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FINAL DRAFT

Reasonable Foreseeable Development Scenario for Geothermal

Lander Field Office Planning Area, Wyoming

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Introduction

A Resource Management Plan is currently being revised for the Bureau of Land Management's (Bureau) Lander, Wyoming Field Office for the Planning Period 2008-2027. The Lander Field Office Planning Area (Planning Area) is located in west-central Wyoming and includes lands in Carbon, Fremont, Hot Springs, Natrona, Sweetwater, and Teton counties. In support of the revised Resource Management Plan, this geothermal energy Reasonable Foreseeable Development scenario has been prepared.

Geothermal leases have not been issued for the state of Wyoming, and only limited development activity has occurred within the Planning Area. This document is presented as a technical analysis of the geothermal resource occurrence within the Planning Area, and of the development that may reasonably be expected to occur during the Planning Period. This analysis represents a base line projection and assumes that future activity levels will not be constrained by management-imposed conditions (Rocky Mountain Federal Leadership Forum, 2002). Where legislatively imposed restrictions are applied to lands within the Planning Area, such restrictions were considered when determining future activity levels.

The Reasonable Foreseeable Development scenario for geothermal resource development presented herein briefly summarizes the types of geothermal systems and their potential uses, the various geothermal environments known or expected to be located within the Planning Area, and the nature of the resource's occurrence and distribution. Recent geothermal resource assessments which include the Planning Area lands are also discussed. This information was used to produce a geothermal resource development potential map (Figure 7) and a projection of the types of geothermal development which may occur during the Planning Period. Other information relevant to geothermal resource development in the Planning Area such as current and past development activity and infrastructure needs were also considered in preparing the development potential projection.

It must be emphasized that the Reasonable Foreseeable Development scenario presented herein is a scientific-based projection of anticipated geothermal development activity and is based on a limited amount of available information relative to the Planning Area lands. The Reasonable Foreseeable Development scenario includes all lands regardless of surface or mineral ownership, with the exception of those areas currently under legislative restrictions for development.

Geothermal Energy

Recent Activity

While Wyoming has one of the largest concentrations of geothermal energy in the United States, very little geothermal development has occurred in the Planning Area. However, various hot springs and thermal anomalies occur across the state, including in the Wind River Basin and the Planning Area. Within the last decade, only one operator has shown interest in leasing lands for geothermal development in the Planning Area; however, the Lander Field Office rejected the application because the existing Resource Management Plan did not address geothermal development; thus, no development has occurred.

Types of Geothermal Systems

There are two main categories of geothermal energy environments. These are hydrothermal environments, where water or steam are the primary carriers of the associated energy, and "dry" environments where hot, water-free rocks and magma are the energy sources. While dry environments are also the primary mechanism from which the hydrothermal environments derive their heat, current technology used to exploit these dry environments for energy use is in the experimental phase and such extraction is usually not economically viable.

Hydrothermal Systems

The U.S. Geological Survey recognizes 4 distinct hydrothermal systems. These are electrical-grade, warm-water, geopressured, and normal-temperature systems (Duffield and Sass, 2003).

Warm-Water Systems

Warm-water systems use waters too cool for electrical generation, but still warmer than surface temperatures, for direct-use in heat exchangers (e.g., heating homes, swimming pools, etc.). As these uses are generally restricted to municipal areas already developed, new housing developments, etc., the disturbance from these types of systems is directly tied to the developments they service. As such, any reasonable foreseeable development will not generally be associated with the energy sector, will likely be restricted to municipalities, and will create little to no impact to lands beyond those associated with the structures they are designed to heat. The most likely areas for development outside of existing municipalities are in lands heated by the Fort Washakie Hot Springs and the thermal springs near Dubois (Figure 1). The remaining thermal springs in the Planning Area are likely too far from any existing cultural or municipal development to likely be candidates for warm-water system development.

Normal-Temperature Systems

Normal-temperature systems use heat-exchange similar to warm-water systems except that the fluid (generally water) is pumped into the ground in a closed system of pipes allowing the fluid to warm to the temperature of the soil and is then brought back to the surface for direct-use. Such systems are generally small in scale, and, if developed in the Planning Area, would be almost exclusively associated with new or existing municipal or residential developments. Like warm-water systems, any reasonable foreseeable development will not generally be associated with the energy sector and will create little to no impact to lands beyond those associated with the structures they are designed to heat.

