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Crossing the Barriers: An Analysis of Market Barriers to Geothermal Development and Potential Improvement Scenarios

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ABSTRACT

Developers have identified many non-technical barriers to geothermal power development, including market barriers. Understanding the challenges to market deployment of geothermal power is important since obtaining power purchase agreements is often cited as one of the largest barriers to geothermal development. This paper discusses the impacts to deployment caused by market challenges, including market demand, price of electricity, policies, and incentives. In this analysis, we graded these market challenges and identified barriers that have the potential to prevent development of geothermal resources. Potential improvement scenarios were identified that could assist with overcoming these barriers and lead to the deployment of additional geothermal resources by 2030 and 2050. The potential market scenarios include (1) support for an increase in renewable deployment, (2) support for an increase in baseload deployment, (3) support for an increase in geothermal deployment, and (4) changes in market conditions. The results show potential for geothermal deployment can be increased most significantly – in excess of 20% – with state and/or federal policies supporting geothermal deployment, similar to those that have previously been implemented for solar and wind. Additional increases in geothermal deployment – in excess of 100% – were observed when improvements scenarios were modeled in combination with improvements for other non-technical barriers, including land access and permitting.

1. Introduction

Geothermal developers involved in this study overwhelmingly comment that the power market – or the ability to obtain a competitive power purchase agreement (PPA) – was one of the largest drivers to geothermal project development. Wall and Young (2016) state that obtaining PPAs is the largest barrier to geothermal projects under development in the United States. To obtain a PPA, a power developer has to provide (among other things) two pieces of information:

1. A demonstrated resource (varies by technology) and,
2. An interconnection study/agreement (typically $50-150k for any technology).

Demonstrating the resource for geothermal is relatively expensive when compared to solar or wind.[1] Per experts interviewed for this analysis, demonstrating the geothermal resource is very expensive and requires multiple surveys (e.g., geophysical surveys, thermal gradient holes, full-size diameter drilling well). Each of these activities cost $1 million or more, resulting in $5 to $10 million to demonstrate a financially viable geothermal resource. Purchasers often require geothermal developers to demonstrate the size of the potential resource using a reservoir model and require third-party verification of the resource. Therefore, developers have to invest significantly more money into a geothermal project than a solar or wind project before knowing whether a PPA can be obtained, creating high up-front risk for geothermal projects. Because of this sunk pre-PPA cost, geothermal developers stated it is important that a competitively priced PPA (that would allow the project to be feasible) with favorable terms and conditions (e.g., no curtailment) be obtainable in order to avoid losses, and to proceed in a timely manner.

In 2015, the Geothermal Technologies Office (GTO) at the U.S. Department of Energy (DOE) initiated a vision study (GeoVision) to conduct analysis of potential growth scenarios across multiple market sectors (e.g. geothermal electric generation, commercial and residential thermal applications) through 2050. As part of the GeoVision, the National Renewable Energy Laboratory led an Institutional Barriers Task Force charged with analyzing non-technical barriers that create delay, increase risk, or increase the cost of project development. The non-technical barriers analyzed by the task force include land access, permitting, transmission, and market conditions. This paper focuses only on the impact to the deployment of geothermal resources due to barriers associated with the market challenges, including market demand, price of electricity, policies and incentives. Separate papers describe the results for each of the other non-technical barriers analyzed (Levine and Young, 2017a; Levine and Young, 2017b).

In this paper we discuss:

- The methodology used to analyze market barriers, including analyzing the market as an "attribute" to geothermal development;
- The sub-attributes that make up the market attribute and a description of the barriers caused by each sub-attribute for geothermal development;

[1] e.g., using the National Solar Radiation Data Base (Renné et al., 2008) or a turnkey solar radiation or wind assessment system (e.g., NRG Systems)

- The influence that market barriers have on the deployment of identified and undiscovered geothermal resources; and
- Potential improvement scenarios to overcome market barriers that may prevent geothermal development.

2. Methodology

2.1 The GeoRePORT System

The GeoRePORT System was developed to address the need of the GTO to track and measure the impact of research, development, and deployment funding for GTO-funded geothermal projects (Young et al., 2015). While other geothermal reporting systems exist, such as the Australian and Canadian Geothermal Reporting Codes (AGEA and AGEG 2010, CanGEA 2010) and the United Nations Framework Classification (UNFC) System (UNECE, 2013), the GeoRePORT System is unique in providing a detailed system for reporting both the resource grade and the project progress, or "readiness level," and is particularly useful for describing early-stage exploration projects. The analysis presented in this paper discusses only resource grade, and not project readiness levels. GeoRePORT is comprised of three assessment tools: Geological, Technical, and Socio-Economic. Each of the assessment tool's resource grades is divided into attributes and sub-attributes that describe the characteristics that contribute to feasibility of project development (Figure 1).

Previous work focused on the development of the Geological Assessment Tool (GAT, Young et al., 2015), the Technical Assessment Tool (TAT, Badgett and Young, 2016), and the Socio-Economic Assessment Tool (SEAT, Levine and Young, 2016). This paper focuses on use of the SEAT to analyze market barriers. Related research and final draft protocol documents for all three tools can be found on the GeoRePORT website (http://en.openei.org/wiki/GeoRePORT).

In addition to the character grade (A-E) for each attribute, the GeoRePORT resource grading system includes an activity index and an execution index. The activity index describes the common activities used to understand the character attributes – both directly (measured values) and indirectly (proxy). The activity index is graded from A–E as well, with E representing the lowest level of certainty. For example, an activity grade of B (high certainty) for marketing may be that a power purchase agreement has been secured.

For the purposes of the baseline analysis conducted for this GeoVision Study, the activity grade is E. This reflects that the data used are national-level spatial datasets and datasets we created based on our general knowledge of a state or region. Developers who begin exploration in a specific area will certainly research each attribute and sub-attribute in greater detail. This research may change (increase or decrease) the reported resource grade, and would increase the activity index, indicating a greater certainty in the reported market character grade.

For the GAT and TAT, the grades also make use of an execution index, describing how well an activity (e.g., geothermometry) was implemented. The execution index is not used in the reporting of Socio-Economic resource grades.

