GEOREPORT

NREL
Transforming ENERGY

PROTOCOL VOLUME IV

SOCIOECONOMIC ASSESSMENT TOOL

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GeoRePORT Protocol Volume IV: Socioeconomic Assessment Tool

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NOTICE

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LIST OF ACRONYMS

BLM	U.S. Bureau of Land Management
CAGR	cumulative annual growth rate
DOE	U.S. Department of Energy
EA	environmental assessment
EIA	U.S. Energy Information Administration
EPAct	Energy Policy Act of 2005
FERC	Federal Energy Regulatory Commission
FIT	feed-in tariff
GeoRePORT	Geothermal Resource Portfolio Optimization and Reporting Technique
GETEM	Geothermal Electricity Technology Evaluation Model
IEA	International Energy Agency
LBNL	Lawrence Berkeley National Laboratory
LCOE	levelized cost of energy
LCOH	levelized cost of heat
MOU	Memorandum of Understanding
NEPA	National Environmental Policy Act of 1969
NREL	National Renewable Energy Laboratory
NVNM	Newberry Volcano National Monument
PHMA	Priority Habitat Management Area
PPA	power purchase agreement
RPS	renewable portfolio standard
SEAT	Socioeconomic Assessment Tool
SHPO	State Historic Preservation Office
USFS	U.S. Forest Service

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I. PRINCIPLES OF THE METHODOLOGY

The Geothermal Resource Portfolio Optimization and Reporting Technique (GeoRePORT) system is based on the concept that a geothermal system can be described both in terms of the quality of the geothermal resource as it relates to the potential to extract heat (resource grade) and the progress of research and development over the lifetime of the project (project readiness level).

By assessing the major characteristics of a geothermal resource, categorizing the techniques used to characterize the resource, and evaluating how well the research techniques were implemented by the researcher, users can report a **resource grade** covering multiple geological, technological, and socioeconomic attributes that can be compared across play types and geothermal areas. The grade of each resource is intended to be refined, if needed, as new and better information is collected and interpreted.

By assessing the exploration and development activities of the project, users can report on past and planned incremental **project readiness levels**. Like the resource grade, the project readiness level will continually be updated throughout the project lifetime.

Resource grade and project readiness level are reported for three assessment categories: geologic, technical, and socioeconomic. Each category has specific criteria and guidelines for assessing both resource grade and project readiness level, as outlined in each of the following assessment tools (and associated colors):

- **Geological Assessment Tool** (representative color: red)
- **Technical Assessment Tool** (representative color: blue)
- **Socioeconomic Assessment Tool** (representative color: green).

These assessment tools are written for geothermal community professionals assigned to report the resource grade and project readiness level to the U.S. Department of Energy (DOE). Therefore, it is assumed that:

- The exploration activities described below will be planned, executed, and interpreted by skilled geoscientists and engineers.
- Preparers of reports using the GeoRePORT Protocol are knowledgeable of geothermal systems and the different exploration activities. The guidance in these documents does not replace intelligent expertise in preparing, selecting, and interpreting data.

For additional background on the GeoRePORT Protocol, see the Background Document.

II. PROJECT READINESS LEVEL

The GeoRePORT Protocol breaks the concept of project readiness level into ordered categories. As projects progress from one development phase to the next, they pass through "activity thresholds"—minimum activities required to qualify for the next category. For each category, numerous qualifying criteria are defined to represent six different levels (0–5) of project readiness: unassessed, undiscovered, inferred, measured, tested, and examined.

The project readiness grade can be correlated with the United Nations Framework Classification for Resources (UNFC) grading system, which was adapted in 2019 for application to geothermal resources. This UNFC system, like GeoRePORT, seeks to standardize reporting of geothermal development. However, the two tools function differently—the UNFC grading system focuses on qualitative assessments of broad aspects of single projects and is tailored toward asset reporting by companies. GeoRePORT focuses more on the resource itself and its favorability and is applicable to multiple projects or on a regional/national scale. Greater granularity and detail are given to earlier project stages. However, GeoRePORT's project readiness tab has similar intent to UNFC classification, assessing the "readiness" or level of development and viability of a geothermal project for the market. As GeoRePORT users may desire the capability for reporting using UNFC language, an approximate UNFC grade equivalent is provided based on inputs in the project readiness tab. However, to most rigorously determine or confirm UNFC grade, one should review UNFC documentation and protocols (see Geothermal Working Group 2016). GeoRePORT does not follow identical methodology to UNFC guidance.

The UNFC system classifies resources into three categories, or axes: the degree of confidence in the resource (the "G-axis"), the social and environmental viability (the "E-axis"), and the level of technical feasibility and maturity (the "F-axis"). The "E-axis" grade is correlated with GeoRePORT's socioeconomic project readiness level.

DEFINING SOCIOECONOMIC PROJECT READINESS LEVEL

Socioeconomic project readiness level is an assessment of the development of a geothermal area as a power generation or direct use facility. Five separate progression levels ranging from "unknown/uneconomic" to "secured" are designated, with criteria specific to socioeconomic development that must be completed to move up the scale, as outlined in Table 1.

Table 1. Criteria to Move Between Levels of Technical Project Readiness Level

Socioeconomic Project Readiness Level		Qualifying Criteria
S1	**Unknown/ Uneconomic**	Resource undeveloped. For a resource to be considered "Unknown/Uneconomic," *one* of the following criteria must be met: 1. No site environmental (including a biological assessment and cultural resources study) or transmission interconnection analysis. 2. Site evaluated and determined not to have economic potential (e.g., development unallowed, or having significant barriers).
	Leasing and Transmission Analysis Complete	
S2	**Feasible**	For a resource to be considered "Feasible," *all* of the following criteria must be met: 1. Environmental analysis required for leasing complete and the land is available for leasing, or a lease is secured. 2. Transmission interconnection analysis (or comparable analysis) complete and determined to be economically feasible. 3. Site evaluated and determined to have economic potential.
	Exploration and Drilling Permits Approved	
S3	**Likely**	For a resource to be considered "Likely," the following criterion must be met: 1. Permits approved for exploration (e.g., Notice of Intent) and well field drilling (e.g., Geothermal Drilling Permit), which includes associated environmental analysis.
	Well Field Drilled and Power Contract Secured (PPA or other mechanism)	
S4	**Commercial**	For a resource to be considered "Commercial," the following criteria must be met: 1. Approval of a Utilization Plan (or comparable permit) for construction and operation and a Commercial-Use Permit (or comparable permit) if on a federally managed mineral estate), AND 2. Approval of any state- or local-level permits/approvals for construction, operation, and sale of the resource. OR 3. Power contract (PPA or other mechanism) secured with off-taker.
	Plant Development	
S5	**Secured**	For a resource to be considered "Secured," the resource must receive all necessary approvals from any federal and state authorities. The following criteria must be met: 1. Approval of a Utilization Plan (or comparable permit) for construction and operation and a Commercial-Use Permit (or comparable permit if on a federally managed mineral estate). 2. Approval of any state- or local-level permits/approvals for construction, operation, and sale of the resource. 3. Power contract (PPA or other mechanism) secured with off-taker.

The **socioeconomic project readiness level** is meant to indicate whether the activities conducted in an area resulted in the identification of an economic geothermal reservoir that can obtain all of the necessary permits and approvals from federal, state, and local regulators. Choose the level of progress that best describes the successful socioeconomic progress that has occurred to date.

The GeoRePORT recognizes that a single axis cannot describe a viable geothermal resource. In this protocol, the project readiness level is determined by the combination of the geological, technical, and socioeconomic project readiness levels. Figure 1 below graphically shows the relationship between these combined project readiness levels. For more information on the technical and geological progress readiness levels, please refer to the Background Document and the associated assessment tools.

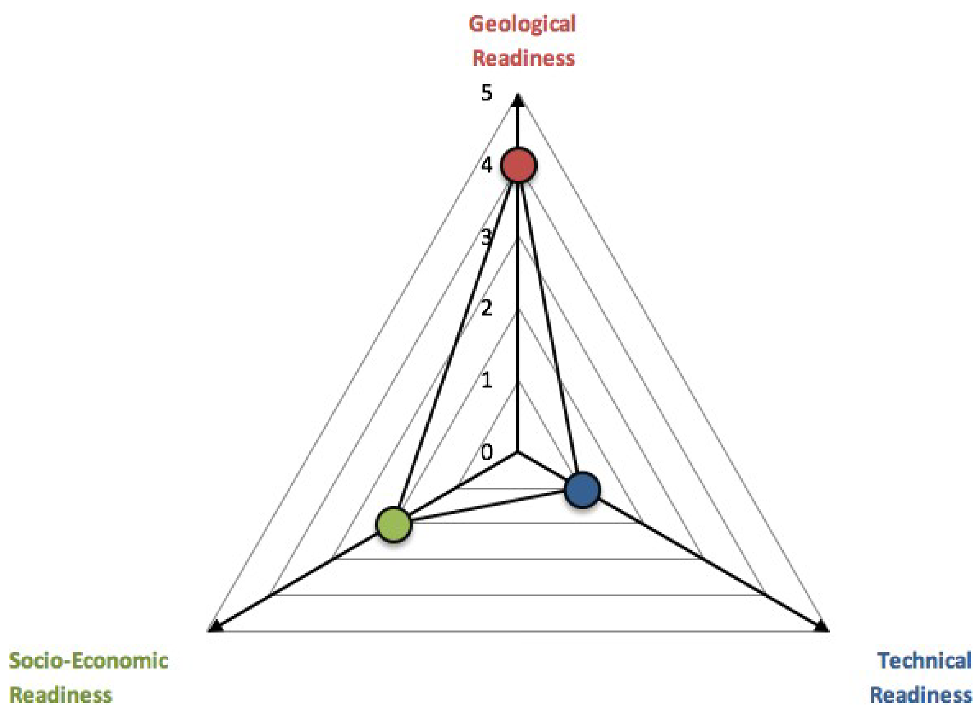

Figure 1. Depiction of socioeconomic progress in relationship to other forms of project readiness level

The socioeconomic readiness grade in GeoRePORT is correlated with the UNFC E-axis, which describes the socioeconomic viability of a project. The E-axis grade is based on factors including the project's status in terms of established resource extraction and sale, its profitability based on current market conditions, legal and regulatory approvals, and socioeconomic and environmental issues (Beardsmore et al. 2020). This criterion aligns well with that of the socioeconomic readiness, with a resource moving from E5 to E1 as a project is determined to be more socioeconomically viable and issues are resolved; just as it would progress from S1 to S5 under socioeconomic readiness terminology (Geothermal Working Group 2016). An example diagram showing corresponding UNFC grades to the project readiness grades in Figure 1 is displayed in Figure 2.