Electrical-Grade Systems

Electrical-grade systems are hydrothermal systems which can generate electricity via geothermal fluids used to drive turbines. Such systems must have relatively high temperature fluids (liquid and/or vapor water) to efficiently drive the turbines. As technology has evolved, the temperatures required have become lower, but generally must still be greater than 150 degrees Celsius (~300 degrees Fahrenheit) (Duffield and Sass, 2003).

There are three types of electrical-grade systems: hot-water, vapor-dominated, and moderate temperature (also known as binary) systems. Hot-water systems require water temperatures of at least 200 degrees Celsius (~390 degrees Fahrenheit) in order to produce steam at pressures high enough to drive the turbines. Water from these systems rise through wells drilled into the reservoir, and convert partially to steam as the overlying pressures decline, and the surrounding temperatures decrease. Once utilized, the water is reinjected into the formation to recharge. Vapor-dominated systems behave essentially the same way except that the fluid is already steam at depth in the reservoir and is condensed at the surface prior to being reinjected. Moderate-temperature systems are not hot enough to produce steam from liquid water, but do have sufficiently high temperatures to cause other liquids with lower boiling points, such as isobutane, to convert to steam in heat-exchangers. These are then used to run turbines for electrical generation in the same way steam would be in a vapor-dominated system.

All electrical-grade systems must be sited as near the wells as possible to avoid heat loss as the water or steam is transported to the facility. Additionally, they benefit also from being near existing infrastructure and customer bases. Presently, there are no known areas within the Planning Area with groundwater temperatures hot enough to reach even the lower limits of the technological feasibility of such projects; thus, the potential for development of electrical-grade hydrothermal systems in the Planning Area during the Planning Period is to be considered negligible.

Geopressured Systems

Geopressured systems are deep water reservoirs where the water is completely or nearly completely sealed off from the surrounding formations. Their depth and seal allows the waters to become heated and pressurized and are often also rich with dissolved methane gas. The heat, pressures, and associated methane all have the potential for use in energy production. However, such systems were in the early experimental stages in the 1980's, and only in off-shore environments (see U.S. Department of Energy, 1985). Industry has not expanded on the U.S. Department of Energy's work, nor have they shown any interest in doing so, primarily due to the unfavorable economics of such projects. Furthermore, no geopressured systems have yet been identified in the Planning Area. Geopressured systems are not expected to be developed in the Planning Area during the Planning Period.

Dry Geothermal Systems

Also known as "Enhanced Geothermal Systems" (Duffield and Sass, 2003), dry geothermal systems are generally deep rock and magma with little to no permeability and no free water, but contain vast amounts of heat compared to hydrothermal systems. Dry systems are "mined" for their energy; that is, deep wells are drilled to the high-temperature rocks and water is pumped down injection wells to be heated or converted to steam and brought back to the surface via production wells for use in electrical power generation plants (Massachusetts Institute of Technology, 2006). As with hydrothermal electrical-grade systems mentioned above, temperatures of the target rock formations generally need to be greater than 150 degrees Celsius (~300 degrees Fahrenheit) (assuming the injected water is allowed enough time to equilibrate to the formation temperature) to efficiently operate the power plants, though the U.S. Geological Survey only considers temperatures in excess of 200 degrees Celsius (~390 degrees Fahrenheit) at depths of 6 kilometers (~20,000 feet) or less (Williams and Pierce, 2008). There are no lands identified within the Planning Area which have rocks in excess of 150 degrees Celsius (~300 degrees Fahrenheit) and as shallow as 4.5 kilometers (approximately 15,000 feet) in depth; however, all lands within the Planning Area have temperatures in excess of 150 degrees Celsius (~300 degrees Fahrenheit) at 7.5 kilometers (approximately 24,600 feet). (Massachusetts Institute of Technology, 2006). Drilling wells to this depth requires large drilling rigs used for oil and gas well drilling. Oil and gas wells 15,000 feet and deeper are classified as "deep" wells (U.S. Geological Survey, 1997), and drilling to such depths greatly increases cost and risk. Drilling wells for geothermal energy production to depths greater than 15,000 feet is currently cost prohibitive. Resultantly, the potential for development of such projects in the Planning Area during the Planning Period is negligible.

Geothermal Resource Assessments

Several recent assessments of geothermal resources covering lands which include Wyoming and the Wind River Basin have been performed and their results help provide an understanding of the potential for occurrence of geothermal resources within the Planning Area. It should be noted, however, that these assessments generally only discuss the potential for the occurrence of the resource and do not include any reserve estimates, with the exception of the U.S. Geological Survey's 2008 (see below) assessment of electrical-grade geothermal resources, and Duffield and Sass' (2003) direct-use resource estimates.

