Feasibility Study of Economics and Performance of Geothermal Power Generation at the Lakeview Uranium Mill Site in Lakeview, Oregon

A Study Prepared in Partnership with the Environmental Protection Agency for the RE-Powering America's Land Initiative: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites

Michael Hillesheim and Gail Mosey

Produced under direction of the U.S. Environmental Protection Agency (EPA) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-09-1751 and Task No. WFD4.1001.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-6A10-60251
November 2013

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Executive Summary

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Lakeview Uranium Mill site in Lakeview, Oregon, for a feasibility study of renewable energy production. The EPA contracted with the National Renewable Energy Laboratory (NREL) to provide technical assistance for the project. The purpose of this report is to describe an assessment of the site for possible development of a geothermal power generation facility and to estimate the cost, performance, and site impacts for the facility. In addition, the report recommends development pathways that could assist in the implementation of a geothermal power system at the site.

The Lakeview Uranium Mill site is a 169-acre parcel of land on which uranium was once extracted from locally mined rocks. It is located approximately 2 miles northwest of downtown Lakeview along Metzker Road. The site is adjacent to an area characterized by a relatively shallow (<750 feet), warm-to-hot water (175°–235°F) geothermal resource that has been developed for direct-use applications such as space heating and greenhouses. A local group, the Lakeview County Resources Initiative, requested that EPA investigate whether the site has the potential to be developed to host a geothermal power system.

Based on review of available information, the Lakeview Uranium Mill site may have an adequate geothermal resource beneath it; however, the resource may not be able to support utility-scale power generation. This is because geothermal resources are discrete reservoirs and their size, distribution, and temperature are controlled by local geology and groundwater flow, which may cause the resource to be too small, outside site boundaries, or too low temperature.

If an adequate resource were to be found within or near the boundaries of the site, the available acreage may be too small to hold the entire well field, as most geothermal well fields are distributed over much larger areas. Other important concerns include whether drilling wells on a site with contaminated groundwater will be permissible and the technical challenge of preventing cross contamination with other aquifers.

The technical feasibility of installing a geothermal-power system at a given location is highly impacted by the availability of an adequate geothermal resource and restrictions caused by resource access rights (i.e., permission to utilize the resource). To a lesser extent, proximity to transmission and roads also affect technical feasibility, but this can be overcome with adequate financing.

The economic feasibility of a potential geothermal system on the Lakeview Uranium Mill site depends greatly on the purchase price of the electricity produced and the available incentives that can reduce development costs. The economics of the potential systems were analyzed using the current Pacific Power electric rate of $0.10/kWh and incentives available to a geothermal development in Oregon, which at this time appears to only be the 30% federal tax credit. State and federal loan programs are also available to geothermal power projects.

Assuming a geothermal resource that could be accessed for power development within or near the Lakeview Uranium Mill site boundaries and working within the constraints of what is known about the geothermal resource found in the area, scenarios were developed for a small-scale and a large-scale power generation system. Table ES-1 summarizes the system performance and economics of potential geothermal-power systems that could be developed at the Lakeview Uranium Mill site. The table shows the annual energy output from the system, the number of average U.S. households that could be powered by such a system, and estimated job creation.

At a power sales rate of $0.10/kW, system payback periods are expected to be slightly more than 10 years. If a 15% rate of return is required by investors, the levelized cost of electricity (LCOE), which is typically $0.01–$0.02/kWh less than the desired power sale price of an operator, is $0.14/kWh and $0.11/kWh for the small-scale system and the large-scale system, respectively. The payback period and LCOE values are marginal with regard to the economic feasibility of developing a geothermal power system at the Lakeview Uranium Mill site.

Table ES- 1. Performance and Economics by Size for a Geothermal Power System at the Lakeview Uranium Mill Site

Scenario	Gross System Size (kW)	Net System Size (kW)	Annual Output (KWh)	No. of Houses Powered[a]	Annual Operating Expenses	System Costs with Incentives	LCOE ($/kWh)	Simple Payback (yrs)[b]	Jobs Created (job-yr)[c]	Jobs Sustained (job-yr)[d]
1	2,500	2,125	15,000,000	1,359	$600,000	$10,410,000	0.14	11.5	40	6
2	15,000	12,750	90,000,000	8,152	$3,600,000	$57,315,000	0.11	10.5	154	18

[a] Number of average U.S. households that could hypothetically be powered by the geothermal power system, assuming 11,040 kWh/yr/household
[b] Based on a power sell rate equivalent to the current power purchase rate in Lakeview
[c] Job-years created as a result of project capital investment including direct and indirect jobs
[d] Jobs (direct and indirect) sustained as a result of operations and maintenance of the system

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1 Site Background

The Lakeview Uranium Mill site is located approximately 2 miles northwest of downtown Lakeview, Oregon. It is comprised of 169 acres and was operated as a uranium mill and tailings disposal site between 1959 and 1960. After closure, the site was acquired by Kerr-McGee Oil Industries in 1961. At the time, the site was 258 acres with a 30-acre tailings pile containing 130,000 tons of tailings surrounded by an earthen embankment. The property changed hands four more times prior to 1968, when it was acquired by Atlantic Richfield Company (ARCO). ARCO began decontamination work and consolidated the contaminated materials into the tailings pile, which was subsequently stabilized with a 2-foot thick earthen cover. In 1976, elevated levels of radiation were found in localized areas on the site, and follow-up decontamination was completed in 1977 to ensure compliance with Oregon state environmental rules. The property was sold in 1978 for use as a lumber mill. Subsequently, a remediation program was begun in 1986 that involved excavating and relocating mill tailings and contaminated soil to a new disposal cell; that work was completed in 1989. The site is currently owned by KEC Holdings, LLC, and is part of the U.S. Department of Energy's Long-Term Surveillance and Monitoring Program, which focuses on monitoring groundwater contaminated with materials generated by uranium ore processing (e.g., molybdenum, radium, arsenic) done at the site.