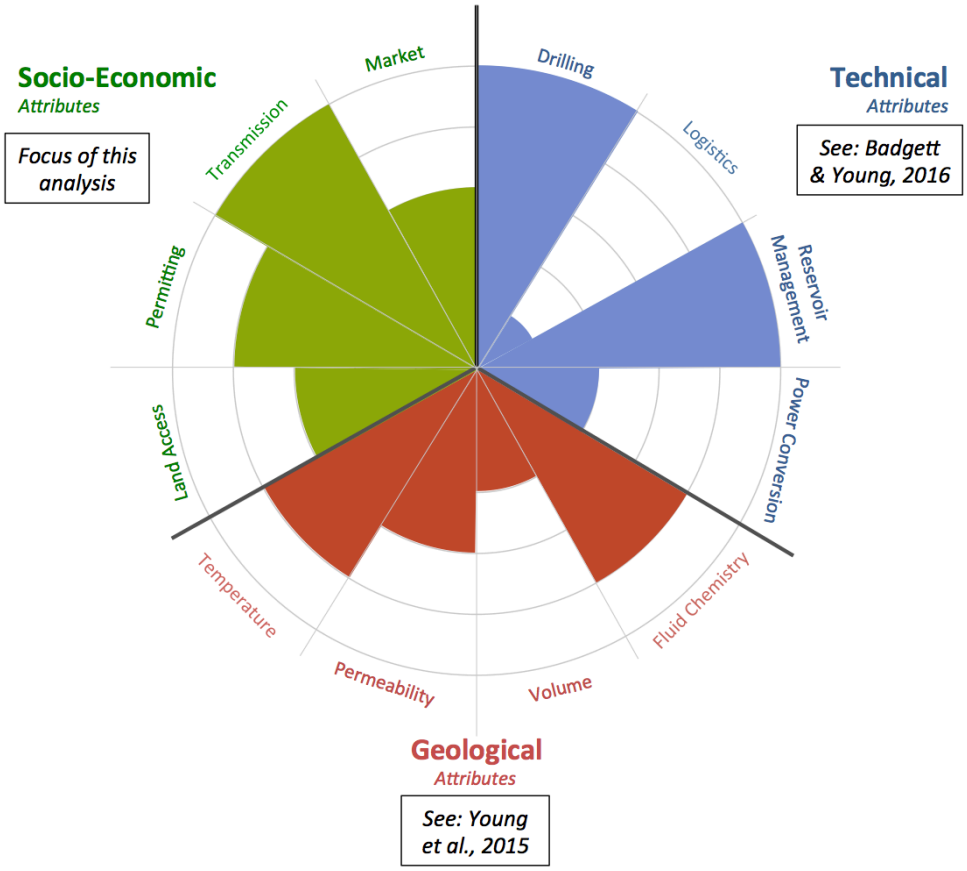

Figure 1. ***Resource Grades*****. The grade of a resource can be described as a combination of intrinsic features of the resource that contribute to economic viability. The GeoRePORT System allows developers to assign grades to each of twelve attributes, providing a clear picture of the development potential and challenges at each location. The highest grade, A, is represented as a full pie piece; the lowest grade, E, is represented as the smallest pie piece. Geological attributes include temperature, volume, permeability, and fluid chemistry. Technical attributes include drilling, logistics, reservoir management, and power conversion; socio-economic attributes include land access, permitting, transmission, and market. Sub-attribute grades, activity and execution indices are not reported in this graphic.**

2.2 Use of the GeoRePORT to Analyze Institutional Barriers

The Socio-Economic Assessment Tool (SEAT) of GeoRePORT includes four attributes: Land Access, Permitting, Transmission, and Market, each of which includes sub-attributes. The sub-attributes are assigned grades which, when combined, provide a single character grade for each attribute. As mentioned, the Market attribute has four sub-attributes: market demand, price of electricity, policies and incentives. Each sub-attribute is graded from A-E. An example for the policy sub-attribute may be reported is shown in Table 1.

Table 1. Character Grades and Descriptions for the GeoRePORT Policy Sub-Attribute.

Policy Sub-Attribute Character Grade	Description
A	Feed-in tariff for geothermal (standard offer contracts)
B	Interconnection set-aside or RPS or state purchase requirement **specific for geothermal**
C	State renewable purchasing requirements or renewable portfolio standard (RPS) - **not preferential to a particular renewable**
D	State purchasing requirements or RPS - **with preferential consideration or set-asides for non-geothermal renewables**
E	No policies beneficial to renewables (no policies)

Each sub-attribute (SA) is given a weight (wt), and the total sub-attribute-weighted sum is calculated as:

$$\text{Sub-attribute-weighted sum} = SAgrade_1 * wt_1 + SAgrade_2 * wt_2 + \ldots + SAgrade_n * wt_n \qquad \text{(eq 1)}$$

where sub-attribute grades of A=5 and E=1. The range of attribute-weighted sums corresponds to grades A-E for each attribute. For example, for the market attribute, the maximum weighted sum (if all grades are A) is 30, while the minimum weighted sum (if all grades are E) is 6. The breakdown of grades based on weighted sum is shown in Table 2.

Table 2. Character Grades for the GeoRePORT Market Attribute including descriptions and corresponding sub-attribute weighted sum. The grades for all sub-attributes are multiplied by the corresponding sub-attribute weight, then added together to calculate the sub-attribute-weighted sum. This sum is then used to determine the attribute character grade using this table.

Market Attribute Character Grade	Description	Sub-attribute Weighted Sum
A	Favorable Market Conditions	>26
B	Manageable Market Conditions	21-25
C	Acceptable Market Conditions	16-20
D	Difficult Market Conditions	11-15
E	Very Difficult Market Conditions	<10

For the Policy sub-attribute example, the grade would be reported using one of the activity indices listed in Table 3.

Table 3. Market Activity Index. For each Market sub-attribute, an activity grade is assigned using the following index. It is often the case that all sub-attributes will have the same activity grade.

	Market Attribute Activity Index	Description
Higher certainty	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.
Lower certainty	E	Market grade is estimated using publically available information and data.

2.3 Institutional Barriers Expert Team

For the institutional barriers analysis we assembled a barriers expert team (BET) of geothermal experts from industry and federal agencies to provide regular, scheduled input and review of our methodology and results through monthly meetings and document review (see *Acknowledgments*).

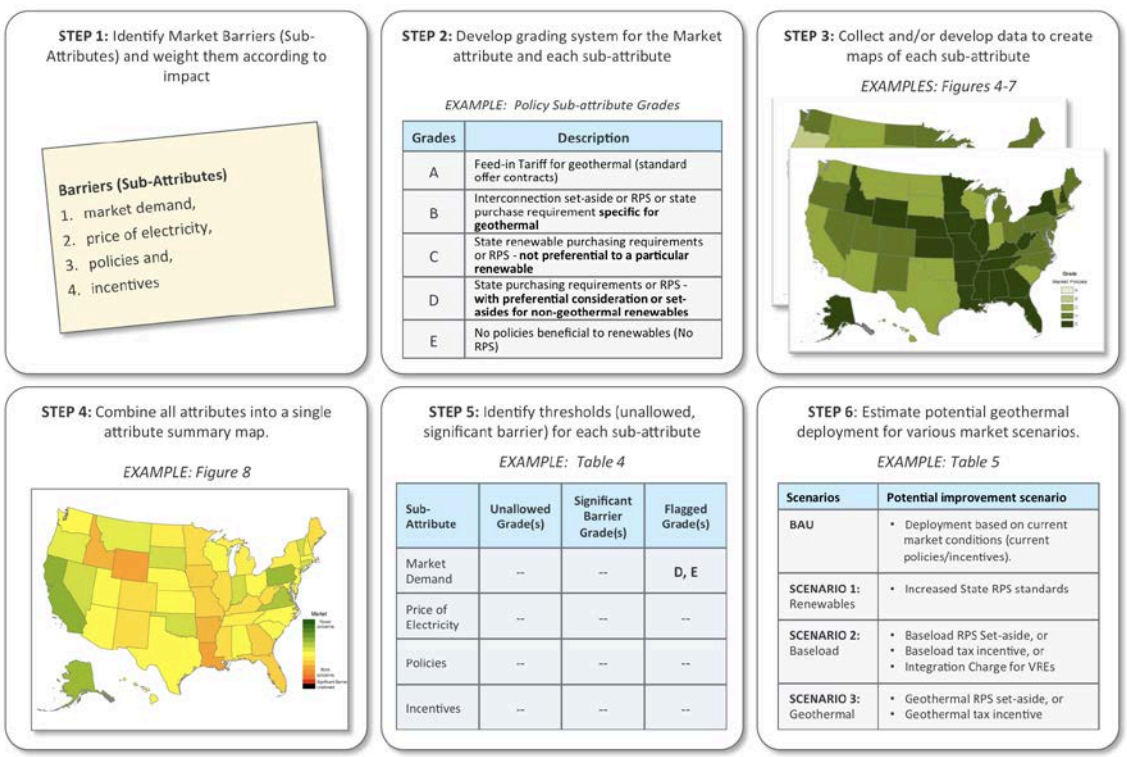

Figure 2. Barriers Analysis Process. Diagram shows the steps in the process of identifying barriers, developing a grading system, mapping the data, and analyzing the impact on geothermal development potential.

We began by creating the socio-economic attributes and sub-attributes to reflect the non-technical barriers faced by the geothermal industry, as shown in Figure 2, Step 1. We then created a grading system, providing each sub-attribute with a descriptive, objective qualifier for letters A-E, with E reflecting the most difficult barrier for the sub-attribute (e.g., Table 1 and Figure 2, Step 2). After grading each sub-attribute, we created a grade from A-E for each attribute that reflects the weighted sums of the sub-attributes to reflect the most difficult barrier for the attribute (e.g., Table 2).

Next, we collected and/or created data to map each sub-attribute for the United States. We then interviewed developers and members of the BET to understand their criteria for decision-making on geothermal projects, recording specific situations they would currently consider *unallowed*, *significant barrier* or might raise *flags* for project development. For the market attribute, the BET identified no *unallowed* sub-attribute grades, no developer-identified *significant barrier* sub-attribute grades, and 2 *flagged* sub-attribute grades. For example, the BET said they would consider low market demand (grades D, E) to be *flagged* situations (Table 4).