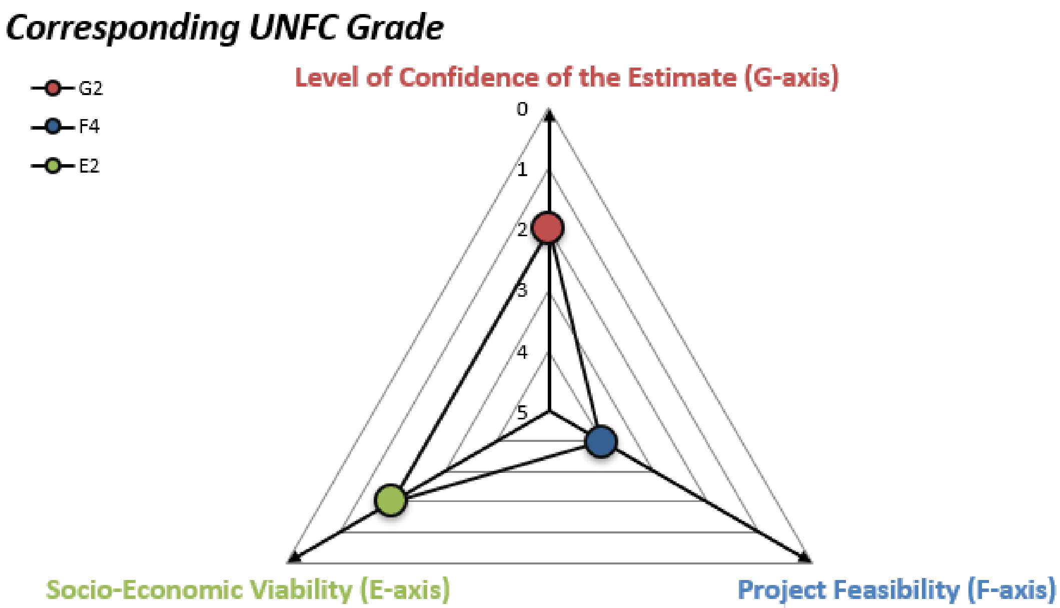

Figure 2. Depiction of E-axis progress in relation to other forms of UNFC grade levels

III. RESOURCE GRADE

The attributes used by this protocol to describe a geothermal resource include the constraints on the quality of the geothermal resource as well as the geological and socioeconomic characteristics that determine whether the heat can be produced.

Each attribute is ranked on a scale of A through E, with A indicating the highest of the range of values for that attribute. ***An attribute grade of A is not necessarily the "best" value for a specific project goal.*** Some business models or plant designs may target grades lower than A for some or all of the attributes. Each developer must evaluate which grades are appropriate for their target business model. Resources with all attribute grades equaling A rarely exist.

SOCIOECONOMIC ATTRIBUTES

The Socioeconomic Assessment Tool (SEAT) encompasses four attributes: land access, permitting, transmission, and market. Each of these attributes includes sub-attributes that, when combined, provide a character grade for each attribute.

COMPONENTS OF SOCIOECONOMIC GRADE

In addition to the attributes listed above, the GeoRePORT also considers the activities conducted to understand each attribute, and what is known about the quality of the data collected. The methodology breaks each attribute into three separate indices describing distinct features of each attribute, outlined in Table 2. Note that the third column contains simple examples from the SEAT.

Table 2. Indices Used to Describe Resource Grades: Character Grade, Activity Index, and Execution Index

Index	Description	Example
Character Grade	Used to describe the character itself—i.e., what is the intrinsic measurement that best describes the geothermal socioeconomics?	Does the project impact no biological resources (Grade A), or is the project in a Sage Grouse Priority Habitat Management Area (PHMA) Focal Area (Grade E)?
Activity Index	Qualitative ranking of activities used to assign the character grade appropriate for each attribute—i.e., how well is the character grade known?	Has the project not started permitting process (Grade E), or have all permits for the power plant and ancillary facilities been approved (Grade A)?
Execution Index	Compares the diligence with which the activity was executed—i.e., how much do we know about the quality of execution of that activity?	Though this is used for the geological and technical assessments, the execution index is not used for socioeconomic grades.

For each attribute, the **character grade** uses quantitative and qualitative measurements that describe the current project within the range of possible outcomes found in geothermal resources and projects.

When evaluating a resource's attribute character grade, there are sometimes multiple aspects of the attribute that contribute to its grade. To assess these multiple aspects, **sub-attribute** indices have been developed for applicable components of the technical grade. For example, when considering the *land access* attribute, we look at several sub-attributes, such as cultural and tribal resources or environmentally sensitive areas.

To determine an attribute's character grade, first evaluate each sub-attribute. Each sub-attribute (SA in the formula below) is given a weight (wt) that was derived based on discussions with industry experts who determined the relative significance of the specific sub-attribute. The total attribute-weighted sum would be calculated as:

$$\text{Sub-attribute-weighted sum} = SA_1*wt_1 + SA_2*wt_2 + SA_3*wt_3 + \ldots + SA_n*wt_n \qquad \textit{(eq 1)}$$

The range of sub-attribute-weighted sums is then broken down into grades A–E for each attribute. For example, for *transmission*, the minimum weighted sum (if all grades are E) is 4, while the maximum weighted sum (if all grades are A) is 20. The breakdown of grades based on weighed sum is as follows:

Land Access Grade	**Sub-Attribute-Weighted Sum**
Grade A	20–18
Grade B	17–14
Grade C	13–9
Grade D	8–6
Grade E	5–4

The **activity index** describes the common activities used to understand the character attributes—both directly (measured values) and indirectly (by proxy). Activity sub-indices are used to evaluate sub-attribute grades. The activity grade is constant within each attribute. To avoid repetitive user inputs, the user will only have to input the activity grade for the first sub-attribute, and the rest of the grades will automatically update. The **execution index** describes how well the activity was implemented. During the exploration process, activities are performed (activity index), the quality of the data is determined (execution index), and the outcome is reported (character grade). Note that the socioeconomic attributes *do not* utilize the execution index.

These five attribute grades, and their associated activity and execution indices, can be displayed graphically in a polar-area chart (Figure 3). The dark wedges indicate resource grade (what is your resource like?); the light wedges indicate certainty (how much do you trust the data?).

The "SocioSummary" tab of the Excel spreadsheet includes a dropdown list in which the user can select the type of geothermal system they are investigating: power generation, direct use, or a combined power and heat system. Figure 3 depicts a hypothetical grade diagram for a power project, so the distribution wedges have been shaded black, indicating that the distribution attribute does not apply to this project and thus does not need to be populated. If the user were to input that this is a direct use project the transmission wedges would be shaded black. Both distribution and transmission attributes are applicable for a combined system, meaning no wedges will be shaded and both attributes should be populated. For more information, please see the Background Document.

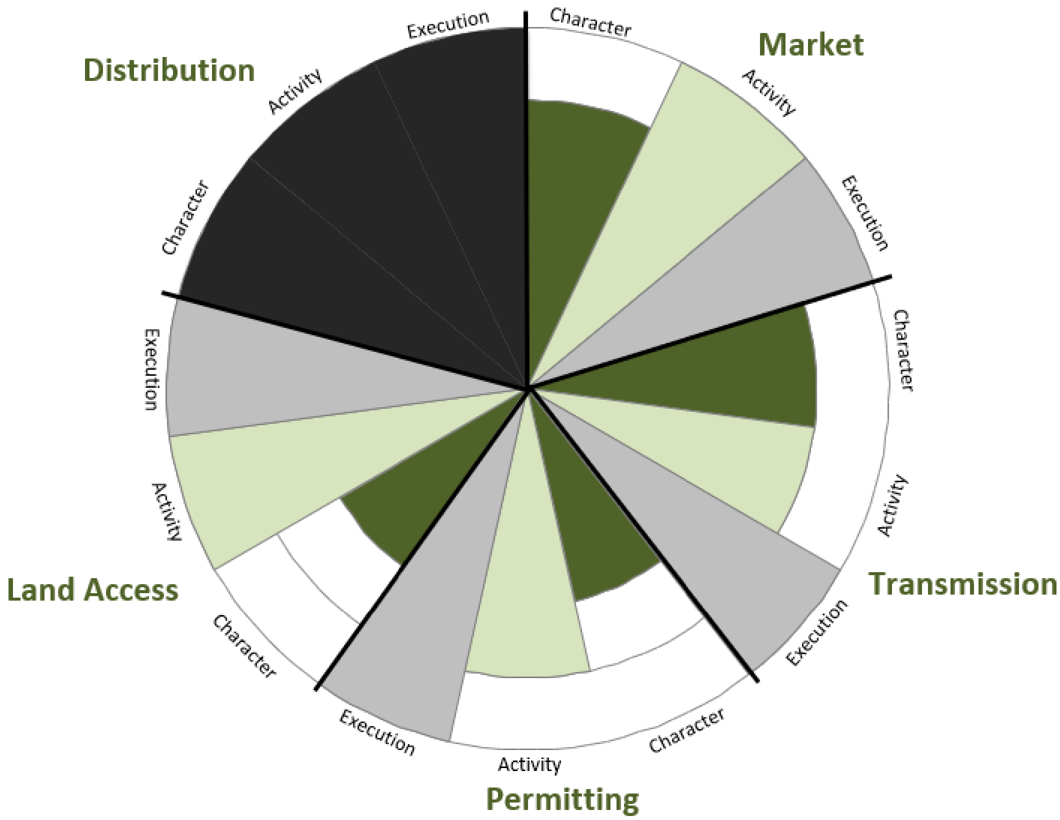

Figure 3. Combined socioeconomic grade diagram of a hypothetical power project

As a reminder, this protocol was developed to provide consistency among the user community in *reporting*; it is neither a prescription for conducting exploration and field development, nor a replacement for expertise and conceptual or reservoir models.