The National Renewable Energy Laboratory (NREL) and the U.S. Environmental Protection Agency (EPA) conducted a site visit hosted by the Lake County Resources Initiative on February 22, 2012, to gather information integral to the feasibility study. Information about the geothermal resource and general site conditions were gathered. During the site visit, the utility infrastructure was not assessed; however, Pacific Power, the local investor-owned utility, has transmission lines in the vicinity. The site is zoned industrial and is easily accessible from Metzker Road, which runs along the western boundary of the site. Approximately 0.5 mile to the east is an industrial park.

2 Geothermal Development at Superfund Sites

Under the RE-Powering America's Land Initiative, EPA funded NREL to support a feasibility study of geothermal renewable energy generation at the Lakeview Uranium Mill site.

A potential use of contaminated sites is to host geothermal power systems. Geothermal power systems will work well on sites where an adequate geothermal resource exists (see Section 3) and favorable power sales rates are possible. Because geothermal resources are geographically limited, the probability of an adequate resource for power generation existing is generally small.

In general, the risks associated with developing geothermal resources for power production are related to the high up-front costs of drilling (and exploration) that do not necessarily translate to a proven or adequate resource (i.e., there is no guarantee that drilling will encounter geothermal brine that is of adequate temperature and sustainable flow rate). Other risks that arise with developing contaminated sites are largely related to drilling disturbance and the possibility of cross contamination of aquifers. There has not been a case of geothermal power development on a contaminated site to our knowledge, and more research into land use restrictions and drilling permitting would be required before doing so.

Renewable technologies other than geothermal power that could be developed at the Lakeview Uranium Mill site include solar photovoltaic, biomass, and waste-to-energy. Because this report focuses solely on the feasibility of developing a geothermal resource for power generation, these other technologies were not considered. The first step in determining whether an alternative technology is feasible would be to complete a resource assessment to determine the facility size for potential power generation at the site.

Power plants in most states rely heavily on fossil fuels for their operation. Compelling reasons to consider moving toward renewable energy sources for power generation include:

- Using fossil fuels to produce power may not be sustainable.
- Burning fossil fuels can have negative effects on human health and the environment.
- Extracting and transporting fossil fuels can lead to accidental spills, which can have impacts devastating to the environment and communities.
- Depending on foreign sources of fossil fuels can be a threat to national security.
- Fluctuating electric costs are associated with fossil-fuel-based power plants.
- Burning fossil fuels may contribute to climate change.
- Generating energy without harmful emissions or waste products can be accomplished using renewable energy sources.

3 Geothermal Power Systems

Geothermal power generation uses fluids heated by the Earth's naturally occurring heat to generate electricity. This heat is extracted from the subsurface using wells drilled into the geothermal reservoir. The geothermal fluid can be in the form of a liquid (typically brine) or a gas (steam) depending on the resource temperature. At the surface, the fluid is moved from the well, or well field (i.e., set of wells), and passed through a geothermal power plant to generate electricity.

Geothermal power plants are a mature, robust technology with environmentally friendly attributes, such as low-to-near zero greenhouse gas emissions and minimal surface footprint and impact. Besides biomass and waste-to-energy technologies, geothermal power systems are one of the few renewable energy technologies that can provide baseload electricity.[1]

A typical geothermal power system (Figure 1) has the following components:

- Geothermal reservoir
- Well or well field
    - Production well(s), Injection well(s), and pump(s)
    - Well field piping, manifolds, and circulation pump(s)
- Geothermal power plant
    - Steam turbine
    - Condenser or cooling tower
    - Circulating water pumps
    - Monitoring equipment
    - Instrumentation and controls
- Electrical Infrastructure
    - Transmission.

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[1] Geothermal power plants normally operate 24 hours per day and 7 days per week with several weeks of downtime per year for maintenance and repairs.

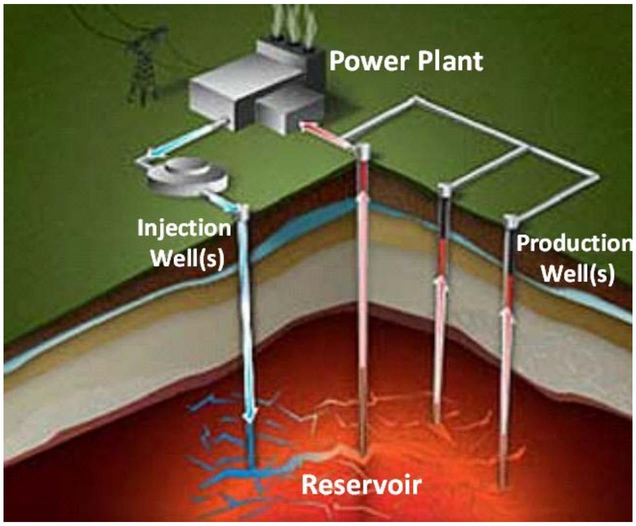

Figure 1. Major components of geothermal power system

Illustration from the website of the U.S. Department of Energy Geothermal Technologies Office

3.1 Geothermal Reservoir

The geothermal reservoir is a permeable rock unit that hosts geothermal fluids. It is created when water or steam heated by the Earth's heat is trapped in permeable and porous rocks under a layer of impermeable rock. In some instances, unless capped by an impermeable unit (e.g., shale or clay), hot geothermal fluid can manifest itself on the surface as hot springs or geysers, but most of it stays deep underground, trapped in cracks and porous rock. For the renewable energy source to be exploitable for power generation, adequate amounts of heat, permeability, and fluid are required. If one of these variables is too low, there is no technical viability without either introducing a fluid or enhancing the permeability. Thus, these barriers currently represent economic barriers more than technical barriers. For this assessment, the presence of all three variables was assumed to be adequate based on available information.