The BET also assigned weights to each of the sub-attributes based on the sub-attributes' contribution to development barriers. Sub-attributes that had the potential to raise flags (e.g., poor market demand) were given higher weights than those that caused less significant barriers (e.g., incentives).

The results of these analyses are presented in Section 3.

After completing this process, we combined the sub-attribute maps into a single market attribute map (Figure 14) using the BET-defined sub-attribute weights. The attribute map reflects the attribute grade (i.e., weighed sum of the sub-attribute grades), including all of the areas where development was *unallowed*. All maps are available on Geothermal Prospector (https://maps.nrel.gov/geothermal-prospector) and the Geothermal Data Repository (https://gdr.openei.org).

The market attribute summary map is presented in Section 4.

2.4 Market Penetration Modeling Methodology

The market penetration modeling requires a geospatial representation of the resource and its cost. Therefore, the next step was to develop geothermal supply curves using the resource assessment methodology described above in conjunction with the Geothermal Electricity Technology Evaluation Model (GETEM). GETEM is an Excel-based tool used to estimate the levelized cost of energy (LCOE) for definable geothermal scenarios, as shown in Figure 3.

These supply curves were used as input (using several scenarios) into NREL's Regional Energy Deployment System (ReEDs) to understand how these barriers impact potential deployment of geothermal power in the United States (http://www.nrel.gov/analysis/reeds/). The ReEDS model is a long-term capacity model for the deployment of electric power generation technologies and transmission infrastructure throughout the contiguous United States. It was designed to analyze critical issues in the electric sector, especially with respect to potential energy policies, such as clean energy and renewable energy standards or carbon restrictions.

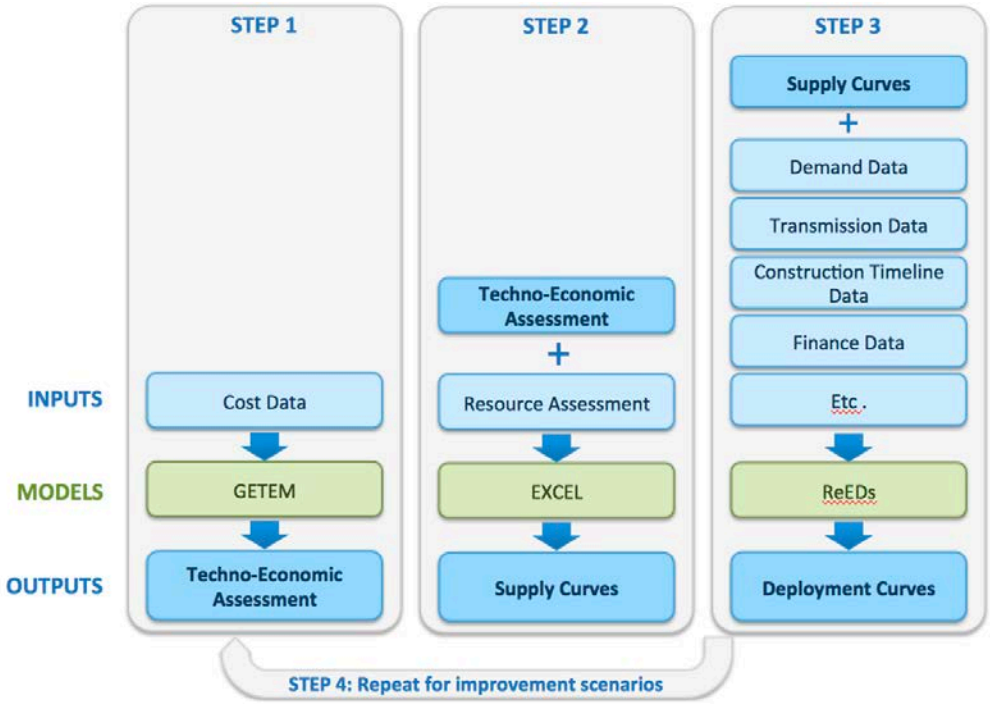

Figure 3. Market Penetration Modeling Process. Diagram shows the steps in the process of running various scenarios, including Business-As-Usual scenarios (including non-technical barriers) and Improvement Scenarios (including potential for reducing these non-technical barriers). The ReEDs model competes geothermal deployment with other renewable and non-renewable resources.

ReEDS provides a detailed representation of electricity generation and transmission systems and specifically addresses a variety of issues related to renewable energy technologies, including accessibility and cost of transmission, regional quality of renewable resources, seasonal and diurnal load and generation profiles, variability and uncertainty of wind and solar power, and the influence of variability on the reliability of electric power provision (Eurek et al., 2017).

The GeoVision utilized a combination of ReEDS and GETEM to forecast both baseline deployment scenarios and potential improvement scenarios for geothermal deployment in the contiguous United States.

The results of the market penetration modeling for Business-As-Usual (i.e., current conditions) and Market Improvement scenarios are presented in Section 5.

3. Analysis of Geothermal Market Barriers

We identified four sub-attributes that most significantly contributed to the ability to obtain PPAs:

1. Market Demand
2. Price of Electricity
3. Policies
4. Incentives.

This section discusses the definition of each Market sub-attribute grade and the results of mapping the grades for each Market sub-attribute. Each mapping activity was vetted with stakeholders during this process. At the conclusion of this section, we map the combined impact.

3.1 Barrier 1: Market Demand

Assessing future demand for additional electricity is important to identifying markets that could have an appetite for geothermal-produced electricity.[2] 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 electricity portfolio through planned retirements. These factors were evaluated by:

1. Calculating a 3-year cumulative annual growth rate (CAGR) for electricity demand by state, utilizing historical electricity consumption by state as reported by the Energy Information Administration (EIA) from 2011 to 2014,
2. Calculating a 10-year CAGR for projected electricity consumption by state using data from EIA's 2015 Annual Energy Outlook (EIA, 2015) for 2015 to 2025, and
3. Evaluating planned retirements of coal and natural gas power plants as reported in the ASEA Brown Boveri (ABB) Energy Velocity Suite power plant database (ABB, 2016). Only currently operating power plants with planned retirement dates between 2016 and 2026 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 2% to 5% increase were graded either C or D; and states with <2% increase were graded E. The higher or lower grade within each category was determined by whether the 3-year historical CAGR was significant (greater or lesser than 5% for grades A and B; greater or lesser than 2% for grades C and D).

No areas are considered *unallowed* for this sub-attribute, but regions that are believed to have little or no need for additional electricity production by 2030 are considered *flags*. Within a state; however, there may be areas of higher demand potential that are not captured by this analysis. Additionally, developers may develop a project in one state and sell the power in another. The results are shown in Figure 4.