Refer to the Geological Assessment Tool and Technical Assessment Tool for details on the factors relevant to geological and technical grades.

ATTRIBUTE: Land Access

Understanding the challenges of accessing land for geothermal development is important, because environmental assessments and private and public leases can take a considerable amount of time and delay or prevent project development. Recent studies (Young et al. 2014) showed that the presence of certain resources and/or previous land uses could cause projects to be delayed several years or more.

Attribute Character Grade

The land access character grade is composed of six or seven sub-attributes (depending on the federal and/or state land jurisdiction of the project). These sub-attributes take into consideration multiple aspects of securing land to develop a project and allow users to assign a character grade based on those individual sub-attributes.

The sub-attributes and their associated weights are shown in Table 3 and are described in more detail below.

Table 3. Land Access Sub-Attribute Weights

Sub-Attribute	Weight
Cultural resources	2
Environmentally sensitive areas	3
Biological resources	3
Land ownership	2
Federal lease queue AND/OR State lease queue	1 1
Conflict zone/military installation	1

The six or seven sub-attribute grades are combined into a single resource grade using the sub-attribute-weighted sum ranges outlined in Tables 4 and 5. Some projects will require a federal land lease AND a state land lease while others will require only one or the other. To reflect this difference in total possible points, the grade range is automatically shifted depending on if the federal and/or state lease queue sub-attributes are applicable to the project. Table 4 displays the grading range if both federal AND state land leases are required while Table 5 shows the grading range if one or the other is applicable.

Table 4. Land Access Character Grade: Sub-Attribute Weighted Sum Ranges (Federal AND State Lease Queue Applicable)

Grade	Sub-Attribute-Weighted Sum	Description
A	65–59	Ideal land access conditions
B	58–48	Favorable land access conditions
C	47–36	Challenging land access conditions
D	35–24 or any significant barrier	Difficult land access conditions
E	23–13 or any unallowed	Very difficult land access conditions

Table 5. Land Access Character Grade: Sub-Attribute Weighted Sum Ranges (Federal OR State Lease Queue Applicable)

Grade	Sub-Attribute-Weighted Sum	Description
A	60–55	Ideal land access conditions
B	54–43	Favorable land access conditions
C	42–31	Challenging land access conditions
D	30–19 or any significant barrier	Difficult land access conditions
E	18–12 or any unallowed	Very difficult land access conditions

Activity Index

The presented sub-attributes can be estimated at different times throughout the process of securing rights to use the land, with grade A representing the greatest level of certainty because the project has secured all leasing and land access. For the land access attribute, the grade would be reported using one of the following activity indices:

Table 6. Sub-Attribute Activities: Land Access

Index	Description
A	Secured all leasing and land access (geothermal lease, rights-of-way, surface access agreement)
B	Land is posted for lease sale (including completion of any required environmental analysis)
C	Land is available for leasing
D	Land is included in a Resource Management Plan, other type of Land Use Plan, or zoned for geothermal development
E	Developer is not aware if land has been evaluated or considered for geothermal development. Land access grade is estimated using publicly available information and data.

Execution Index

Unlike the majority of geological and technical attributes considered within the GeoRePORT, the land access attribute does not typically vary in its execution of activities. As most sub-attributes can be evaluated accurately with publicly available data sets, an execution index was not developed. However, any reported values that are uncertain should be noted in a submitted report.

Sub-Attribute Character Grades

The following tables provide descriptions of each sub-attribute grade and associated weight, the sum of which is used to assign the land access grade in Tables 4 and 5. For each sub-attribute, select the most appropriate grade to describe land access and the associated activity indices that describe how you arrived at the reported grade.

Land Access Sub-Attribute 1: Cultural and Tribal Resources

The cultural and tribal resources sub-attribute grades address whether a known cultural or tribal resource is present at the project location and the anticipated complexity of addressing or mitigating those resource concerns.

Tribal concerns, particularly tribal involvement through significant public comment, were recorded as some of the most significant variables in the length of the National Environmental Policy Act of 1969 (NEPA) process for geothermal development (Young et al. 2014). The median environmental assessment (EA) with tribal concerns took 81 days longer to complete on average, while projects with significant tribal comments took 57 days longer to complete (Young et al. 2014).

Table 7. Land Access Sub-Attribute Grades: Cultural and Tribal Resources

Grade	Description	
A	No known cultural or tribal resources present. No State Historic Preservation Office (SHPO) concurrence required. 60- to 90-day review.	
B	Manageable cultural/tribal resources. State recognized jurisdictional tribal boundaries and 50-mile buffer for federally recognized jurisdictional tribal boundaries. ~4 months for U.S. Bureau of Land Management (BLM) (if applicable) and SHPO concurrence.	
C	Cultural/tribal resource complications or federally recognized jurisdictional tribal boundaries. 6–9 months for BLM (if applicable) and SHPO concurrence.	
D	Difficult cultural/tribal resource complications. +/- 1 year for BLM (if applicable) and SHPO concurrence.	Significant barrier
E	Extreme cultural/tribal resource complications. 1–2 years for BLM (if applicable) and SHPO concurrence.	Unallowed

Land Access Sub-Attribute 2: Environmentally Sensitive Areas

The environmentally sensitive areas sub-attribute grades address whether the project is located on or impacts an environmentally sensitive area, such as Waters of the United States, national wildlife refuges, national parks, or other areas that may complicate or prevent development.

For example, the Crump Geyser Geothermal Project in Lake County, Oregon, included well sites determined to be in a wetland (i.e., Waters of the United States), which required extra permit approval from the state of Oregon and U.S. Army Corps of Engineers (Nevada Geothermal Power Inc. 2012). Another example is the Newberry Volcano Enhanced Geothermal System Demonstration Project, located next to the Newberry Volcano National Monument (NVNM) in Oregon. Development within the NVNM was strictly prohibited, and stipulations included a 500-meter buffer between the created reservoir and rocks under the NVNM, as well as a mitigation plan to protect the NVNM assets and visitors from the impacts of potential seismic events caused by the project (BLM, Record of Decision Newberry Volcano Enhanced Geothermal System Demonstration Project).

Table 8. Land Access Sub-Attribute Grades: Environmentally Sensitive Areas

Grade	Description	
A	Not located in an environmentally sensitive area. 2- to 3-month staff review.	
B	Manageable environmental sensitivities (e.g., recreational, geologic, wildlife, or scenic value). 3- to 6-month staff review.	
C	Environmentally sensitive area complications (e.g., Waters of the United States). 6- to 12-month staff resolution.	
D	Difficult environmentally sensitive area complications (e.g., Wild and Scenic Rivers, National Wildlife Refuge, National Preserves). Not likely to resolve. 1–2 years or longer if resolution possible.	Significant barrier
E	Extreme environmentally sensitive area complications (e.g.,National Park, National Monument, wilderness areas or wilderness study areas, U.S. Forest Service (USFS) inventoried roadless areas,* state and private conservation land). Not likely to be resolved. 2+years.	Unallowed

**The 2001 USFS Roadless Rule prohibits road construction, road reconstruction, and timber harvesting on 58.5 million acres of inventoried roadless areas within the National Forest System.*

Land Access Sub-Attribute 3: Biological Resources

The biological resources sub-attribute grades whether the project may impact species or their habitat, including species of concern, threatened and endangered species, protected avian species, and sage grouse habitat.

The presence of federally endangered species and migratory birds was recorded as two of the most significant variables in the length of the NEPA process for geothermal development (Young et al. 2014). The median EA with federally endangered species present took 69 days longer to complete, while the median EA with migratory birds present took 177 days longer to complete (Young et al. 2014).

Additionally, current sage grouse rules have created challenges for geothermal developers. The BLM and U.S. Forest Service finalized new land use plans in 2015 to conserve habitat and identify threats to sage grouse and sagebrush. In part, the new land use plans seek to eliminate most new surface disturbance in sage grouse PHMA focal areas, avoid or limit new surface disturbance in PHMAs, and minimize surface disturbance in General Habitat Management Area (BLM 2015).

Table 9. Land Access Sub-Attribute Grades: Biological Resources

Grade	Description	
A	No biological resource issues. 60- to 90-day staff review.	
B	Manageable biological resource issues (e.g., nearby species of concern). 3- to 6-month staff review.	
C	Biological resource complications (e.g., endangered or threatened species nearby, migratory birds, bald/golden eagles); Sage Grouse General Habitat Management Area. 6- to 12-month staff resolution.	
D	Difficult biological resource issues (e.g., nearby or present endangered species); Sage Grouse Priority Habitat Management Areas (PHMA). Not likely to resolve. 1–2 years or longer if resolution possible.	Significant barrier
E	Sage Grouse PHMA Focal Areas.	Unallowed

Land Access Sub-Attribute 4: Land Ownership

The land ownership sub-attribute grades whether the project is located on federal, state, or private land.

The ownership of land sought for geothermal development may increase project costs or development time. Projects with multiple landowners, particularly in the form of distinct surface owners and sub-surface owners (i.e., split estate) or multiple federal agencies may increase project complexity. For example, Young et al. (2014) analyzed the timeframe for NEPA process for EAs, which showed that the average time for the 11 projects with U.S. Forest Service *and* BLM jurisdiction took 60 days longer to complete than the 28 projects completed solely by the BLM.

Table 10. Land Access Sub-Attribute Grades: Land Ownership

Index	Description
A	Private land, single owner
B	Private land, multiple owners (with potential split estate issues)
C	Federal or state land with well-defined geothermal leasing regulations
D	State land without defined geothermal leasing regulations
E	Multiple landowners (federal, state, or private combination with potential split estate issues)

Land Access Sub-Attribute 5: Lease Queue

Some projects will require EITHER a federal land lease OR a state land lease, in which case, only provide information for the applicable sub-attribute (sub-attribute 5a or 5b). Other projects will require a federal land lease AND a state land lease, in which case, provide information for both sub-attributes (sub-attributes 5a and 5b). The land access grading scale, as seen in Tables 4 and 5, will change to reflect the applicability of sub-attributes 5a and/or 5b.