3.2 Well Field

To access the geothermal reservoir, a well or set of wells (i.e., a well field) must be drilled. At a minimum, one well must be drilled to extract the geothermal fluid from the reservoir. For small-scale power generation (<1 MW) or direct-use applications (see Section 3.3.1), a single production well may be adequate. Depending on the chemical composition of geothermal fluid and local regulations, the geothermal fluids can either be discharged to the surface (typically with residence in a cooling pond) or re-injected into the subsurface (not necessarily the same formation as the geothermal reservoir). Typically, a well doublet is required: one well is used for production and the other is used for injection. For larger-scale development, a series of production wells is required to produce geothermal fluid to run the power plant. A typical well field configuration includes two or three production wells per injection well.

The well field also consists of piping infrastructure that moves the geothermal fluid from the wells head or wellheads to the power plant and from the power plant to the cooling pond or injection well. Wells within a field can be widely spaced (typically greater than ½ mile apart) and the power plant and piping can be extensive. In some cases, if the wells are far enough from the power plant or the resource temperature is marginal, the pipes may be insulated to mitigate temperature lose.

3.3 Power Plants

The amount of energy that can be produced by a geothermal power system depends on the several factors, including the size of geothermal resource (i.e., temperature, permeability, and presence of fluid), the technology employed, and several economic factors (see Section 6). Geothermal power systems are highly scalable and can be sized (from 100s of kWs to 10s of MWs) to supply internal energy needs only or sized larger to feed energy to the grid for sale; however, plant size is largely dictated by the geothermal resource and its location relative to infrastructure and demand, due to the high up-front cost of development. In general, power plants are sized to fully utilize the proven resource (i.e., if a given resource can support a 20-MW plant, a 20-MW plant will be built).

Geothermal power conversion technologies fall into two broad categories: flash and binary power plants. Flash plants require resource temperatures above 360°F (the temperature required to convert water to steam), while binary plants can generate power at temperatures as low as 165°F, depending on local climate and cooling water availability. Flash plants either harness steam that comes directly from the reservoir (dry steam) or they use a steam separator to separate pressurized geothermal brine into steam and brine (i.e., flash), and the steam is delivered to the turbine. In a binary plant, the geothermal fluid is used to heat either another liquid with a lower boiling point or a working fluid (e.g., isobutene and pentafluoropropane), via a heat exchanger, causing the working fluid to expand into gaseous vapor. The force of the expanding vapor, like steam, turns the turbines that power the generators. Regardless of the technology type, the goal is to either harness the steam directly or create steam to drive a turbine, which turns a generator that converts the power into electricity. Most of the installed geothermal power capacity in the United States comes from flash-type systems; however, all new developments are installing binary plants or flash/binary hybrids.

3.3.1 Alternative Uses of Geothermal Resources

Several alternative applications for using geothermal resources can be broadly categorized as either direct use or combined heat and power applications. Direct use includes space heating/conditioning, agriculture, aquaculture, and snow melting. In some cases, geothermal resources can be used to generate process water for industrial purposes. This concept may be worth investigating for the Lakeview Uranium Mill site because of its proximity to the Lakeview industrial park, assuming an adequate resource is found within the boundaries of the site.

Combined heat and power is technically the concurrent generation of multiple forms of energy in a single system. While generating electric power, the thermal energy from the system can be used for one or more direct use applications in an attempt to maximize utilization of the resource. If the combined heat and power system will be used to service the thermal loads of more than one system, the heat is typically “cascaded” down to operations that require subsequently smaller amounts of heat to be effective. A combined heat and power system is similar to a cascaded system, but the geothermal fluid is used for space conditioning after it exits the power plant.

3.4 Geothermal Power System Operations

3.4.1 Sustainability

Geothermal resources if managed correctly can be sustainable for many years (i.e., decades), especially if re-injection of the geothermal fluid occurs. The temperature of a geothermal resource will diminish with time; however, if proactive resource management techniques are in place, the impact on the resource conditions (i.e., temperature and flow rate) can be minimized. At a minimum, the pressure/water level, temperature, and flow rate of the resource should be monitored at regular intervals. If any of these changes drastically over a given period, the system should be re-evaluated and possibly scaled back.

3.4.2 Operation and Maintenance

Geothermal power plants are typically designed for a 40-year useful life but can last years longer with proper operation and maintenance. Well fields typically have operational lives of 15 to 25 years due to casing failures in wells caused by corrosive geothermal brines. Typically, a strategy is developed to replace a well or two each year beginning in year 15 until well replacements are complete. Then, the cycle begins again. Pumps have short life spans (<10 yrs). Depending on the chemical composition of the brine, piping may need to be replaced once or twice during the lifetime of the plant.