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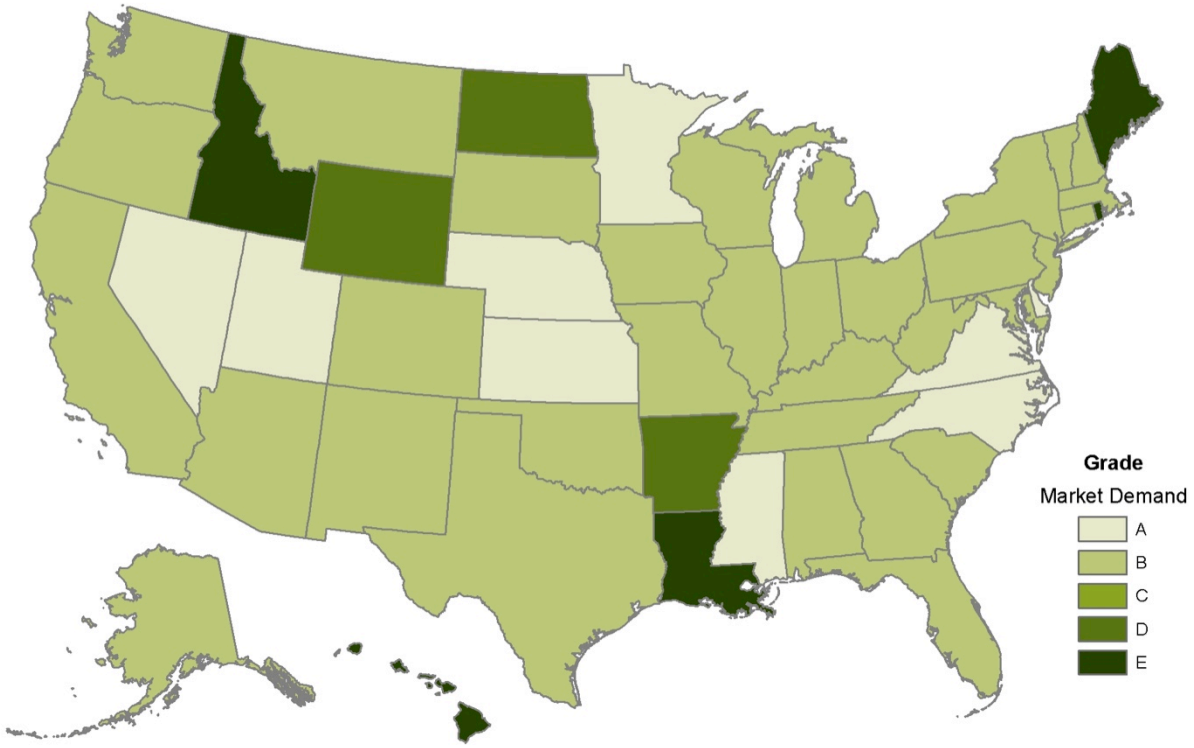
[2] Often, market demand is reviewed at a regional level (e.g., the ReEDS model discretizes the U.S. into 356 regions), but given available data, market demand was evaluated at the state level. This was identified as an area for improvement in future work.



A	Strong current & long-term electricity demand (either usage increase or from retirements)	
B	Current demand & strong long-term demand (either usage increase or retirements)	
C	Moderate current & long-term demand (either usage increase or retirements)	
D	Current & long-term demand uncertain OR peak load only (e.g., high solar/wind states)	Flag
E	Neither current nor long-term demand (e.g., energy market shrinking)	Flag

Figure 4. ***Map of Market: Demand Sub-attribute.*** **This map represents an activity level of E, with a weighting factor of 1 in the Market attribute summary map.**

3.2 Barrier 2: Wholesale Price of Electricity

Using the wholesale price of electricity as a Market sub-attribute provides a better understanding of the price point a geothermal power plant may need to reach to make a profit (Figure 5). The wholesale electricity price generally reflects the marginal cost of generating electricity and delivering it through the transmission system. The prices for 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 power plant would currently receive, depending on the impacts of system constraints on the wholesale price.

We calculated the average geothermal 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[4], and were associated with each state based on proximity and regional transmission organizations (RTO). In the southeast, where there are no electricity pricing hubs, the national average price was assigned.

Although prices presented here are represented on a state-level, 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.

The map in Figure 5 shows that for the majority of the western United States, where the hydrothermal resources are located, wholesale prices for electricity are the lowest grade (E) in the country. The exceptions would be Hawaii and Alaska (grade A) and California (grade D).

3.3 Barrier 3: Policies

Renewable energy policies such as FITs, RPSs, and carbon emission limits 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 (REN21 2015).

In the United States, RPSs are more common (see dsireusa.org). They are a large driver of renewable deployment, as they regulate intrastate electricity markets (Barbose, 2017). RPS programs require certain retail suppliers of electricity – regulated utilities included – to procure a percentage of their generation from specified renewable resources by a stated date. These standards often preclude the use of existing, or new large-scale hydroelectric generation, in favor

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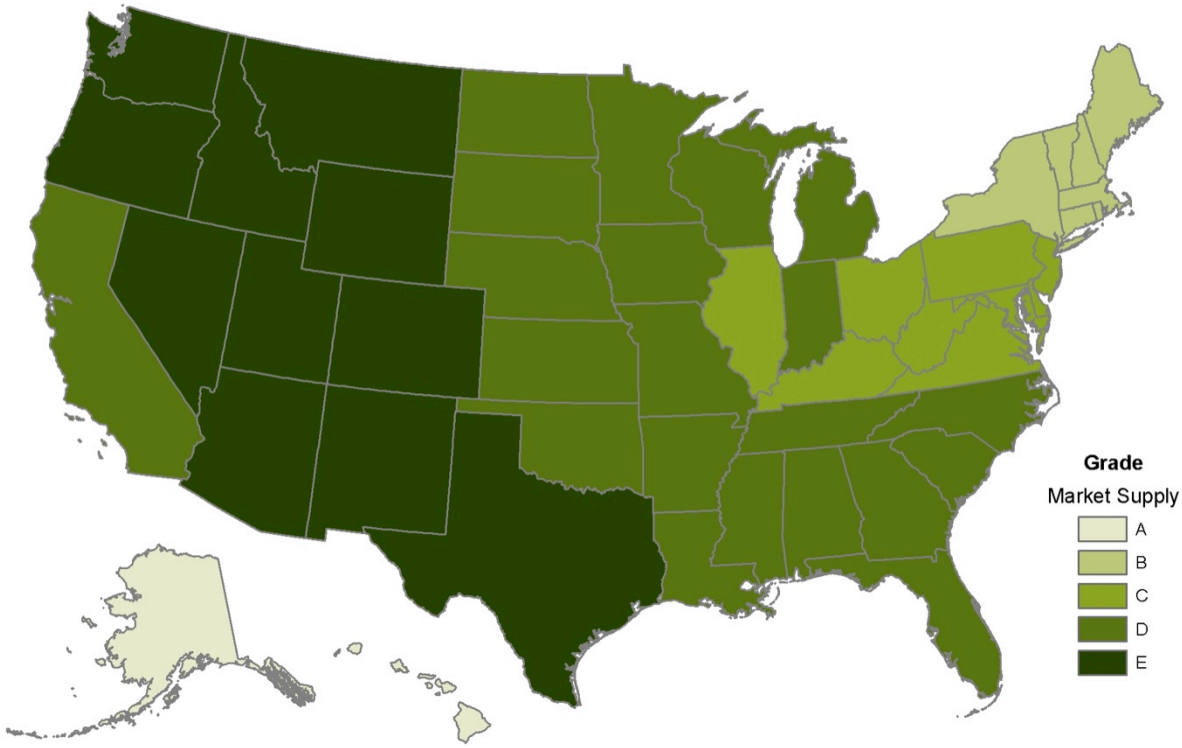
[3] PPA prices are a compilation of public press statements and reports. This work was expanded upon and used as a basis for Hernandez, Richard, and Nathwani (2016).
https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2016/Hernandez1.pdf
[4] http://www.eia.gov/electricity/wholesale/

of the adoption of other forms of renewable generation. [5] In addition, these programs often ramp up requirements in a stepwise fashion where suppliers have low requirements in early years and higher requirements in future years.



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 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	*(no flags/no-gos)*

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

Figure 5. ***Map of Market: Wholesale Price of Electricity Sub-attribute.*** **This map represents an activity level of E, with a weighting factor of 1 in the Market attribute summary map.**

[5] RPS requirements developed by states may exclude hydropower installed before the date of enactment of the RPS or another specified date, limit the type of hydropower that qualifies for the RPS, or even exclude hydropower installations from the RPS entirely. For example, California's RPS excludes hydropower facilities greater than 30 MW (or 40 MW if operated as part of a water supply or conveyance system) (California Energy Commission, 2017) and New Mexico's RPS limits hydropower eligibility to facilities brought into service after July 1, 2007 (NMAC 17.9.572).

Iowa adopted the first RPS in 1983 and today 29 states and the District of Columbia have a mandatory RPS in place, with most states adopting standards between 1997 and 2008 (Barbose, 2017). Lawrence Berkeley National Laboratory has tracked RPS requirements and compliance dating back to 1999 and demonstrated that compliance with these programs required at minimum 147 Terawatt hours (TWh) of renewable generation in 2016. State RPS requirements as of July 2016 are expected to result in 40% renewable energy penetration (including hydropower) in the United States by 2050, whereas without these requirements (using RPS requirements as of 2014) the 2050 generation mix would likely see around 34% renewable penetration (Mai et al., 2016).