Land Access Sub-Attribute 5a: Federal Lease Queue

Federal lands nominated for geothermal leases must go through an environmental review process by the agency. In the past, low levels of geothermal funding and available staff—particularly at the U.S. Forest Service—created backlogs of geothermal project leases awaiting processing, with some applications sitting in the queue for 34 years (BLM and USFS 2008). Section 225 of the Energy Policy Act of 2005 (EPAct) required a program for reducing the backlog of geothermal lease applications on National Forest System lands by 90% within 5 years of enactment. In furtherance of this requirement, in October 2008, the U.S. Department of Interior (which oversees the BLM) and the U.S. Department of Agriculture (which oversees the Forest Service) finalized a Programmatic Environmental Impact Statement for Geothermal Leasing in the Western United States (BLM and Forest Service 2008). EPAct temporarily increased funding for geothermal lease processing, helping to address the backlog. However, with the end of this funding, the agencies returned to pre-EPAct levels. The federal lease queue sub-attribute grades address the anticipated time a project proponent may have to wait on the BLM or the U.S. Forest Service to complete the applicable pre-leasing analysis and post the parcel for lease sale after nomination.

Table 11. Land Access Sub-Attribute Grades: Federal Lease Queue

Grade	Description	
A	<1 year	
B	<2 years	
C	<3 years	Flagged
D	<5 years	Flagged
E	>5 years	Significant barrier

Sub-Attribute 5b: State Lease Queue

The state lease queue sub-attribute grades address the anticipated time a project proponent may have to wait for a state land board to complete any applicable pre-leasing analysis and post the parcel for lease sale.

State leasing may be an issue if the state does not have experience in leasing state land for geothermal development or does not have a specific regulation in place for leasing state land for geothermal development.

Table 12. Land Access Sub-Attribute Grades: State Lease Queue

Grade	Description	
A	<1 year	
B	<2 years	
C	<3 years	
D	<5 years	
E	>5 years	Significant barrier

Land Access Sub-Attribute 6: Military Installations

In the western United States, where a large portion of the 30 million acres of U.S. Department of Defense-managed land exists, the potential for geothermal resources occurring near or on a military base can be high (e.g., Sabin et al. 2004; Sabin et al. 2010). Chief concerns among all installation commanding officers are meeting mission requirements and preventing encroachment.[1] By definition, the use of military land for anything other than mission-related activities (e.g., developing utility-grade or direct use geothermal resources) is potentially in conflict with an installation's mission. Proposed exploration and development activities on or near base boundaries may also be perceived as encroaching on mission activities.

[1] Encroachment is a term used by the U.S. Department of Defense to refer to incompatible uses of land, air, water, and other resources. Encroachment is "the cumulative impact of urban and rural development that can hamper the military's ability to carry out its testing and training mission." Certain types of land use near military installations can interfere with military operations by obstructing air routes and communications by cellular towers, power lines, and other similar structures; competing for or interfering with data and communications frequencies; depleting ground or surface water supplies, water treatment capacity, and other resources; using extra air emissions in areas that may have emission thresholds; and requesting changes in testing because of residents' noise concerns. New development can also drive threatened and endangered species onto a military installation, limiting its operations (http://www.ncsl.org/research/military-and-veterans-affairs/minimize-encroachment-on-military-installations.aspx)

The *military installations* sub-attribute grades and map (Figure 4) address the distance to known military bases and other areas under military control.

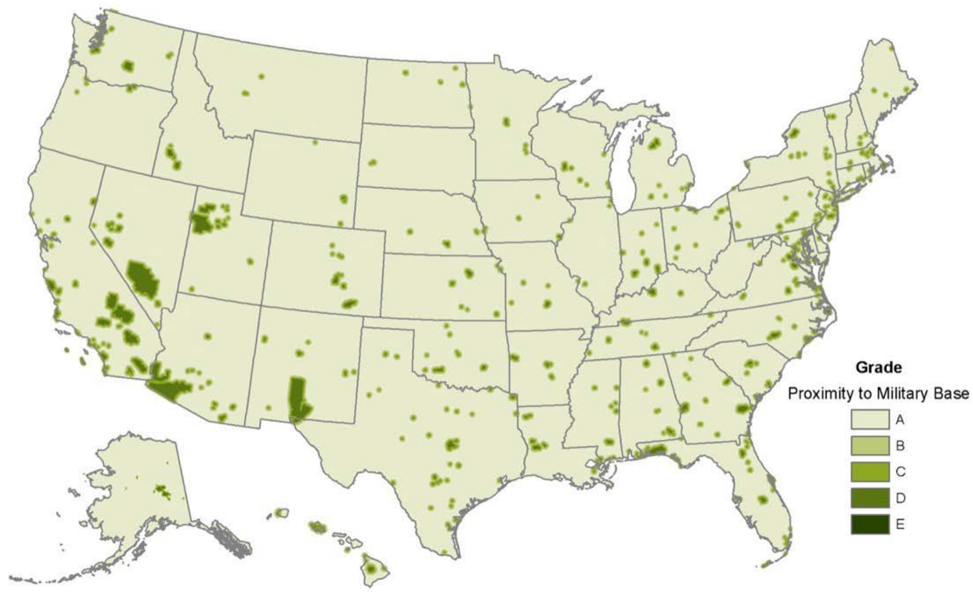

Figure 4. United States military installations sub-attribute grades and map, corresponding with Table 13

Table 13. Land Access Sub-Attribute Grades: Military Installations

Index	Description	
A	Not located near military installations	
B	Located within 10 miles of military installations	
C	Located within 5 miles of military installations	
D	Located on a military installation	
E	Negatively impacting a military installation	Significant barrier

ATTRIBUTE: Permitting

Development of a geothermal project requires a variety of different permits. These may vary based on whether the project is on nationally and/or locally managed land, invoking the administrative procedures of several overlapping national and local authorities. Delays can be caused by many factors, including a lack of knowledge of the details of geothermal development, under-staffed offices, vacation schedules, or the number of permits and/or parties involved. These complex and sometimes time-consuming procedures can impact the investment potential of the geothermal project (Levine et al. 2013).

Attribute Character Grade

The permitting character grade is composed of three or four sub-attributes (utilizing either the state and/or federal regulatory framework). These sub-attributes take into consideration multiple aspects of permitting and allow users to assign a character grade based on those individual sub-attributes.

The sub-attributes and their associated weights are shown in Tables 14 to 16 and are described in more detail below. Some projects will fall in the jurisdiction of the state regulatory framework AND the federal regulatory framework while others will be applicable within only one or the other. To reflect this difference in total possible points, the grade range is automatically shifted depending on the applicability of the state and/or federal regulatory frameworks sub-attributes to the project. Table 15 displays the grading framework if the project falls within both national and local jurisdictions while Table 16 displays the grading framework if the project falls within either one or the other.

Table 14. Permitting Sub-Attribute Weights

Sub-Attribute	Weight
State regulatory framework AND/OR Federal regulatory framework	2 2
Environmental review process	3
Ancillary permits	1

Table 15. Permitting Character Grade Criteria (State AND Federal Regulatory Framework Applicable)

Grade	Sub-Attribute-Weighted Sum	Description
A	40–35	No permitting barriers present
B	34–28	Manageable permitting barriers
C	27–20	Permitting barriers present
D	19–14	Difficult permitting barriers
E	13–8 or any significant barrier	Extreme permitting barriers

[2] No exploration or drilling permits are required on military bases in California or Nevada, although a base's real estate or environmental office may want to seek concurrence of state authorities, for instance, before drilling.

Table 16. Permitting Character Grade Criteria (State OR Federal Regulatory Framework Applicable)

Grade	Sub-Attribute-Weighted Sum	Description
A	30–26	No permitting barriers present
B	25–21	Manageable permitting barriers
C	20–15	Permitting barriers present
D	14–10	Difficult permitting barriers
E	9–6 or any significant barrier	Extreme permitting barriers

Activity Index

The activity index for permitting is based on the project phase performed by developers, with activity index A representing approval of all permits required to develop a geothermal power plant and ancillary facilities.

Table 17. Sub-Attribute Activities: Permitting

Index	Description
A	Power plant/district heating system and ancillary facilities permits approved
B	Well field permits approved
C	Exploration permits approved
D	Review of NEPA analyses for nearby projects that indicate potential concerns in the area
E	Permitting process has not yet begun. Permitting grade is estimated using publicly available information and data.

Execution Index

Unlike the majority of geological and technical attributes considered within the GeoRePORT, the permitting attribute does not typically vary in its execution of activities. As most sub-attributes can be evaluated accurately with publicly available data sets, an execution index was not developed. However, any reported values that are uncertain should be noted in a submitted report.

Sub-Attribute Character Grades

Permitting Sub-Attribute 1: Regulatory Framework

Some projects will fall in the jurisdiction of EITHER the state regulatory framework OR a federal regulatory framework, in which case, only provide information for the applicable sub-attribute (sub-attribute 1a or 1b). Other projects will fall within both the state AND federal regulatory frameworks, in which case, provide information for both sub-attributes (sub-attributes 1a and 1b). The permitting grading scale will change to reflect the applicability of sub-attributes 1a and/or 1b, as seen in Tables 15 and 16, above.

Permitting Sub-Attribute 1a: State Regulatory Framework

The state regulatory framework sub-attribute grades address the relative sophistication of the permitting regulations and knowledge within the state specific to geothermal development. A state or county without geothermal regulations or experience successfully permitting a geothermal project may cause project delays.

Table 18. Permitting Sub-Attribute Grades: State Regulatory Framework

Grade	Description	
A	State/county has a permit coordinating office, geothermal regulations, and experience successfully permitting projects	
B	State/county has geothermal regulations and experience successfully permitting projects	
C	State/county has geothermal regulations, but has not successfully permitted a project or is in the process of changing the regulations	
D	State/county has a definition of geothermal resources, but does not have permitting regulations	
E	State/county does not have any geothermal regulations	Significant barrier

Permitting Sub-Attribute 1b: Federal Regulatory Framework

A lack of experienced regulatory personnel and lack of interagency coordination were two situations cited by industry and agency personnel to delay geothermal project development (Young et al. 2014). The map shown in Figure 5 geographically identifies BLM field office areas with experience and facilitated coordination (MOUs) with the state regulatory agencies. These grades apply only to development on federal lands in these regions.