4 Geothermal Resource Assessment

Geothermal resource assessment is the process of collecting and analyzing data to determine resource characteristics and potential. In its simplest form, it involves a review of existing literature to develop a generic conceptual model of a potential system. In its most complex form, a resource assessment consists of a multi-million dollar exploration and drilling program resulting in a detailed conceptual model that can be used to develop numerical models of the reservoir. Because this project involved a feasibility study, this assessment used the simple form of resource assessment.

4.1 Lakeview Uranium Mill Site Assessment and Suitability

A fairly robust set of information exists for the geothermal resource in the vicinity Lakeview, Oregon.[2] A distinct zone of elevated groundwater temperatures is located just northeast of the Lakeview Uranium Mill site, in an area known as the North Lakeview Geothermal Resource Area (NLGRA).[3] At least 14 wells have been drilled in this area; each has had temperature above 175°F, with the highest reported temperature being 235°F (Figure 2). Depths reported for the 14 wells ranges from 35 feet to 1,310 feet; however, the total depth of a well is not necessarily a good indicator of true resource depth. For example, one well drilled to 1,300 feet below the ground surface in the area had a reported temperature of 203°F, while that measured 235°F was only drilled to 394 feet. A well drilled to 690 feet and the spring (known as Hunter Hot Spring), located one-quarter mile northeast of the site, had a reported inlet temperature of 205°F. Most of the wells drilled in the NLGRA are currently used for space conditioning and direct use purposes.

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[2] Boyd, T. (2006). *Possible Oregon Geothermal Power Plant Sites. Geo-Heat Center*. Oregon Institute of Technology, Klamath Falls, OR. 8 pp.

Boyd, T. (2007). *Oregon Geothermal Direct-Use Projects*. Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR. 12 pp.

Bugenig, D.; Rafferty, K. (2011). *Lakeview Geothermal Heating District Feasibility Study. Town of Lakeview*. Anderson Engineering & Surveying, Inc. 138 pp.

Rafferty, K. (2006). *Lake County Geothermal Resource Areas: Lake County Geothermal Agriculture/Industrial Park Preliminary Site Selection Report*. South Central Oregon Economic Development District. 47 pp.

Rafferty, K.; D. Sawyer, D. (2006). *Geothermal Business Development Plan. South Central Oregon Economic Development District and Town of Lakeview*. Lakeview, OR: Anderson Engineering & Surveying, Inc. 32 pp.

[3] Rafferty, K. (2006). *Lake County Geothermal Resource Areas: Lake County Geothermal Agriculture/Industrial Park Preliminary Site Selection Report*. South Central Oregon Economic Development District; 47 pp.

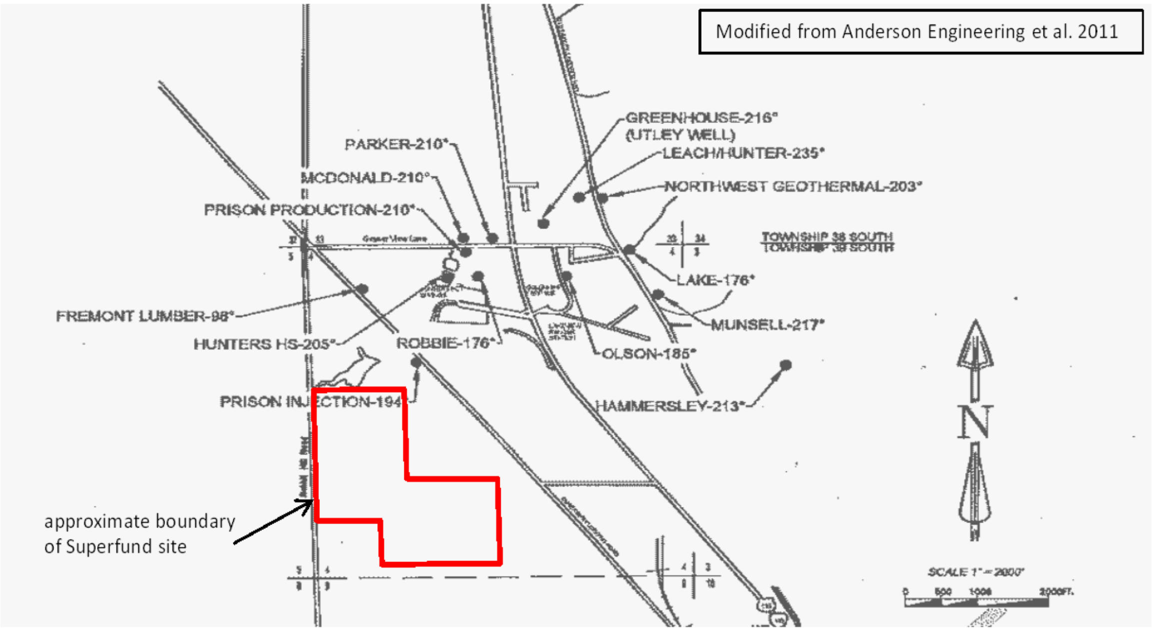
Modified from Anderson Engineering et al. 2011

Figure 2. Map of wells completed in the geothermal resource north of Lakeview, Oregon

Illustration from Bugenig and Rafferty (see footnote 4)

Temperatures are in degrees Fahrenheit.

Based on a literature review, the NLGRA is understood to be a zone of active upwelling and outflow.[4] The dominant control of the upwelling of geothermal brine is the local northwest trending range-front fault that parallels the Warner Mountains, which rise east of Lakeview. Groundwater circulates from the surface to depth along large faults and fractures. As the fluid descends, it is heated and eventually begins to rise back toward the surface. This type of phenomenon is known as convection. Figure 3 provides a conceptual model of a convective geothermal system.