In early years, RPS requirements and total non-hydro renewable generation were closely linked, but since 2008 more non-hydro renewable generation has been deployed than is required by RPS programs. Some of this separation results from regulated utilities installing qualifying renewable energy to meet future compliance years. In addition, the declining cost of renewable energy has encouraged voluntary procurement. Nevertheless, RPSs represent a minimum threshold for renewable deployment and these policies have been influential on the power market.

Geothermal power hasn't always benefitted from RPSs. While RPSs tend to be driven by generation (MWh), some requests for proposals authorized by state legislatures or public utilities commissions (PUCs) 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 if geothermal power 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)).

Similarly, the *Clean Power Plan* had credit multipliers or would have provided extra allowances for states who use wind and solar to comply with the state's clean power plan requirements in 2020 and 2021 under the Clean Energy Incentive Program to encourage early investment (40 CFR Part 60).[6]

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[6] On March 28, 2017, President Trump signed an Executive Order titled Promoting Energy Independence and Economic Growth. In part, the Executive Order requires the Administrator of the Environmental Protection Agency to review the final rule entitled "Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units" 80 Fed. Reg. 64661 (October 23, 2015) commonly referred to as the Clean Power Plan (CPP). The review must consider whether the CPP is consistent Trump Administration policy that existing regulations not potentially burden the development or use of domestically produced energy resources. If a review finds that the CPP does burden the development or use of domestically produced energy resources the Administrator is directed to publish for notice and comment proposed rules to suspend, revise, or rescind the CPP (Executive Order Promoting Energy Independence and Economic Growth).

Seventeen states (e.g., NV, AZ, CO) and the District of Columbia have adopted solar or distributed-generation carve outs that supported the role of solar in serving RPS demand (Barboase, 2017). In 2016, 5.5 TWh of solar generation was deployed to meet these carve-out requirements. Experts interviewed stated that these set-asides and multipliers have prevented geothermal power from competing in the market, allowing more expensive renewable technologies to be deployed when geothermal would have been more economically competitive (e.g., Figure 6).

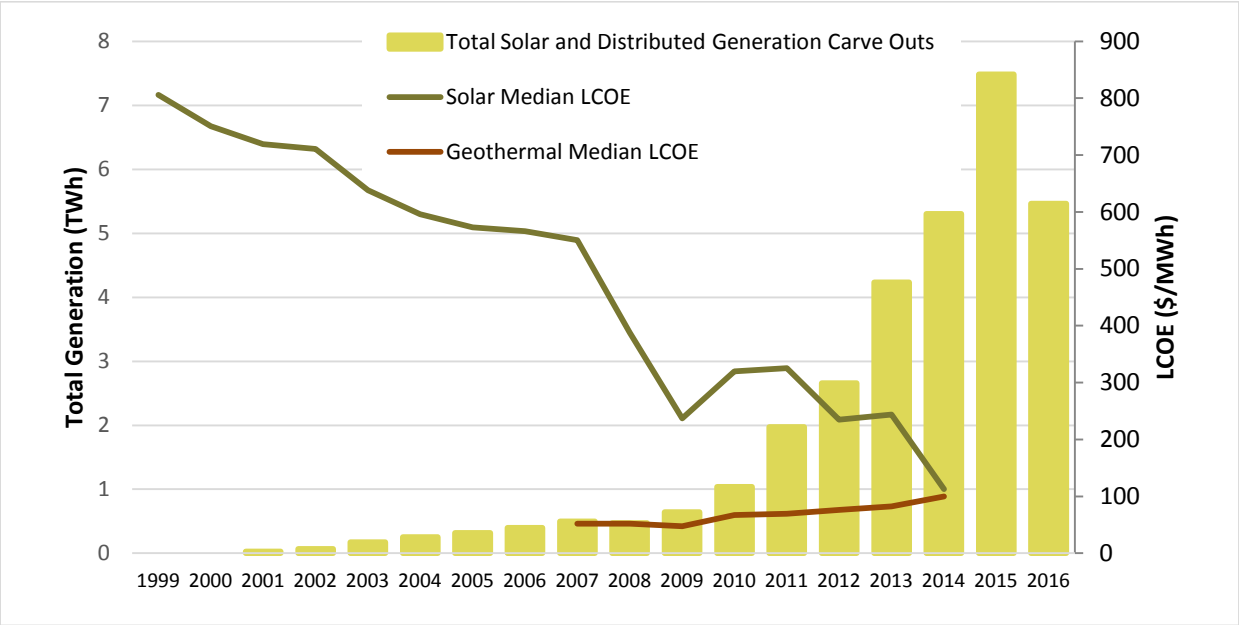


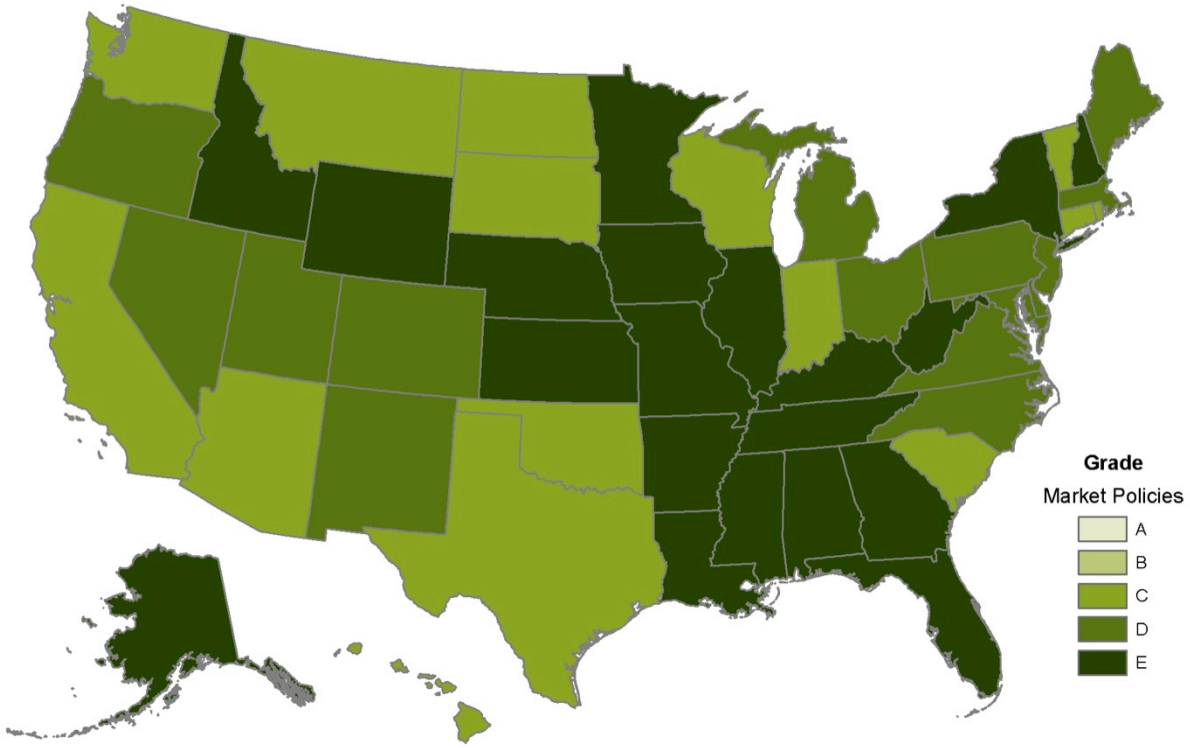
Figure 6. Solar and distributed generation carve out requirements from 1998 – 2016 (Barbose, 2017) and median LCOE for solar and geothermal (OpenEI, 2014; NREL, 2016).

The map in Figure 7 outlines the different policy conditions for geothermal development projects. Voluntary renewable goals (e.g., Virginia's voluntary RPS goal of 15% of 2007 consumption) are not included in these grades. While there aren't any *unallowed* or *significant barrier* conditions indicated, there also aren't any grade A or grade B market policies for geothermal. In fact, 8 of the 13 western states with the greatest potential are grades D (preferential treatment for other renewables) and E (no policy support).