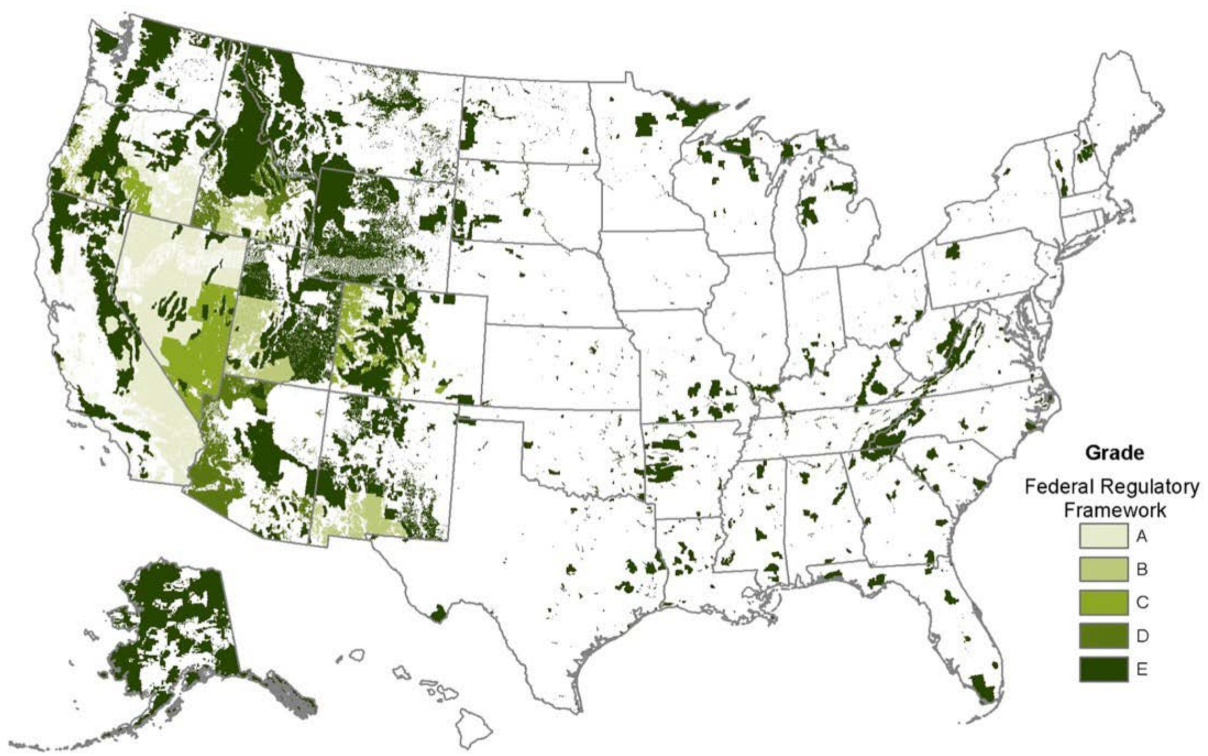

Figure 5. United States BLM field office areas with experience and facilitated coordination (MOUs) with state and regulatory agencies, corresponding with Table 19

The federal regulatory framework sub-attribute grades the relative sophistication of the permitting experts and knowledge within regional offices (BLM district level or individual national forest) specific to geothermal development as well as whether the regional office has a Memorandum of Understanding (MOU) with the applicable state.

Table 19. Permitting Sub-Attribute Grades: Federal Regulatory Framework

Grade	Description
A	BLM-administered mineral estate/groundwater rights in an area with experience permitting geothermal exploration and development projects, and BLM has an MOU with the state.
B	BLM-administered mineral estate/groundwater rights in an area with experience permitting geothermal exploration and development projects, and BLM **does not have an MOU** with the state.
C	BLM-administered mineral estate/groundwater rights in an area **without experience** permitting geothermal exploration and development projects, and BLM has an MOU with the state.
D	BLM-administered mineral estate/groundwater rights in an area **without experience** permitting geothermal exploration and development projects, and BLM **does not have an MOU** with the state.
E	No geothermal staff or funding.

Permitting Sub-Attribute 2: Environmental Review Process

Geothermal projects may have to go through the environmental review process as many as six times, and depending on the type of review (e.g., categorical exclusion, environmental assessment, environmental impact statement) and complexity of the proposed activity, each review may take anywhere from one month to three or more years (Young et al. 2014). These reviews will help to inform decisions on how best to mitigate environmental impacts to meet any required environmental standards. If more than one jurisdiction (e.g., state, federal) requires review processes, the process may be slowed; however, coordination among these regulators can help facilitate permitting.

The environmental review process sub-attribute grades address the environmental review process specific to the land where the project is located. Our grading focused on which states had environmental review processes, whether the project was on federal land and would require NEPA review, and the level of environmental review required.

Table 20. Permitting Sub-Attribute Grades: Environmental Review Process

Grade	Description
A	Project is not subject to any federal or state environmental review process for any permits required for the project. Country approval assumed to take less than 180 days.
B	Project is subject to **one** federal or state environmental review process for any permits required for the project. Federal review 18–24 months, State review <12 months.
C	Project is subject to **two** or more federal or state environmental review processes for any permits required for the project. Federal and State review will take 18–24 months.
D	Project is subject to **one** federal or state environmental review process for any permits required for the project and **has a significant impact on the environment**. Review will take >24 months.
E	Project is subject to **two** or more federal or state environmental review processes for any permits required for the project and **has a significant impact on the environment**. Review will take >24 months and results in a *no-go* decision.

Permitting Sub-Attribute 3: Ancillary Permits

Ancillary permits include air quality, water quality, waste disposal, highway and state land rights-of-way, and public utility commission approvals and siting processes. The type and number of permits required by a project is dependent on the type of geothermal system (power, direct use, or combined) as well as the country or jurisdiction it is located within. Ancillary permit approvals may require conducting studies, filing applications, public hearings, and other elements. The more time consuming the process is for receiving these permits, the greater the impact may be on project costs and timelines. Therefore, it is surmised that a greater number of permits is less beneficial to the development of a project, independent of the type or location of the project.

The ancillary permits sub-attribute grades address the number of permits the project may require not covered under geothermal specific regulations in the state (e.g., exploration and well field drilling regulations).

Table 21. Permitting Sub-Attribute Grades: Ancillary Permits

Grade	Description
A	Project requires ≤4 permits
B	Project requires 5–6 permits
C	Project requires 7–8 permits
D	Project requires 9–10 permits
E	Project requires >10 permits

POWER ATTRIBUTE: Transmission

Access to transmission is a critical component of a successful geothermal project (Hurlbut 2012). Even when a geothermal project is near a transmission line, the cost of interconnecting the project to the electric grid (if possible) and wheeling the power to the off-taker may create challenges.

Attribute Character Grade

The transmission character grade is composed of three sub-attributes. These sub-attributes take into consideration multiple aspects of transmission costs and allow users to assign a character grade based on those individual sub-attributes. The sub-attributes and their associated weights are shown in Table 22 and are described in more detail below.

Table 22. Transmission Sub-Attribute Weights

Sub-Attribute	Weight
Distance to nearest transmission line	1
Interconnection costs (including upgrades)	1
Transmission costs	1
Transmission policies	1

Table 23. Transmission Character Grade Criteria

Grade	Sub-Attribute-Weighted Sum	Description
A	20–18	Ideal transmission conditions
B	17–14	Favorable transmission conditions
C	13–9	Challenging transmission conditions
D	8–6 or any significant barrier	Difficult transmission conditions
E	5–4 or any unallowed	Very difficult transmission conditions

Activity Index

The activity indices for transmission are based on the project phase performed by developers, with activity index A representing constructed transmission requirements (electrons flowing to the grid).

Table 24. Sub-Attribute Activities: Transmission

Index	Description
A	Transmission fully constructed and electrons flowing to the grid
B	Transmission NEPA analyses complete
C	Transmission feasibility and grid connection analysis complete
D	Transmission engineering studies completed and submitted for feasibility and grid connection study
E	Transmission feasibility study not yet completed. Transmission grade is estimated using publicly available information and data.

Execution Index

Unlike the majority of geological and technical attributes considered within the GeoRePORT, the transmission attribute does not typically vary in its execution of activities. As most sub-attributes can be evaluated accurately with publicly available data sets, an execution index was not developed. However, any reported values that are uncertain should be noted in a submitted report.

Sub-Attribute Character Grades

Transmission Sub-Attribute 1: Distance to Nearest Transmission Line

Distance to the nearest transmission line is important because it reflects developers' costs to permit and construct generation tie-lines to connect their projects to the grid.

Table 25. Transmission Sub-Attribute Grades: Distance to Transmission

Grade	Description	
A	Distance to nearest transmission line: <5 km	
B	Distance to nearest transmission line: 5–10 km	
C	Distance to nearest transmission line: 10–20 km	
D	Distance to nearest transmission line: 20–30 km	Significant barrier
E	Distance to nearest transmission line: >30 km	Significant barrier

Transmission Sub-Attribute 2: Interconnection Costs

Interconnection costs are upfront costs paid by the developer to connect to the grid. The interconnection process starts with a query to a utility/transmission line operator to access their lines, and the Federal Energy Regulatory Commission (FERC) models all requests. This process provides developers a path with available capacity and estimates the interconnection cost. Interconnection costs include:

- *Engineering costs*: for developer engineering drawings to submit with interconnection request to utility (approximately $10,000–$20,000).
- *Feasibility and grid connection study costs:* costs paid by developer to utility for utility to conduct feasibility and grid connection analysis (approximately $50,000–$150,000). These costs may vary, and as cluster participants and situations change over time prior to development, feasibility and grid connection analyses may need to be redone. Some developers reported paying more than $1,000,000 in study costs for a single plant due to the need for repeat analysis. Repeated cycles also take considerable time and delay project development.
- *Interconnection costs:* costs to connect to the grid including transmission system upgrade costs and distribution network upgrade costs. Costs are determined by feasibility and grid connection studies and vary from zero to millions of dollars per megawatt. Some costs (e.g., transmission network upgrade costs) are required by FERC to be paid back to the developer over time—either through reduction in transmission costs or through direct payback.

Engineering costs and feasibility and grid interconnection study costs are relatively inexpensive and predictable. Interconnection costs can vary significantly, however, and are node-specific.

For this sub-attribute, there are instances (grade E) where interconnection studies reveal that interconnection is not possible.