As the brine rises, it sometimes encounters horizontal permeable units that permit it to flow out from the zone of upwelling. This is referred to as an outflow plume, which can result in a bull's-eye pattern of elevated groundwater temperature that diminishes away from the center (Figure 4). A vertical temperature profile through an outflow plume shows increasing temperature with depth until the base of the plume (i.e., the transition from permeable to low-permeability rock) when the temperature begins to either become stable (i.e., isothermal) or even decrease.

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[4] Bugenig, D.; Rafferty, K. (2011). *Lakeview Geothermal Heating District Feasibility Study. Town of Lakeview*. Anderson Engineering & Surveying, Inc. 138 pp.

Rafferty, K. (2006). *Lake County Geothermal Resource Areas: Lake County Geothermal Agriculture/Industrial Park Preliminary Site Selection Report*. South Central Oregon Economic Development District. 47 pp.

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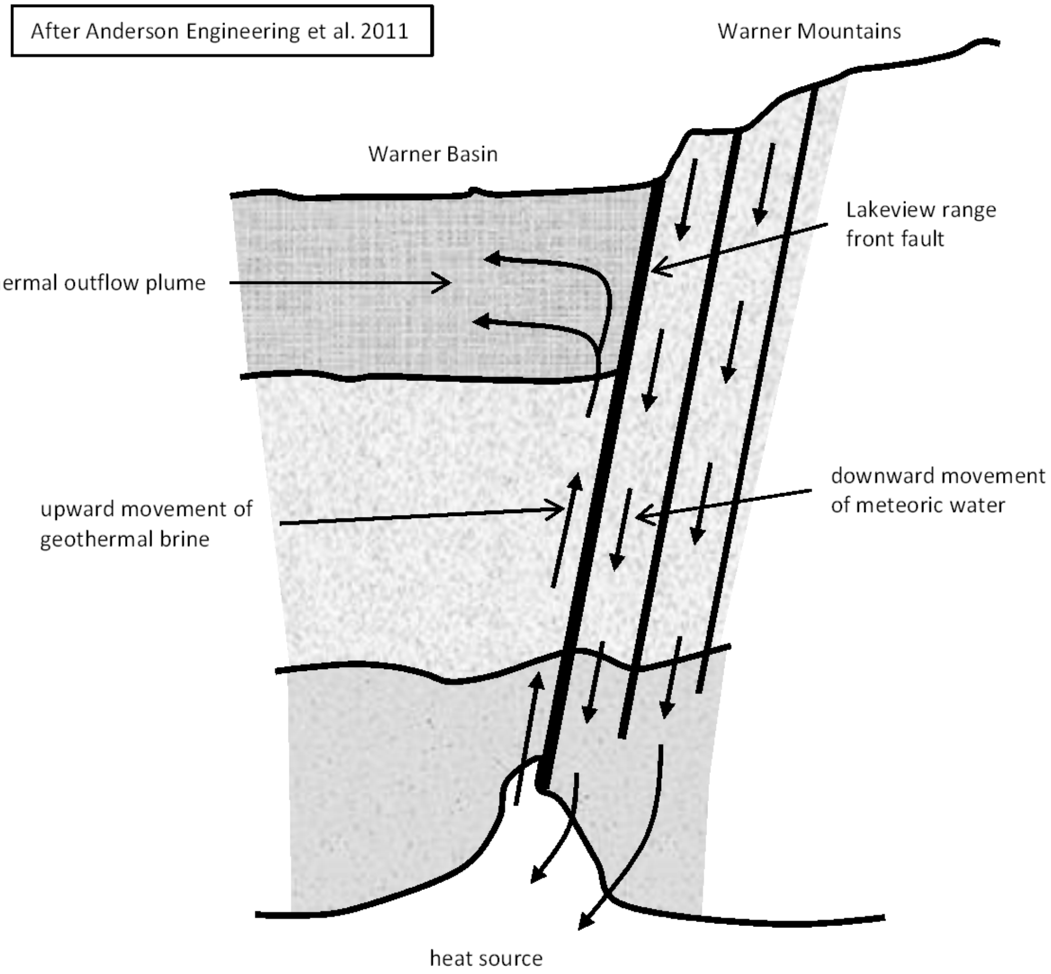

Figure 3. Conceptual model of deep circulation along the Warner Mountains range-front fault[5]

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[5] Bugenig, D.; Rafferty, K. (2011). *Lakeview Geothermal Heating District Feasibility Study. Town of Lakeview.* Anderson Engineering & Surveying, Inc. 138 pp.