3.4 Barrier 4: Incentives

Effective incentives can be drivers for renewable deployment, as well. For instance, as highlighted in the *Wind Vision Study* (DOE, 2015) and illustrated in Figure 8, tax credits played a noticeable role on wind deployment over time. Extensions of the production tax credit (PTC) drove deployment, while expiration stalled wind installations. Historically, the PTC has expired and then been renewed for short timeframes relative to geothermal development timeframes and at uncertain intervals (Figure 9), and thus has not been a primary driver of geothermal project development (Doris et al., 2009). Because geothermal projects take 5-7 years to plan, developers

cannot start a project and rely on a 2-year PTC extension to balance the finances of a project (e.g., PTCs of 2004, 2005). The lesson learned is that for tax incentives to be impactful for geothermal deployment, they must have certainty and longevity.



A	Feed-in Tariff for geothermal (standard offer contracts)	
B	Interconnection set-aside 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 non-geothermal renewables**	
E	No policies beneficial to renewables (No RPS)	*(no flags/significant barriers)*

Figure 7. *Map of Market: Policies Sub-attribute.* This map represents an activity level of E, with a weighting factor of 2 in the Market attribute summary map.

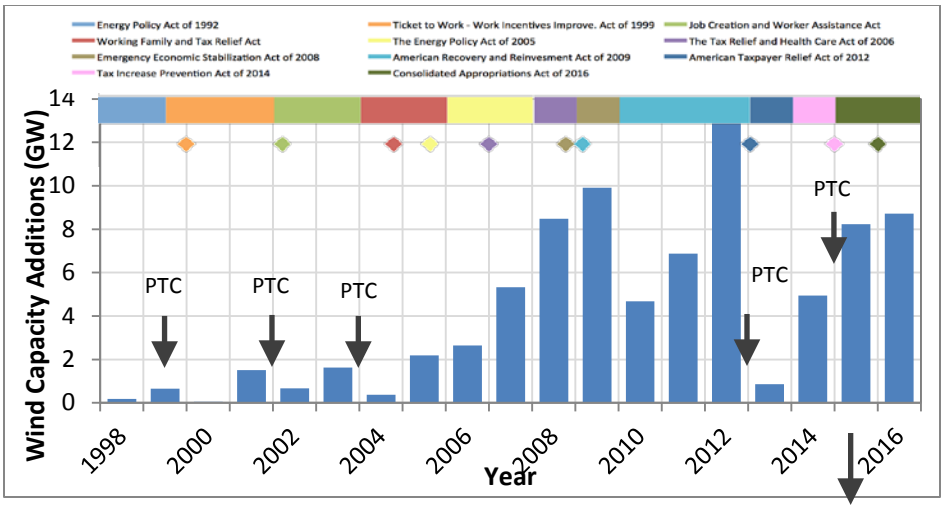


Figure 8. The effect of incentives on wind deployment in the United States between 1997 and 2014. Wind capacity additions each year are shown in blue columns. The bar graph at the top shows when policies were enacted (diamonds), and the eligibility window (corresponding color bar). The figure suggests a strong correlation between tax credit availability and wind deployment. When the tax credit expires, a drop off in wind development is observed. Because of the short development timeframe for wind projects (less than 1 year), these projects are better positioned to take advantage of short PTC extension timeframes. The latter two PTC expirations at the end of 2013 and 2014 appear to have little impact on deployment, suggesting the PTC may no longer be as significant a driver of wind deployment. Deployment data: (EIA, 2017b). PTC data: (Sherlock, 2015).

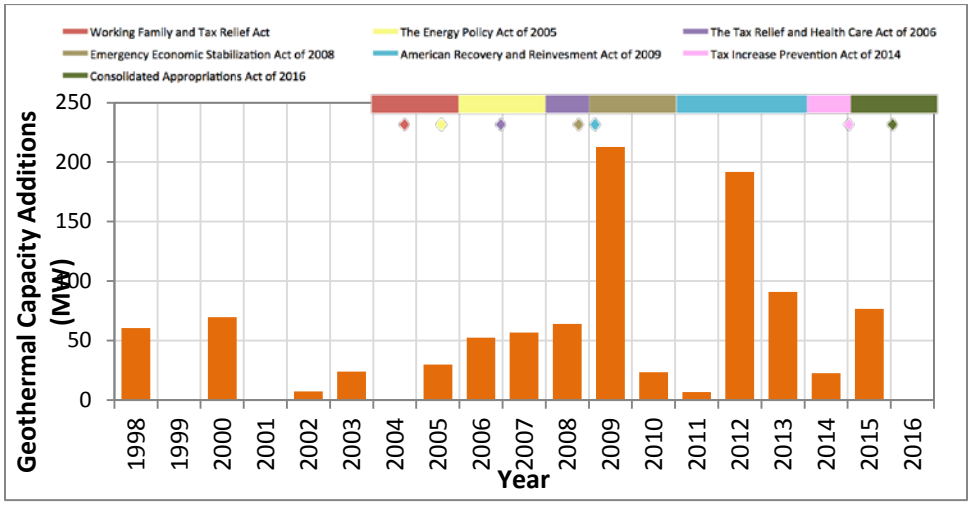


Figure 9. ***Impact of Incentives on Geothermal Deployment.*** **Geothermal capacity additions each year are shown in orange columns. The bar graph at the top shows when policies were enacted (diamonds), and the eligibility window (corresponding color bar). Both the Working Family and Tax Relief Act (red) and the Tax Increase Prevention Act of 2015 (pink) had retroactive eligibility windows. Of the six extensions, only one, the American Recovery and Reinvestment Act of 2009 provided certainty of the PTC for 5 years (through the end of 2013), the shortest time frame for geothermal power development. This suggests that plants that were already planned an in the development process could have taken advantage of the PTCs, but new geothermal projects couldn't rely on the PTC being available when the plant went into production. Deployment data: (EIA, 2017b). PTC data: (Sherlock, 2015).**

Though these data suggest that both technologies have been able to utilize the tax incentives, it appears to have been more impactful in influencing wind deployment. This is also illustrated in Figure 10, which shows the amount of tax credits paid out to energy projects from for the same time frame (1998-2015). Wind projects received approximately $10 billion total between 2006 and 2015. Total wind tax credits received under the PTC are expected to reach $34 billion by 2020. By comparison, reported payouts for geothermal projects are estimated at less than $50 million a year (or less than $5 billion) for the same period (2006-2015) (Joint Committee on Taxation, 2017; Department of the Treasury, 2017; Dinan, 2017).

The latest legislation to extend the 30% tax credits was the Consolidated Appropriations Act of 2016, which created a five-year extension and phase out for the wind energy PTC. In addition, the Act extended the solar investment tax credit (ITC) for five years (*see* Section 301 and 302 of the Consolidated Appropriations Act of 2016). The geothermal ITC currently is only 10%, and was phased out for geothermal power plants not put into service before the end of 2016 (*see* 26 USC § 48 and Consolidated Appropriations Act of 2016).

The wind tax expenditures curve correlates with the data presented in Figure 8: with consistent tax credits starting in 2005, we see increasing tax expenditures for wind. The dip in 2014 in this curve reflects the expiration of the tax credit in 2014. Due to relatively long development timeframes and short extension windows of the tax credit, geothermal projects were not able to utilize the tax credit. Credits received by oil and gas are for exploration and development in early phases of project development and prove to be effective for this industry (Joint Committee on Taxation, 2017; Department of the Treasury, 2017; Dinan, 2017). A tax incentive similar to oil and gas credits may be a more effective tool for geothermal projects, as it would also help to reduce upfront exploration risk.