Table 26. Transmission Sub-Attribute Grades: Interconnection Costs

Grade	Description	
A	No interconnection system costs (plus engineering cost and feasibility costs)	
B	Minor transmission system costs (get paid back)—$2 to $3M (plus engineering and feasibility costs)	
C	Significant transmission system costs (get paid back) OR distribution network costs (do not get paid back)—up to $1M/MW (plus engineering and feasibility costs)	
D	Significant transmission system costs (get paid back) OR distribution network costs (do not get paid back)—greater than $1M/MW (plus engineering and feasibility costs)	Significant barrier
E	Utility says interconnection is not possible	Unallowed

Transmission Sub-Attribute 3: Transmission Costs

Transmission wheeling costs (or tariffs) are operational costs to transmit power from the point of interconnection to the power purchaser. If the point of interconnection is to the power purchaser's grid, there are no transmission, or "wheeling," costs. If the electricity must be transmitted over another utility's grid to the power purchaser, the operator must pay the utility for use of its grid (grade B). Transmission costs must be paid for each authority—or "wheel"—crossed (grades C–E). Because this cost is project-specific, calculating costs would require knowing where the project will tie in to the grid (point of interconnection), and who the purchaser is (delivery point).

Table 27. Transmission Sub-Attribute Grades: Transmission Costs

Grade	Description	
A	Customer is inside utility power purchase agreement (PPA)—transmission cost = $0	
B	*Single wheel*—utility takes power into system and sells out of system (see prices above—$4 to $12/MWh—for examples given)	
C	*Two wheels ($4 to $12/MWh/wheel)* OR single wheel + system upgrade (path full), so one-time $50M transformer upgrade PLUS transmission costs ($4 to $12/MWh)	
D	*Three wheels ($4 to $12/MWh/wheel)* OR path does not exist, but transmission path proposed waiting for subscribers—developer can pay for subscription	
E	*Four wheels ($4 to $12/MWh/wheel)* OR no path to sell power, so need to build path (billions of $)	Significant barrier

Transmission Sub-Attribute 4: Transmission Policies

Favorable transmission policies can play an important role in lowering the up-front risk inherent in geothermal energy and make it competitive against alternative electricity sources. Transmission connection priority guarantees (Grade A) ensure that there will be available transmission space for the geothermal plant on lines that are already built, lowering costs and shortening the project timeline. Transmission loan guarantees (Grade B) help to decrease the risk and cost involved in building or upgrading transmission lines and systems, thus boosting development.

Table 28. Transmission Sub-Attribute Grades: Transmission Policies

Grade	Description	
A	Qualifies for significant transmission incentives (connection priority upon construction of facility)	
B	Qualifies for moderate transmission incentives (loan guarantees)	
C	Qualifies for minor transmission incentives	
D	Qualifies for any transmission incentives	Flagged
E	Does not qualify for any beneficial transmission policies	Significant barrier

DIRECT USE ATTRIBUTE: Distribution

When developing a direct use or combined heat and power project, one of the bigger components of both capital expenses and operation and maintenance costs is the distribution network (Rafferty 1989; Bloomquist et al. 1989). The "distribution" system is defined here as the network of piping that connects the well(s) to the use sites. Many factors control the initial installation cost of the distribution system, including length of piping, price of materials, and the excavation setting. Whether these expenses can be recovered depends on operation and maintenance costs such as pumping, the level of heat loss, and customer demand for the heat (sub-attributes 1 and 2). All of these factors combine to determine the distribution capital cost per unit heat delivered (Persson et al. 2019). Whether such a price is financially viable depends on the local heat market and policies or incentives (see the market attribute), and so the distribution capital cost itself cannot be graded by GeoRePORT. The distribution attribute instead grades different factors that can contribute to cost and economic favorability of the project.

Attribute Character Grade

The distribution character grade is composed of six sub-attributes. These sub-attributes take into consideration multiple aspects of distribution costs and allow users to assign a character grade based on those individual sub-attributes.

The sub-attributes and their associated weights are shown in Table 29 and are described in more detail below.

Table 29. Distribution Sub-Attribute Weights

Sub-Attribute	Weight
Heat density	2
Utilization efficiency/load factor	2
Peaker plant	1
Distance from well to terminal use site	1
Cost of supplemental injectant	1
Pumping pressure	3

Table 30. Distribution Character Grade Criteria

Grade	Sub-Attribute-Weighted Sum	Description
A	55–45	Ideal distribution conditions
B	44–38	Favorable distribution conditions
C	37–28	Challenging distribution conditions
D	27–18	Difficult distribution conditions
E	17–11	Very difficult distribution conditions

Activity Index

The activity indices for distribution are based on the permitting process required for liquid reinjection, with activity index A representing all permits and rights secured.

Table 31. Sub-Attribute Activities: Transmission

Index	Description
A	Water use, permits, rights secured
B	Water use, permits, rights applied for and in the process of being secured (process straightforward)
C	Water use, permits, rights applied for and in the process of being secured (process uncertain; e.g., court process required)
D	Identification of water source, owner (if applicable), and process to obtain rights
E	Information derived from available regional water reports

Execution Index

Unlike the majority of geological and technical attributes considered within the GeoRePORT, the transmission attribute does not typically vary in its execution of activities. As most sub-attributes can be evaluated accurately with publicly available data sets, an execution index was not developed. However, any reported values that are uncertain should be noted in a submitted report.

Sub-Attribute Character Grades

Distribution Sub-Attribute 1: Heat Density

With space heating systems, especially district heating, the area requiring heating determines the amount of piping and other distribution infrastructure needing to be constructed. This can be measured using the metric of *heat density,* or the heat demand per unit area of the direct use site. Higher heat densities, or more concentrated heat demand per unit area, require less piping between demand centers than projects with lower heat densities. In these cases, the cost of distributing heat constitutes a lower proportion of the total project cost (Persson et al. 2019).

Heat density inversely relates to factors of heat loss and system costs—the lower the heat density, the more extensive the piping network needing to be built, which increases heat losses in fluid transport as well as capital expenses in pipe construction and materials (as such, heat density is incorporated both into the project's technical and socioeconomic grades) (Persson and Werner 2011).

The U.S. Energy Information Administration (EIA) provides data on heat density, or heat energy intensity, across different building sizes and types in the United States. EIA's 2016 data set provides a range of annual 20,000 Btu/ft^2 to 80,000 Btu/ft^2, which roughly equates to a range of 225 MJ/m^2 (low heat density) to more than 740 MJ/m^2 (high heat density). GeoRePORT calculates heat density by dividing the annual heating demand (as input in the System Configuration section of the tool) by the building floor space input. Assigned grades for heat density are given in Table 32 (EIA 2016).

Table 32. Distribution Sub-Attribute Grade: Heat Density

Grade	Annual Heat Density (M/m^2)
A	≥740
B	570–740
C	400–570
D	225–400
E	≤225

Distribution Sub-Attribute 2: Utilization Efficiency/Load Factor

The load factor, sometimes also termed the utilization efficiency, of a site is the percentage of time that the site is utilized compared to its installed capacity. The load factor impacts the economic viability of the site by determining the necessary minimum capital charge per unit heat delivered. The more that the site is utilized, the greater income from the direct use customers, and the more that initial capital costs can be offset. A higher load factor also decreases the cost per unit heat, making the project more financially appealing to customers. As such, the utilization of the direct use site determines whether costs involved in construction and maintenance of the distribution network will be practical (Rafferty 1989; Fry 2021; Thompson 2021).

Utilization efficiency is dependent on considerations such as seasonal temperature changes, demand for the direct use product, and regulatory incentives (see the market attribute). Whether load is sufficient to support economic viability will vary between projects and thus cannot be prescribed by GeoRePORT. However, the EU's Regional Development Fund, or Interreg, has developed a "Benchmark" methodology under its Danube Region Geothermal Information Platform for categorizing and assessing direct use geothermal resources. Interreg's benchmark values for utilization efficiency are here used as parameters for determining the GeoRePORT utilization efficiency/load factor grade (Prestor et al. 2015).

Table 33. Distribution Sub-Attribute Grade: Utilization Efficiency/Load Factor

Grade	Utilization Efficiency/Load Factor (%)	EU Interreg Benchmark Assessment (Prestor et al. 2015)
A	>60	Very good practice
B	45–60	Good practice
C	30–45	Reasonable practice
D	15–30	Need for improvement
E	<15	High need for improvement

Distribution Sub-Attribute 3: Peaker Plant

If temperature or flow rate of a geothermal site is not sufficient to meet peak heat demand, it may be necessary to construct a "peaker plant," which combusts fossil fuel at high demand times to supplement geothermal heat (Afework et al. 2018). The construction and operation of peaker plants increases project costs. Thus, the need for a peaking plant is graded less favorably for distribution.

Table 34. Distribution Sub-Attribute Grade: Fossil Fuel Peaking

Grade	Peaking With Fossil Fuel Required?
A	Peaker plant is not required
C	Peaker plant is required but the peak heat demand can be supplied by a pre-existing source (no peaker plant construction required)
E	A new peaker plant must be constructed to meet peak heat demand

Distribution Sub-Attribute 4: Distance From Well to Terminal Use Site

The extent of materials and excavation required for the piping infrastructure largely determines the cost of the distribution system. Variables such as pipe diameter and composition are dependent on pumping pressure, fluid temperature, and fluid chemistry (Bloomquist et al. 1989), making it difficult to encompass in a single attribute. However, length of required piping can indicate the general scale of piping that will be needed as well as the surface area requiring excavation. The longest component of distribution infrastructure tends to be the connection between the geothermal well to the direct use site. District heating systems in the United States have pipeline lengths ranging between 7,000 and 44,000 ft long, or between about 2 and 13 km. However, some systems with high profitability can build even longer pipeline systems—one system in the Reykjavik area has a pipeline of 63 km long. The financial viability of the piping network depends on the intended use and the level of heat demand at the site (higher demand increases profits and can make pipeline costs more financially viable—see sub-attribute 2: utilization efficiency/load factor) (Angelino et al. 2021). However, it can be generally stated that pipeline length directly contributes to capital expenditures, and GeoRePORT grades longer pipelines with lower scores.