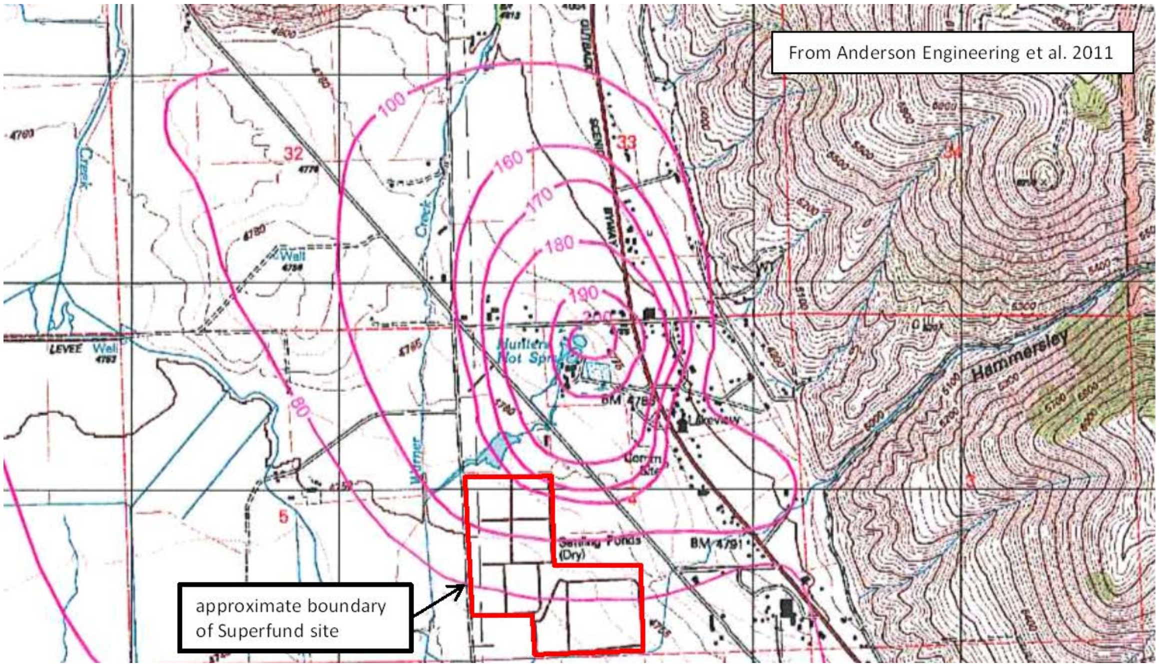

Figure 4. Map of groundwater temperature distribution for the North Lakeview Geothermal Resource Area[6]

Figure 2 indicates that wells within 0.25 mile of the boundary of the Lakeview Uranium Mill site exhibit temperatures in the 175°–195°F range at depths as shallow as 200 feet.[7] The Geo-Heat Center at the Oregon Institute of Technology in Klamath Falls, Oregon, estimates the average temperature, depth and sustainable flow rate of the NLGRA to be 235°F, 643 feet, and 1,727 gallons per minute (gpm) per well, based on information gathered from 32 wells and 4 springs located in the area.[8]

4.2 Resource Access Issues

Two distinct barriers need to be addressed before development of the NLGRA for power generation can occur: (1) rights to the geothermal resource (i.e., water rights) and (2) permission to drill through the contaminated aquifer that underlies the Lakeview Uranium Mill site.

Obtaining rights to further develop the shallow geothermal resource could be difficult as evidenced by resistance from right holders to the other geothermal development projects in the vicinity. For example, the drilling of the production well used to provide hot water for heating of

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[6] Bugenig, D.; Rafferty, K. (2011). *Lakeview Geothermal Heating District Feasibility Study. Town of Lakeview*. Anderson Engineering & Surveying, Inc. 138 pp.

[7] K. Rafferty, K.; D. Sawyer, D. (2006). *Geothermal Business Development Plan. South Central Oregon Economic Development District and Town of Lakeview*. Lakeview, OR: Anderson Engineering & Surveying, Inc. 32 pp.

[8] Boyd, T. (2006). *Possible Oregon Geothermal Power Plant Sites. Geo-Heat Center*. Oregon Institute of Technology, Klamath Falls, OR. 8 pp.

Boyd, T. (2007). *Oregon Geothermal Direct-Use Projects*. Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR. 12 pp.

a nearby corrections facility was highly contested.[9] And at this time, it is unknown whether a permit could be obtained that would allow drilling of wells through the contaminated aquifer that underlies the Lakeview Uranium Mill site, although drilling techniques exist that would prevent cross contamination. Permission would likely have to be granted by not only the state but also by the U.S. Department of Energy (which oversees the site). In general, getting the rights and permission to drill at or near a Superfund site can prove difficult and could cause a development project to be too difficult to initiate.

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[9] Bugenig, D.; Rafferty, K. (2011). *Lakeview Geothermal Heating District Feasibility Study. Town of Lakeview*. Anderson Engineering & Surveying, Inc. 138 pp.

Rafferty, K. (2006). *Lake County Geothermal Resource Areas: Lake County Geothermal Agriculture/Industrial Park Preliminary Site Selection Report*. South Central Oregon Economic Development District. 47 pp.

Rafferty, K.; D. Sawyer, D. (2006). *Geothermal Business Development Plan. South Central Oregon Economic Development District and Town of Lakeview*. Lakeview, OR: Anderson Engineering & Surveying, Inc. 32 pp.

5 Feasibility Assessment

As mentioned in Section 3, three primary requirements must be met for a geothermal resource to be technically viable; adequate amounts of heat, permeability, and fluid are needed. If one of these factors is absent or inadequate, development is not possible (in the conventional sense). For the rest of this assessment, it is assumed that all three requirements are met.

This section presents two scenarios for geothermal development based on the results of the geothermal resource assessment for the Lakeview Uranium Mill site, and the area surrounding it (Table 1). The scenarios assume that a geothermal resource is (1) found on or within a reasonable distance from the site so that the site can host the power plant and all or part of the well field and its associated infrastructure, and (2) rights to the geothermal resource can be acquired.