Direct-Use (warm-water and normal temperature) Systems

Several past studies have characterized the direct-use geothermal resource in the U.S. and Wyoming, though most recent characterizations have focused on electrical-grade and enhanced geothermal resources. However, Duffield and Sass (2003) have estimated Wyoming's direct-use geothermal energy capacity to be 10 megawatts of energy which would be derived almost exclusively from warm-water thermal aquifers such as those associated with the thermal springs found within the Planning Area. The following is a discussion of those studies which analyzed lands for the various warm-water direct-use systems.

In their 1971 and 1978 assessments, the U.S. Geological Survey characterized several areas within the Planning Area as prospectively valuable for geothermal resources (Godwin, et al., 1971; U.S. Geological Survey, 1978). Lands classified as such contain thermal springs of at least 40 degrees Fahrenheit higher than the average ambient temperature. The lands classified as such are those associated with each of the identified thermal springs in the Planning Area, with the exception of the Conant Creek Springs (Figure 1). Conant Creek Springs have an average temperature of only 60 degrees Fahrenheit (16 degrees Celsius) and were therefore not considered as prospectively valuable in this U.S. Geological Survey study.

The University of Wyoming (Heasler, et al., 1983) also rated the springs identified by the U.S. Geological Survey as geothermal resources, but in contrast they show each of these as thermal springs with surface temperatures of 50 degrees Celsius (~120 degrees Fahrenheit) or less, and include Conant Springs. Also included as potential for direct-use applications in the study are those lands which are "known or inferred to be underlain at shallow depth [less than 1000m (~3280 feet)] by low-temperature [less than 90 degrees Celsius (~200 degrees Fahrenheit)] thermal water (Heasler, et al., 1983)" (Figure 1).

In Hinckley and Heasler's (1987) study of the geothermal resources of the basin, they note that even the most attractive geothermal resources in the Wind River Basin (the thermal anomalies north of Lander, and the thermal springs in the Planning Area) are unlikely to have aquifer temperatures in excess of 150 degrees Fahrenheit (65 degrees Celsius) (Figure 2). The study did suggest that the deepest parts of the basin contain aquifer waters at temperatures greater than 150 degrees Fahrenheit, though most is too deep for economic use. Only those areas found at depths less than 4,500 feet (~1.4 kilometers) would likely be considered for direct-use geothermal systems; however, no such lands have as yet been identified.

Anderson and others (1990) ranked known geothermal resource lands within the Planning Area for their geothermal resource potential (Figure 3). Those areas outside of known geothermal mineral deposits were all ranked as low potential. The lands associated with the various identified thermal springs and geothermal mineral deposits within the Planning Area were ranked as moderate potential for geothermal favorability, with a concentrated area representing those lands associated with the Fort Washakie Hot Springs ranked as high. One assumption in the study was that development of these geothermal resources would principally be for recreational use, as evidenced at Fort Washakie.

The Bureau of Land Management and the Department of Energy (U.S. DOI and U.S. DOE, 2003) joint report on the potential for renewable energy on public lands assessed in a broad sense those areas in the United States that may prove suitable for future geothermal energy development. Their report includes a map produced by the Southern Methodist University outlining areas of geothermal potential based on heat flow, thermal gradient, sediment thickness and hot springs data (Figure 4). The study outlines the whole of the Planning Area as falling within medium or low development potential for the geothermal resource. Additionally, in late 2008, the Bureau of Land Management and the U.S. Forest Service published their Final Programmatic Environmental Impact Statement for Geothermal Leasing in the Western United States (U.S. DOI and U.S. DOA, 2008). Those areas deemed as "favorable for shallow, direct-heat geothermal resources" were identified based on the occurrence of shallow [less than 1000 meters (~3280 feet)] thermal water for direct-heat applications (Figure 5).

Electrical-Grade Hydrothermal and Dry Geothermal Environments

In 2008, the U.S. Geological Survey published an update to their geothermal resource assessment of 1978 (U.S. Geological Survey, 2008; Williams and Pierce, 2008). This assessment studied the electrical power generation potential of geothermal resources concentrated in the western United States (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming). These 13 states contain all of the identified moderate temperature [90 to 150 degrees Celsius (~195 to 300 degrees Fahrenheit)] and high temperature [greater than 150 degrees Celsius (300 degrees Fahrenheit)] geothermal systems located on private or accessible public lands within the U.S. Geothermal systems located on closed public lands (e.g., National Parks such as Yellowstone) were not included in the assessment. The assessment also included an estimate of the power generation potential of dry geothermal systems in several of these states, including Wyoming.