Table 35. Distribution Sub-Attribute Grade: Distance From Well to Terminal Use Site

Grade	Distance Between Well and Terminal Use Site (km)
A	<5 km
B	5–10 km
C	10–20 km
D	20–30 km
E	>30 km

Distribution Sub-Attribute 5: Cost of Supplemental Injectant

A typical hydrothermal system contains a natural fracture network or interconnected pore spaces that facilitate fluid flow through a reservoir. This fluid flow typically exists naturally and is recharged over time. However, when this fluid is recovered through a production well, the reservoir fluid content may not recharge quickly enough to maintain its undisturbed water level.

Reinjecting spent fluids into the geothermal reservoir via injection wells is the best way to ensure that water and pressure levels are sustained over the course of long-term production. In addition, reinjection alleviates the problem of dealing with produced brines and helps to reduce the amount of subsidence that occurs over the reservoir. However, injection can also have less desired effects, such as induced seismicity and accelerating thermal breakthrough. Geothermal reservoirs are typically not closed systems; water injected into the reservoir is not all recovered, and notable amounts are lost in the subsurface.

Including reinjection into the distribution network may also increase total project costs by requiring the construction of additional piping for delivery of spent fluids and the drilling and maintenance of the reinjection well. Furthermore, additional pumping may be required to deliver injection fluids to the well site. However, such additional costs must be weighed against the potential expenses of reservoir drawdown or regulatory constraints on fluid disposal.

This sub-attribute is graded in units of dollars per megawatt (MWth) of unappropriated groundwater ($/MWth). This sub-attribute does not have an associated execution index, as the activities documented in Table 36 do not typically have any uncertainty associated with them.

Table 36. Reservoir Management Sub-Attribute Grade: Cost of Supplemental Injectant for Pressure Maintenance

Grade	Cost of Unappropriated Groundwater (USD/MWth)	Description
A	N/A	Supplemental injectant not needed
B	<$1,000/MWth	Water available and is economical for purchase
C	$1,000–25,000/MWth	Water available, may be expensive or difficult to acquire
D	>$25,000/MWth	Some water available, may not be enough and is expensive to acquire
E	N/A	Water needed and unavailable

Distribution Sub-Attribute 6: Pumping Pressure

A significant proportion of operation and maintenance costs of direct use systems is the cost and energy involved in pumping fluid to and from the use site. Pumping pressure is determined by factors including pipe diameter, heat demand, elevation change between the well and use site, and flow rate. This sub-attribute broadly summarizes the economic feasibility of a project's pumping pressure by defining it as the proportion of total operational costs (Fry 2021; Thompson 2021).

Table 37. Distribution Sub-Attribute Grade: Pumping Pressure

Grade	Pumping Cost Proportion of Total Operating Costs	Description
A	Low	Low pumping pressures required—pumping does not significantly increase operational costs
C	Moderate	Moderate pumping pressures required—pumping moderately increases operational costs
E	High	High pumping pressures required—pumping increases operational costs to a potentially prohibitive level

ATTRIBUTE: Market

The market attribute uses five sub-attributes: *demand* drives development; *wholesale price of electricity/levelized cost of heat* and *additional revenue sources* drive revenues; *policies* and *incentives* determine the type of development (e.g., geothermal, solar) deployed.

The content within the sub-attributes changes slightly between the GeoRePORT spreadsheet for power and that for direct use, to reflect differing market-related considerations for the sale of electricity versus heat. The tables for power and direct use versions are both presented within each sub-attribute.

Attribute Character Grade

The market character grade is composed of four sub-attributes. These sub-attributes take into consideration multiple aspects of the geothermal power market and allow users to assign a character grade based on those individual sub-attributes. The sub-attributes and their associated weights are shown in Table 38 and are described in more detail below.

Table 38. Market Sub-Attribute Weights

Sub-Attribute	Weight
Market demand	1
Wholesale price of electricity (power) AND/OR Levelized cost of heat (direct use)	1 1
Policies (power) AND/OR Policies (direct use)	2 2
Incentives	2
Additional sources of revenue	1

Table 39. Market Character Grade Criteria

Grade	Sub-Attribute-Weighted Sum	Description
A	9–10	Favorable market conditions
B	11–15	Manageable market conditions
C	16–24	Acceptable market conditions
D	25–31	Difficult market conditions
E	32–35	Very difficult market conditions

Activity Index

The activity indices for market are based on the project phase performed by developers, with activity index A representing electrons being delivered to the customer.

Table 40. Sub-Attribute Activities: Market

Index	Description
A	Electrons being delivered to customer under a PPA (or other mechanism)
B	PPA is secured
C	PPA is under negotiation
D	PPA applied for (resource is demonstrated, transmission interconnection study completed), OR PPA was secured and was lost
E	Market grade is estimated using publicly available information and data

Execution Index

Unlike the majority of geological and technical attributes considered within the GeoRePORT, the market attribute does not typically vary in its execution of activities. As most sub-attributes can be evaluated accurately with publicly available data sets, an execution index was not developed. However, any reported values that are uncertain should be noted in a submitted report.

Sub-Attribute Character Grades

Market Sub-Attribute 1: Market Demand

Assessing future demand for additional electricity/heat is important to identify markets that could have an appetite for geothermal-produced electricity/heat. Future demand is a function of direct increases in demand, reductions due to increases in energy efficiency and demand response, and changes in a region's current portfolio through planned retirements.

In the case of electricity, these factors were evaluated by:

1. Calculating a 3-year cumulative annual growth rate (CAGR) for electricity demand by state, utilizing the most recent historical electricity consumption data.
2. Calculating a 10-year CAGR for projected electricity consumption by state using EIA's most recent Annual Energy Outlook (EIA 2015) for 2015 to 2025.
3. Evaluating planned retirements of coal and natural gas power plants as reported in the ASEA Brown Boveri Energy Velocity Suite power plant database. Only currently operating power plants with planned retirement dates within a 10-year span were utilized in this evaluation, and those plants were assumed to be operating as baseload generation until retirement. Additionally, it was assumed that a power plant's output is being consumed within the state in which it falls. In reality, the electricity may be exported to other markets.

The grade was assigned based on a combination of the expected increase in long-term electricity needs (the projected 10-year CAGR modified to account for potential retirements), and the historical 3-year CAGR. States with a greater than 5% increase in expected long-term electricity needs were graded either A or B; states with a 2%–5% increase were graded either C or D; and states with a <2% increase were graded E. The higher or lower grade within each category was determined by whether the 3-year historical CAGR was as significant (greater or lesser than 5% for grades A and B and greater or lesser than 2% for grades C and D).

Heat demand can be assessed based on the total heat consumption in a given area, heat consumption by sector, or in relation to the construction of a specific site. However, such data are often not reported or reported in coarse resolution. GeoRePORT's demand attribute for direct use was considered in the context of a McCabe et al. (2016) study, in which heat demand was calculated for the residential, commercial, manufacturing, and greenhouse sectors by county in the United States (see Figure 6). The data from this study are available in a visual format on NREL's Geothermal Prospector interactive map (https://maps.nrel.gov/geothermal-prospector/). Those developing a site in the United States may use this tool to guide their selection in the demand attribute, with darker coloration representing higher heat demand for the given use sector. Projects outside of the United States may use this tool as a guide for determining the level of heat demand in their own region (i.e., 25 to 80 trillion BTUs, or 26 to 84 million GJ, is defined in McCabe's key as very high heat demand for the commercial sector) (McCabe et al. 2016). For further guidance on determining heat demand of a site or area, see the IRENA publication, *Integrating low-temperature renewables in district energy systems,* section B.3.1: "Guide to Mapping Heating and Cooling Demand" (Angelino et al. 2021).

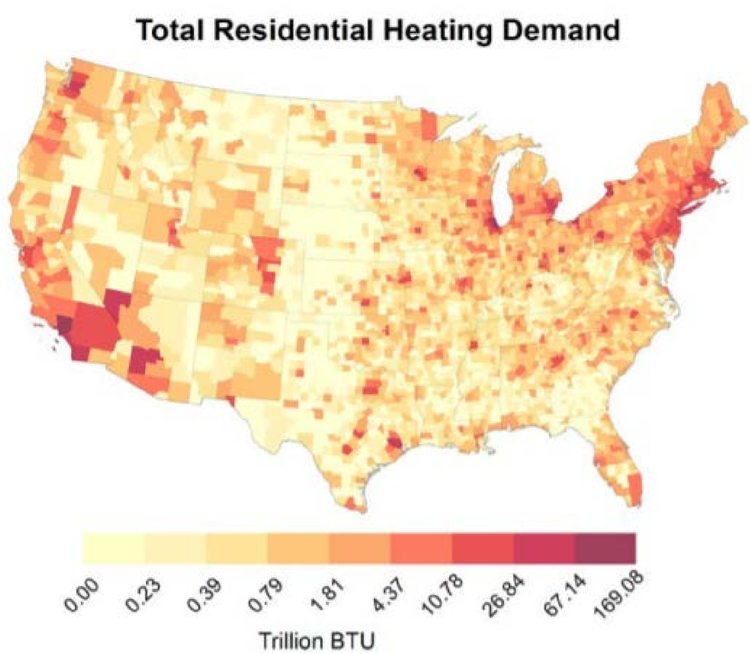

Figure 6. Example map of residential thermal demand in the United States. From McCabe et al. (2016).

Table 41. Market Sub-Attribute Grades: Demand

Grade	Description
A	Strong current and long-term electricity or heat demand (either usage increase or from retirements)
B	Current demand and strong long-term demand (either usage increase or retirements)
C	Moderate current and long-term demand (either usage increase or retirements)
D	Current and long-term demand uncertain OR peak load only
E	Neither current nor long-term demand (e.g., energy or heat market shrinking)

Market Sub-Attribute 2: Cost of Energy

Depending on the type of project (power, direct use, or a combination of the two), the cost of energy is expressed as either the wholesale price of electricity, levelized cost of heat (LCOH), or both. Provide information for only the applicable sub-attribute(s) (market sub-attribute 2a and/or 2b). The grading scale, as seen in Tables 40 and 41, will change to reflect the applicability of sub-attributes 2a and 2b.