Table 1. Physical Parameters for each Scenario

Input	Unit	Scenario 1	Scenario 2
Resource T	°F	225	300
Flow rate (per well)	gpm	2,000	2,000
Gross plant size	kW	2,500	15,000
Net plant size	kW	2,150	13,000
Well depth	ft	1,500	5,000
Number of production wells	-	2	4
Number of injection wells	-	1	2

5.1 Scenario 1: Small-Scale Power Generation

The small-scale power generation scenario calls for the development of a 2.5-MW binary geothermal power plant. It assumes that the shallow outflow plume currently being utilized for direct use applications extends far enough westward that it could be exploited. It also assumes that by drilling slightly deeper (1,500 feet) than most wells in the area, a higher (and more consistent) resource temperature (i.e., 225°F) would be encountered. Due to the nature of outflow plumes, however, this may not be the case (see Section 4.1 for more details). Table 1 lists additional assumptions about the resource and summarizes the parameters used in our economic assessment (see Section 6). In general, there is a low probability of finding the parameters necessary to achieve small-scale power generation solely within the boundaries of the Lakeview Uranium Mill site, and efforts should be made to explore over a larger area.

5.2 Scenario 2: Utility-Scale Power Generation

The utility-scale power generation scenario calls for the development of a 15-MW binary geothermal power plant. It assumes that the primary source of the geothermal outflow plume could be tapped at a much deeper depth (i.e., 5,000 feet) than in Scenario 1, resulting in higher resource temperatures (i.e., 300°F). This assumption is based on conceptual model illustrated in Figure 3. Table 1 lists the other assumptions made about the resource and summarizes the parameters used in our economic assessment (see Section 6). Just like Scenario 1, the probability of finding the parameters necessary to achieve utility-scale power generation within the boundaries of the Lakeview Uranium Mill site is low. If utility-scale geothermal power generation is desired efforts should be made to explore over a much larger area (i.e., even greater than that of Scenario 1).

5.3 Power Off-Take Market

The potential for sale of the power generated at the Lakeview Uranium Mill site is good. At this time, the site does not have an energy load, as no business is operating on site. However, utility easements have been installed within the site in anticipation of future industrial development. Additionally, a small industrial park is located less than 0.5 mile east of the site. Geothermal power is also an attractive power source for utilities because it is consistent (i.e., provides baseload power), which enhances the chances for establishing a power purchase agreement.

6 Economics and Performance

In addition to technical viability, several other variables influence the economic viability of developing a geothermal resource for a given purpose, including: exploration costs; resource depth, which controls drilling costs; sustainability/size of the reservoir, which dictates power plant size; transmission availability and capacity; and market factors, such as electricity sell price, raw material and drilling (and exploration) costs.

6.1 Input Data and Assumptions for Analysis

For this analysis, cost data were gathered from available literature and benchmarked against industry data. Additionally, several assumptions were made to fill data gaps and to simplify the analysis. The input data and assumptions are listed in Table 2. All assumptions are based on conservative estimates and, therefore, the results are toward the higher end of the potential spectrum. The economic analysis was made at certainty (i.e., no risk of failure to access an adequate resource was assumed).

Table 2. Economic and Financial Inputs for Each Scenario

Input	Unit	Scenario 1	Scenario 2
Exploration and confirmation costs	$	1,000,000	7,000,000
Number of full-scale wells	-	3	6
Well costs	$	600,000	2,500,000
Gross plant size	kW	2,500	15,000
Plant costs	$/kW	4,000	3,000
	$	10,000,000	45,000,000
Total installed costs	$	12,800,000	67,000,000
Federal incentives	%	30	
Operating expenses	$/kWh	0.04	
Debt financing	%	50	
Interest rate	%	7.0	

To complete the analysis, the Cost of Renewable Energy Spreadsheet Tool (CREST) Geothermal model, version 1.3,[10] was used. The CREST model is a cost-of-energy analysis tool intended to assist policymakers in evaluating the appropriate payment rate for a cost-based renewable energy project. The model aims to determine the cost-of-energy, or minimum revenue per unit of production needed for a sample (modeled) renewable energy project to meet its investors' assumed minimum required after-tax rate of return.

The installed cost of the geothermal power system includes the costs for materials (i.e., power plant, cooling system, and balance-of-system costs) and construction, as well as all estimated "soft" costs, including development and interconnection fees and the costs associated with

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[10] Gifford, J.S.; Grace, R.C. (2012). *Cost of Renewable Energy Spreadsheet Tool: A Model for Developing Cost-Based Incentives in the United States: User Manual Version 3*. Framingham, MA: Sustainable Energy Advantage, LLC, 2012; 37 pp.

financing. The economics of the geothermal power system also depend on resource exploration and development (i.e., well-field development) costs and the sale price for electricity. For this analysis, a sale price for electricity of $0.10/kWh was used.

It was assumed for this analysis that federal incentives were received. It is important to find incentives or grants to make geothermal power generation cost effective. If the geothermal power system is owned by a private tax-paying entity, this entity may qualify for a 30% federal tax credit[11] and accelerated depreciation on the system, which can account for approximately 15% of the total project cost. The total potential tax benefits to the tax-paying entity are about 45% of the system cost. Because the state and federal governments do not pay taxes, private ownership of the geothermal power system would be required to capture tax incentives.

6.1.1 Other Incentives and Financing Opportunities

The Database of State Incentives for Renewable Energy (DSIRE) provides a summary of net metering, interconnection, and incentives available to customers.[12] A few small state incentives or grants were identified in a review of DSIRE database that could be applied to geothermal power development but were not included in the economic analysis due to the small or limited funding amounts and the competitive nature of the award process.