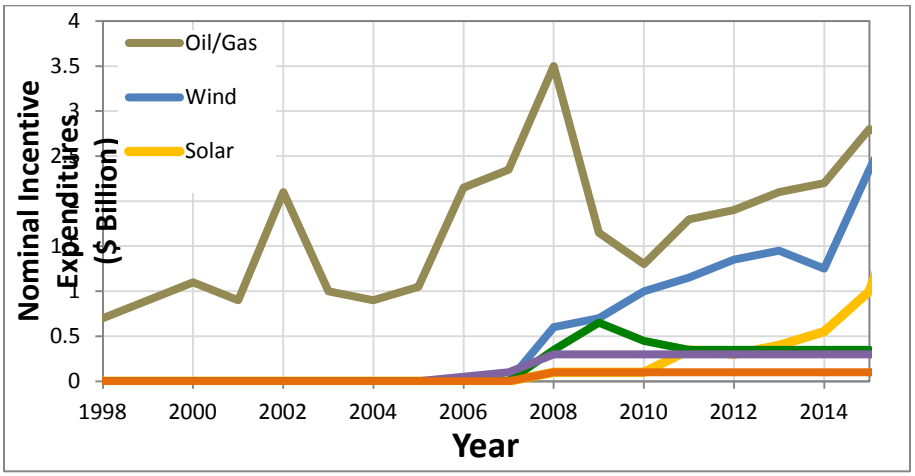
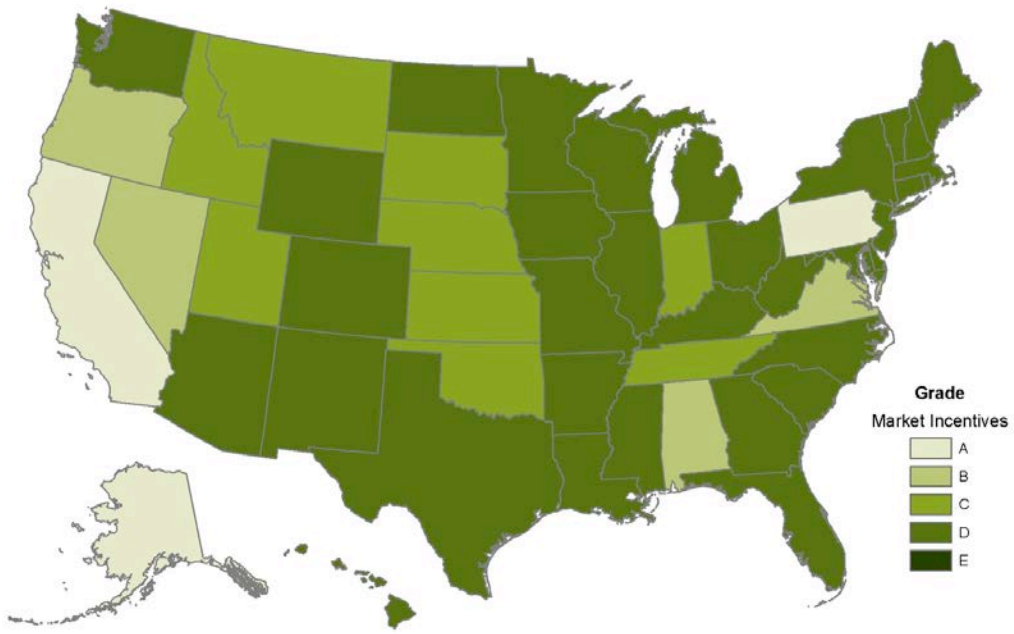


Figure 10. Federal tax expenditures by energy projects. Wind, solar, biomass, coal, and geothermal were eligible for tax credits. The wind tax expenditures curve correlates with the data presented in Figure 8: with consistent tax credits starting in 2005, we see increasing tax expenditures for wind. The dip in 2014 in this curve reflects the expiration of the tax credit in 2014. Due to relatively long development timeframes and short extension windows of the tax credit, geothermal projects were not able to utilize the tax credit. Credits received by oil and gas are for exploration and development in early phases of project development and prove to be effective for this industry. This type of tax incentive may be a more effective tool for geothermal projects, as it would also help to reduce upfront exploration risk. (Data: Joint Committee on Taxation, 2017; Department of the Treasury, 2017; Dinan, 2017)

Much of the literature on geothermal incentives focuses on those programs that lower upfront exploration risk (e.g., Speer et al., 2014; Sanyal et al., 2016). These types of incentives were mapped as grade A in our system (Figure 11). Developers noted that some of these incentives, such as the grant-to-loan program in California (California PRC 3800 et seq.) favor smaller companies who do not have the risk tolerance of larger companies. Larger companies fund these exploration activities using their balance sheets. The wells funded by these loan-to-grant programs may have lower success rates than company-funded exploration. This drives the overall industry drilling success rates down, increasing the perceived investment risk for investors. Developers suggested that other programs, such as government-led exploration, would be more equitable for both large and small companies, and could potentially have higher success rates. Government could then recover their costs in lease auctions.



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)	*(no flags/significant barriers)*

Figure 11. ***Map of Market: Incentives Sub-attribute.*** **This map represents an activity level of E, with a weighting factor of 2 in the Market attribute summary map.**

As discussed, the tax incentives can be effective drivers of deployment. Geothermal developers interviewed suggested that the ITC is more impactful than the PTC, because developers can recover their capital costs more immediately after construction commences, and construction timeframes are no longer an issue. The ITC or the PTC can be used even if the developer does not have sufficient tax appetite, because a third-party tax equity investment can be utilized to monetize the tax benefits.

The remaining incentive grades mapped in Figure 11 show a mix of federal and state incentives for grades B-D and no incentives for grade E. In evaluating the incentives, a 20-MW project size threshold was utilized, and incentives intended for smaller plants are not included.[7] There are no *flags*, *significant barriers* or *unallowed* situations within the Incentive sub-attribute.

3.5 Barrier 5: Funding for Research, Development & Deployment

An additional policy that can influence deployment is funding for research, development and deployment (RD&D). Though deployment and cost reductions are driven by many factors (e.g., policies, incentives as discussed) RD&D funding (e.g. through a country- or state-funded RD&D program, or through private investment in RD&D) can have an impact on deployment. Historical budgets for energy technologies are shown in Figure 12. This figure shows a surge in geothermal funding in the 80s, a surge in oil and gas funding in the 90s, a surge in solar funding since 2006, and consistently high funding for coal.

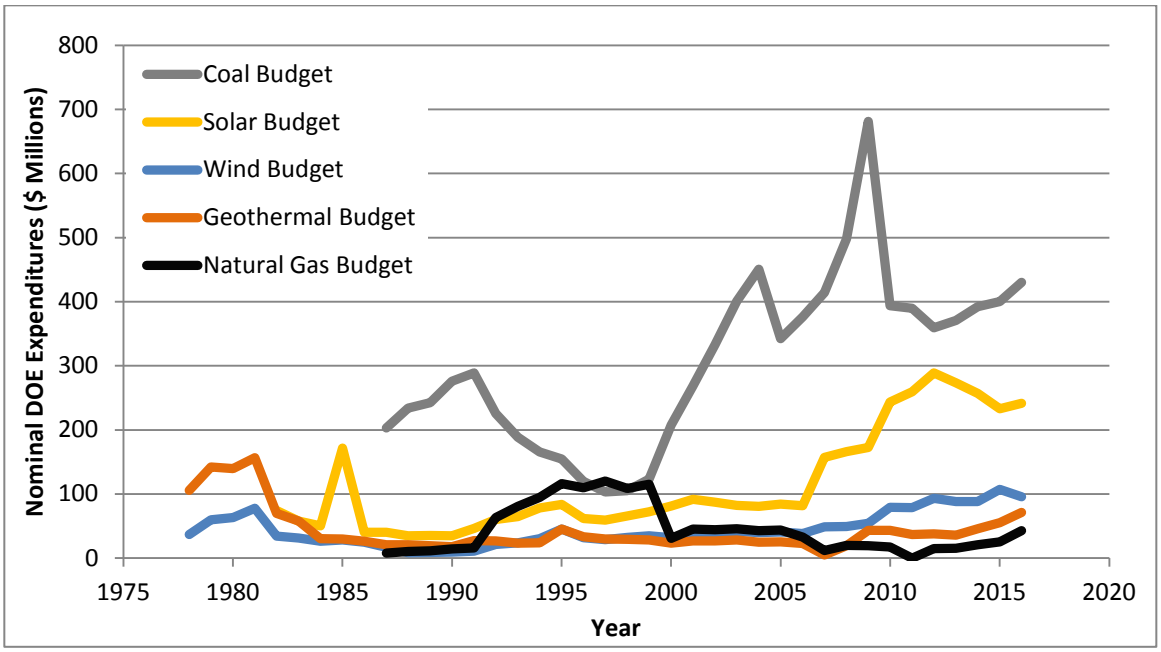


Figure 12. Federal spending on energy technologies. This graph shows a surge in geothermal funding in the 80s, a surge in oil and gas funding in the 90s, a surge in solar funding since 2006, and consistently high funding for coal. (DOE, 2017).

