly and identify promising drilling targets.
Big Timber	Burns 1 DST recorded approximately 384–392°F below 10,500 ft.	**Moderate to High**	Investigate the relationship between the deep thermal anomaly, fault structures, and Hunter's Hot Springs using additional geophysical surveys and integrated modeling.
Poplar Dome	Approximately 300°F modeled near 7,300 ft in localized areas; approximately 358°F projected at the top of the basement near 9,800 ft.	**High**	Drill a dedicated geothermal science well to verify temperature estimates and characterize basement rock and fracture conditions.
Colstrip	Approximately 300°F modeled at 13,425 ft using a regional gradient of about 1.9°F per 100 ft.	**Very Low**	Defer major exploration under current assumptions; reconsider only if new evidence or a compelling partnership changes the development outlook.

Montana Geothermal Potential

The preliminary assessments of the four high-priority areas (table 1) indicate that existing data can identify promising geothermal targets but are too limited to confirm them. Beyond the 15 initial AOIs identified in this project, other areas warrant further investigation, including the approximately 46 intermontane basins in western Montana. However, many of these areas lack the foundational geologic, geophysical, and temperature data needed to determine the presence, extent, and development potential of geothermal resources. As a result, Montana's statewide geothermal potential remains incompletely characterized.

Closing these data gaps is an essential next step, and the MBMG will continue to pursue funding for targeted geoscience data collection and analysis, prioritizing the following:

Gravity Data Collection: Additional gravity surveys would help refine interpretations of basin geometry, depth to crystalline basement, and major subsurface structures. Integrated with existing geological and geophysical information, these data would improve understanding of the structural framework that may influence geothermal heat and fluid circulation.

Magnetotelluric (MT) Surveys: MT surveys measure variations in subsurface electrical resistivity and can help identify structures, alteration zones, and potential fluid pathways associated with geothermal systems. When integrated with geological mapping, temperature data, and other geophysical data, MT surveys can help refine geothermal targets and guide subsequent exploration.

Structural and Fault Characterization: Faults and fractures can provide pathways for geothermal fluids and influence subsurface heat distribution. However, potentially favorable structures may be concealed beneath sedimentary cover and have little or no surface expression. Improved seismic, gravity, MT, and well data will enable better mapping and characterization of these structures and help identify and evaluate geothermal targets that might otherwise go unrecognized.

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