As mentioned in Section 6.1, tax incentives can only be captured for privately owned geothermal power systems. Third-party ownership under a power purchase agreement works by having a geothermal contractor install, finance, and operate the system while a contract is in place for a utility company to purchase the electricity generated by the system. The system is financed by the biomass contractor, and the payments are made via the electricity that is sold to the utility. In this arrangement, the land that the biomass system occupies must be leased to the owner of the system for the duration of the contract.

6.2 Economic Results

Results of this analysis are summarized in Table 3. For scenario 1, the payback is approximately 11.5 years based on a power sale price of $0.10/kWh, which is reasonable given the live expectancy of a geothermal power system is at least 30 years. If a 15% rate of return is required by investors, which is typical for geothermal power development financing, the levelized cost of electricity (LCOE) is approximately $0.14/kWh, which is higher than the current purchase rate and likely not tenable considering that the power purchase agreement rate would be $0.01–0.02/kWh above the LCOE.

For scenario 2, the payback is approximately 10.5 years, based on a power sale price of $0.10/kWh, which is again reasonable given the live expectancy of a geothermal power system. If a 15% rate of return—which is typical for geothermal power development financing—is

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[11] "Database of State Incentives for Renewables and Efficiency (DSIRE)." 2012. The North Carolina Solar Center, North Caroline State University. Accessed December 12, 2012: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_ Code=OR03.

[12] "Database of State Incentives for Renewables and Efficiency (DSIRE)." 2012. The North Carolina Solar Center, North Caroline State University. Accessed December 12, 2012: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_ Code=OR03.

required by investors, the LCOE is approximately $0.11/kWh, which is still higher than the current purchase rate but which might be tenable if other incentives are available.

At this time, development of a geothermal power system at the Lakeview Uranium Mill site is economically marginal, especially when considering the assumed certainty of the technical viability. If state incentives or grants could be brought to bear, the potential for development improves slightly. The likelihood of finding a higher temperature resource capable of supporting a 15-MW power plant capable of providing power at a reasonable sale price is much lower than the potential of developing a 2.5-MW geothermal system that utilizes the existing shallow geothermal resource.

Table 3. Results of Economic Analysis

Scenario	Gross System Size (kW)	Net System Size (kW)	Annual Output (KWh)	No. of Houses Powered[a]	Annual Operating Expenses	System Costs with Incentives	LCOE ($/kWh)	Simple Payback (yrs)[b]	Jobs Created (job-yr)[c]	Jobs Sustaine d (job-yr)[d]
1	2,500	2,125	15,000,000	1,359	$600,000	$10,410,000	0.14	11.5	40	6
2	15,000	12,750	90,000,000	8,152	$3,600,000	$57,315,000	0.11	10.5	154	18

[a] Number of average U.S. households that could hypothetically be powered by the geothermal power system assuming 11,040 kWh/yr/household
[b] Based on a power sell rate equivalent to the current power purchase rate in Lakeview
[c] Job-years created as a result of project capital investment (i.e., construction) including direct and indirect jobs
[d] Jobs (direct and indirect) sustained as a result of operations and maintenance of the system

6.3 Job Analysis and Impact

Our analysis used the Jobs and Economic Development Impact (JEDI) geothermal power model to estimate the gross national employment and economic impacts of the proposed geothermal power project. JEDI is a flexible input-output modeling tool designed to estimate the economic impacts of expenditures during the construction and operation of power generation facilities.

Like other input-output models, the JEDI model represents the entire economy as a system of interactions or linkages between subsectors of the economy. JEDI uses inputs including the installed project cost ($/kW), system capacity (kW), operation and maintenance costs ($/kWh), location, and the domestic content (or local share) of labor and materials. It estimates and reports the number of jobs, expressed as full-time equivalent (FTE), where one FTE (or job-year) is equal to full-time employment for one person for the duration of a year, created during the construction period and sustained during the operational phase of the project. However, the model does not account for the displacement of jobs or economic activity related to changes in the utilization of existing power plants, electricity utility revenues, and household and business energy expenditures. For this reason, JEDI results should be interpreted as gross rather than net estimates.

For the small-scale power generation scenario, the JEDI model estimated the equivalent of 40 full-time jobs would be created during the construction period, while the equivalent of 6 jobs would be sustained during the operational phase. For the large-scale scenario, the JEDI model estimated that the equivalent of 154 full-time construction jobs and 18 full-time sustained operations jobs would be create (see Table 3).

7 Conclusions and Recommendations

Based on the results of the techno-economic analysis, it is believed that development of a geothermal power system on the Lakeview Uranium Mill site would prove difficult. This is largely due to development barriers and risk related to site access and a lack of data indicating the location of a deeper geothermal resource capable of supporting a utility-scale development.

If the site facilitator, the Lakeview County Resources Initiative, wishes to pursue opportunities for a geothermal power system at the Lakeview Uranium Mill site, it is recommended that more resource information be gathered. This can be accomplished by funding an exploration program aimed at identifying a deeper and hotter resource. The exploration program should include areas outside the site along the range front of the Warner Mountains. Exploration costs could potentially be reduced if state aid and expertise were sought and gained. If the existence of a higher temperature resource can be confirmed, developers will often be more interested.

Finally, power can be purchased via a power purchase agreement; and it is, therefore, recommended any request for a bid that would be issued for development of a geothermal power system at the site be to a third-party entity that could capture all the incentives available and would optimize the system configuration.