Within the Planning Area, the U.S. Geological Survey identified no conventional (hydrothermal) geothermal resources capable of electricity generation. Additionally, the study reported geothermal resource occurrence potential as low for the entire Planning Area (Figure 6). It should be noted, however, that at an average depth of 7.5 kilometers (~24,600 feet), all of the lands within the Planning Area have temperatures in excess of 150 degrees Celsius (~300 degrees Fahrenheit), sufficiently hot enough for hot- and moderate-temperature hydrothermal systems, but at depths currently uneconomic for development.

Dry/enhanced geothermal systems are characterized in the assessment as those areas where temperatures exceed 200 degrees Celsius (~390 degrees Fahrenheit) at depths less than 6 kilometers (approximately 20,000 feet). The U.S. Geological Survey assessment identified no such systems within the Planning Area.

The state of Wyoming was estimated to contain approximately 31 Megawatts of identified electrical power generating capacity. However, only one electrical-grade geothermal system was identified in Wyoming which is located outside of the Planning Area.

The 2008 study did not characterize direct-use (warm- and normal-temperature) hydrothermal, nor geopressured geothermal resource potentials. Similar studies by the U.S. department of Energy's National Renewable Energy Laboratory (Petty and Porro, 2007) and the Massachusetts Institute of Technology (2007) also recognize the lack of suitable electrical-grade hydrothermal and dry geothermal environments in the Planning Area.

Geopressured Systems

As mentioned above, the only testing of geopressured systems in the U.S. was conducted off-shore in the 1980's (U.S. Department of Energy, 1985). No lands onshore have been studied for either the potential for occurrence nor development of such systems.

Geothermal Development Potential and Projections of Future Activity

Several maps have been compiled showing various features discussed in the above referenced documents which may suggest areas of future interest in geothermal development within the Planning Area. Figure 1 shows the thermal springs and aquifers with water temperatures exceeding 50 degrees Celsius (~120 degrees Fahrenheit) as identified by Anderson and others, 1990, and Heasler, 1985. Figure 2 shows the areas of anomalous temperature gradients in the subsurface as identified by Hinckley and Heasler (1987). Figures 3 shows the favorability for geothermal resource occurrence as ranked by Anderson and others (1990). Figure 4 outlines the areas of low and medium geothermal resource development potential as identified the U.S. DOI and U.S. DOE (2003). Figure 5 outlines the areas identified as "favorable for shallow, direct-heat geothermal resources" in the Final Programmatic Environmental Impact Statement for Geothermal Leasing in the Western United States (U.S. DOI and U.S. DOA, 2008). Lastly, Figure 6 shows the electrical-grade geothermal resource favorability within the Planning Area as identified in the U.S. Geological Survey's (2008) resource assessment. These maps and the above discussion were used to create a development potential map for geothermal energy within the Planning Area during the Planning Period (Figure 7).

As can be seen by reviewing each of the above maps, geothermal resources and the favorability for the occurrence of those resources are generally shown around areas of known thermal springs and anomalies in the subsurface temperature gradient. These areas are considered to have some potential for future exploration, but due to the expected nature of future projects (small, direct-use, systems) it is unlikely that development will occur outside of established municipalities or other isolated lands developed for other commercial or residential use. Areas in this category are marked as "low" development potential on Figure 7.

Areas marked "very low" on Figure 7 are those which are underlain by aquifer waters with temperatures in excess of 50 degrees Celsius (~120 degrees Fahrenheit) as identified by Anderson and others (1990), as well as those deemed favorable for shallow, direct-heat resource development by the U.S. DOI and U.S. DOA (2008). These waters, while too cool for electrical generation may still be utilized in direct-use systems, though less effectively than those waters found associated with thermal springs.

Areas marked "negligible" represent the remainder of the lands within the Planning Area. As the entire area is underlain by rocks in excess of 150 degrees Celsius (~300 degrees Fahrenheit) at an average depth of 7.5 kilometers (~24,600 feet), the whole of the Planning Area may be suitable for future deep enhanced geothermal development as the technology for such systems is improved upon. However, as such projects are currently not economically feasible, such development is the least likely type of geothermal development to occur in the Planning Area during the Planning Period.

Quantifying the potential surface disturbance for areas of "low," very low," and " negligible" development potential is not at this time possible, as there is not a way to determine (based on historical development, or development in similar areas) what form such development would take. As any such development in the above categories is unlikely, and these developments would be concentrated on lands with disturbance associated with other activities (e.g., municipal, residential, industrial, etc), future surface impacts directly related to geothermal energy development are projected to be minimal on Bureau managed lands.

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