Market Sub-Attribute 2a: Wholesale Price of Electricity (Power)

Using the wholesale price of electricity as a market sub-attribute, we can better understand the price point a geothermal plant may need to hit to be economically competitive. The wholesale electricity price generally reflects the marginal cost of generating electricity and delivering it through the transmission system. These different electricity prices fluctuate depending on the system conditions and fuel prices. The largest portion of the wholesale price is the cost of producing electricity, but this will also change based on consumer demand, transmission congestions, and line losses. As such, the average annual wholesale price is closely related to the PPA price a geothermal plant would currently receive, depending on the impacts of system congestion on the wholesale price.

We calculated the average PPA price for 16 available PPA contracts[3] placed between 1981 and 2015, with project sizes ranging from 2 to 50 MW. The PPA prices ranged from $0.0365/kWh to $0.1020/kWh, and the average price was $0.0781/kWh. This average PPA price was then compared to the regional 2015 wholesale price of electricity reported by EIA. Wholesale prices are reported for regional transmission operating market hubs (http://www.eia.gov/electricity/wholesale/) and were associated with each state based on proximity and regional transmission organizations. In the southeast, where no electricity pricing hubs were located, the national average price was assigned.

Wholesale price of electricity data should be sourced from the most local, up to date reports available. When local data are not available, the national average price should be assigned. Wholesale prices of the main advanced economy electricity markets and in select developing economy markets are tracked by the International Energy Agency (IEA) (IEA 2020). A detailed geothermal levelized cost of energy (LCOE) can be calculated using the DOE Geothermal Technologies Office's Geothermal Electricity Technology Evaluation Model (GETEM). GETEM is downloadable at https://www1.eere.energy.gov/geothermal/getem/DownloadTools.aspx. A less detailed estimate of a project's LCOE can be calculated using NREL's Levelized Cost of Energy Calculator (https://www.nrel.gov/analysis/tech-lcoe.html).

For each power project, a project-specific PPA could be estimated that would account for differences in regional fuel mixes (total system fuel costs being offset by geothermal energy), load patterns that affect transmission congestion, and other regulatory requirements.

Table 42. Market Sub-Attribute Grades: Wholesale Price of Electricity

Grade	Cost of Supplying Geothermal to the Market Relative to Weighted Average of Other Technologies on the Grid
A	**Slightly less:** Regional 2015 wholesale **price ≥1x** average geothermal levelized cost of electricity (LCOE)
B	**More:** Regional 2015 wholesale price between **1–0.6x** average geothermal LCOE
C	**More:** Regional 2015 wholesale price between **0.6x–0.5x** average geothermal LCOE
D	**More:** Regional 2015 wholesale price between **0.5x–0.4x** average geothermal LCOE
E	**More:** Regional 2015 wholesale price ≤**0.4x** average geothermal LCOE

**Avg PPA price for 20-MW plant; $0.0781/kWh*

[3] PPA prices are a compilation of public press statements and reports. This work was expanded upon and used as a basis for Hernandez, Richard, and Nathwani (2016).

Market Sub-Attribute 2b: Levelized Cost of Heat (Direct Use)

In order to assess whether a geothermal heating source will be competitive in the heating market, one can compare the price per unit heat of the geothermal to that of the heating source that would otherwise be used. For a geothermal heat source to be preferable and chosen over another heating source, its price likely must be below or equivalent to the delivered price of the alternative. (This heuristic, however, does not account for market drivers such as policies or incentives, or for environmentally minded consumer decision-making). The metric for determining the price of the geothermal heat supply is the LCOH, which takes into account the capital costs, operation and maintenance costs, capacity factor, and other factors.

To determine the sub-attribute grade, calculate the LCOH for the geothermal heat and the alternative heating source. For guidance in calculating LCOH, consult the ScienceDirect overview of LCOH (https://www.sciencedirect.com/topics/engineering/levelized-cost-of-heat) or use NREL's open-source GEOPHIRES tool (Code: https://github.com/NREL/GEOPHIRES-v2; Background document: https://www.nrel.gov/docs/fy18osti/70856.pdf).

The LCOH grade is determined by a ratio between the geothermal LCOH and that of the heating alternative.

Table 43. Market Sub-Attribute Grades: Levelized Cost of Heat

Grade	Geothermal LCOH Compared to Delivered Price of Non-Geothermal Heating Alternative
A	≤0.4x alternate source
B	0.5–0.6x alternate source
C	1–0.6x alternate source
D	1–1.5x alternate source
E	≥1.5x alternate source

Market Sub-Attribute 3: Policies

Renewable energy policies such as feed-in tariffs (FITs), renewable portfolio standards (RPSs), and carbon emission limits (e.g., the former Clean Power Plan, *40 CFR Part 60 Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units; Final Rule*) can be large drivers of renewable deployment. FITs and RPSs are the most widely adopted renewable energy support policies around the world (Cox and Esterly 2016). As of 2013, 98 national and local governments had implemented FITs, a growth of nearly three times the number that had adopted them by 2004 (REN 21 2015). In the United States, RPSs are more common (see dsireusa.org); however, they are still large drivers of renewable deployment.

While RPSs tend to be driven by generation (MWh), some requests for proposals authorized by state legislatures or public utilities commissions are capacity-driven (MW) programs that favor solar and wind (e.g., Nevada SB 123 2013). For example, a capacity-driven program would treat a 20-MW wind farm (~35% capacity factor), a 20-MW solar plant (~25% capacity factor), and a 20-MW geothermal plant (~80% capacity factor) equally, despite the difference in MWh delivered. Even generation-driven (MWh) RPSs can favor specific renewables by having set-asides or multipliers for certain renewables.

Set-asides require the purchase of a certain type of renewable, so even when geothermal can compete on price, the policy may require the purchase of a more expensive alternative. Multipliers allow utilities to effectively lower their compliance standards if they use the specified technologies. For example, the Oregon RPS had a 2.0x multiplier for utilities that use solar PV to meet the RPS requirements through the end of 2015 (ORS 757.375(2)).

Policies supporting renewable heat sources are comparatively minimal worldwide compared to those existing for renewable energy. As of 2019, only 23 countries had national regulatory policies in place for renewable heating and cooling, most of which are in the European Union. A slightly larger proportion of countries had financial policies in place (Ferroukhi et al. 2020). In the United States specifically, some states have renewables tax credits or have integrated renewable heating sources into their RPS, but no comprehensive or national policies are in place (IEA 2018). As such, existing heat policies worldwide cannot be easily summed into various categories. However, as much of the world transitions to renewable energy sources, it is likely that more policies will be established that support geothermal (and other renewable) heat supplies.

Depending on the type of project (power or direct use), descriptions of the types of applicable government policies changes. Provide information for only the applicable sub-attribute(s) (market sub-attribute 3a and/or 3b). The grading scale, as seen in Tables 40 and 41, will change to reflect the applicability of sub-attributes 3a and 3b.

Market Sub-Attribute 3a: Policies (Power)

Government policies for electricity power generating geothermal projects are graded according to the type of policy in place and its orientation to geothermal energy. Table 46 depicts this scale, with an A grade corresponding to an FIT available for geothermal power generation, and an E grade corresponding to a complete lack of policies benefiting any form of renewable energy.

Table 44. Market Sub-Attribute Grades: Policies (Power)

Index	Description
A	Feed-in tariff for geothermal (standard offer contracts)
B	Interconnection set asides or RPS or state purchase requirement **specific for geothermal**
C	State renewable purchasing requirements or RPS—**not preferential to a particular renewable**
D	State purchasing requirements or RPS—**with preferential consideration or set- asides for nongeothermal renewables**
E	No policies beneficial to renewables (no RPS)

Market Sub-Attribute 3a: Policies (Direct Use)

Government policies for direct use projects are described in general terms in Table 47. This grading scale summarizes the level to which a policy may support geothermal direct use. Grade A corresponds to policies supporting geothermal direct use heat purchasing requirements, while grade E corresponds to policies that benefit non-renewable heat sources over any renewable energy.

Table 45. Market Sub-Attribute Grades: Policies (Direct Use)

Index	Description
A	National or local heat purchasing requirements or incentives specific to geothermal direct use
B	Renewable heat purchasing requirements/incentives for any kind of renewable heat
C	Renewable heat purchasing requirements/incentives favor other renewable heat sources over geothermal
D	No renewable heat purchasing requirements/incentives
E	National or local policies favor non-renewable heat sources over renewables

Market Sub-Attribute 4: Incentives

Much of the literature on geothermal incentives focuses on those programs that lower upfront exploration risk (e.g., Speer et al. 2014). Incentives, such as the grant-to-loan program in California (California PRC 3800 et seq.) favor smaller companies that do not have the risk tolerance of larger companies. Larger companies fund these exploration activities using their balance sheets. The wells funded by these grant-to-loan programs may have lower success rates than company-funded exploration, driving down overall industry success rates, making it harder for investors to trust geothermal investments. Others have suggested that programs, such as government-led exploration, would be more equitable for both large and small companies. Government could then recover the costs in public auctions. Additional incentives, such as the federal investment tax credit and the production tax credit can also be helpful.

Table 46. Market Sub-Attribute Grades: Incentives

Index	Description
A	Qualifies for federal or state incentives that offset exploration costs and reduce project risk (e.g., California's Geothermal Grant and Loan program, Alaska's Renewable Energy Grant program). Includes grant-to-loan programs and loan guarantees.
B	Qualifies for mix of both state and federal tax incentives AND financial incentives—includes grants, loans, and investment and productivity tax incentives
C	Qualifies for mix of both state and federal tax incentives (includes state property tax incentives)
D	Qualifies for either federal or state financial and tax incentives (not mixed), may require renewal of incentive
E	Does not qualify for state or federal incentives (no incentive available)

Market Sub-Attribute 5: Additional Revenue Sources

A project may be more financially viable if additional profit comes from side streams related to the geothermal plant. Excess heat not used by the power plant or primary direct use process can drive cascaded uses, producing an additional product or heating source for sale. Precious minerals can also be extracted from geothermal brines, such as lithium or sulfur (a byproduct of hydrogen sulfide purification). If an additional revenue stream is expected from the geothermal resource, the sub-attribute is graded more favorably.

Table 47. Market Sub-Attribute Grade: Additional Revenue Sources

Grade	Additional Revenue Expected?	Description
A	Yes	Additional revenue to come from mineral extraction, cascading heat use, or other secondary resource utilization
C	No	No additional revenue expected to come from secondary resource utilization

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