[7] The DSIRE database is the primary source of information on these incentives, but may not be complete. For example, the California grant-to-loan program is not listed in DSIRE.

Historically, there has been a correlation between deployment of renewable energy and RD&D support from the federal government (DOE, 2017; EIA, 2017b). As seen in Figure 12 and Figure 13, DOE funding for geothermal increased to its highest levels in the late 1970s and early 1980s. The spike in funding was a response to the oil crisis of the 1970s when the government was searching for forms of energy that were not dependent on fossil fuels. The increase in funding for geothermal energy was subsequently followed by a sharp rise in the deployment of geothermal energy five to ten years after the increase in funding. The deployment lag is the result of a typical geothermal power plant requiring several years of exploration, permitting, and construction before the plant can become operational. Increase in deployment post 2009 are likely correlated with 2009 funding from the American Reinvestment and Recovery Act (DOE 2017).

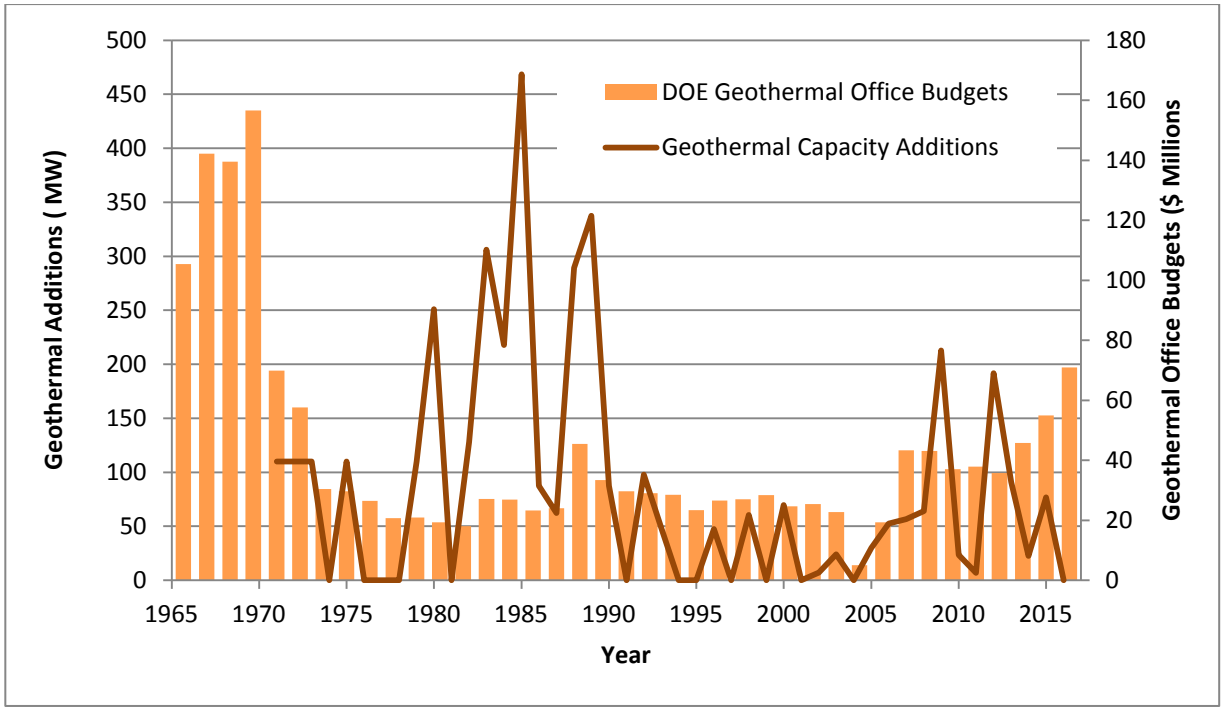


Figure 13. DOE Funding for Geothermal relative to Capacity Additions. This figure shows a correlation between sustained increased RD&D funding and increased deployment in the late 1970s and early 1980s. The figure does not include a one-year spike in funding due to the American Recovery and Reinvestment Act in 2009, which likely impacted deployment in subsequent years. Budgets: (DOE, 2017). Capacity Additions: (EIA, 2017b).

Similar impacts can be seen in the natural gas industry with the spike in R&D funding in the 1990s contributing to an increase in tight shale gas development and natural gas deployment, as well as a decrease in natural gas prices.[8]

[8] Large-scale natural gas production from shale began around 2000, when shale gas production became a commercial reality in the Barnett Shale located in north-central Texas. Production of natural gas in the United States reached its highest recorded total in 2015. The increase in production was mainly the result of horizontal drilling and hydraulic fracturing techniques (EIA, 2017a).

States have also provided research dollars into renewable RD&D. For example, California's Electric Program Investment Charge (EPIC) program[9] has invested money into researching flexible generation capabilities and economically recovering lithium from geothermal brines, among other things. RD&D investments by state were not analyzed as part of this barriers task force analysis, but improvements in geothermal technology and potential impacts to geothermal deployment were analyzed by other task forces (e.g. exploration, reservoir, power plant) for the GeoVision study, and results can be found in related reports (e.g., pending DOE GeoVision report).

4. Market Summary: Influence on Geothermal Deployment Potential

This section summarizes the weighting of each Market sub-attribute and the grading of the combined sub-attributes (i.e., attribute grade).

Scores for each of the sub-attributes were weighted as follows and summed to create a Market attribute summary map.

1. Market Demand (Weight = 1)
2. Wholesale Price of Electricity (Weight = 1)
3. Policies (Weight = 2)
4. Incentives (Weight = 2)

Table 4 summarizes the current *unallowed*, *no-go* and *flagged* grades for each of the Market sub-attributes. The market analysis identified no *unallowed* sub-attribute grades, no developer-identified *significant barrier* sub-attribute grades, and 2 *flagged* sub-attribute grades.

Table 4. Summary of *Unallowed, Significant Barrier* and *Flagged* Market Sub-attribute Grades. Bolded sub-attribute grades have been mapped for this analysis. Sub-attribute grades listed in italics were unable to be mapped using publically available data; They may impact additional areas not shown on these maps, and may prevent development of additional geothermal potential not indicated in this analysis.

Sub-Attribute	Unallowed Grade(s)	Significant Barrier Grade(s)	Flagged Grade(s)
Market Demand	--	--	**D, E**
Wholesale Electricity Price	--	--	--
Policies	--	--	--
Incentives	--	--	--

The colors in the map in Figure 14 reflect a range of scores from 6 (all three sub-attributes graded as A) to 30 (all three sub-attributes graded as E). No *unallowed* or developer-identified *significant barriers* occur for the market attribute. The market summary map shows that some

[9]The California Public Utilities Commission established the purposes and governance for EPIC in Decision 12-05-037 for Rulemaking 11-10-003 on May 24, 2012. In this decision, the CPUC designated the Energy Commission (CEC) as one of four administrators of the program and required administrators to submit coordinated investment plans to the CPUC for consideration. The CEC's development work on EPIC is being conducted in accordance with recent legislation, Senate Bill 1018 (Statutes of 2012, Chapter 39), as well as the CEC's broad authority under Public Resources Code Sections 25216(c) and 25401.

states (e.g., CA, NV) are more attractive than others (e.g., ID, WY) for geothermal sales. This does not restrict development in less attractive states, since power can (and often is) developed in one state and shipped to an end user in another state. States in the east with favorable market conditions (e.g., PA, VA) are near areas that have recently been investigated for EGS development (e.g., Cornell University et al., 2015).

The breakdown of grades based on weighed sums is shown in Table 2.

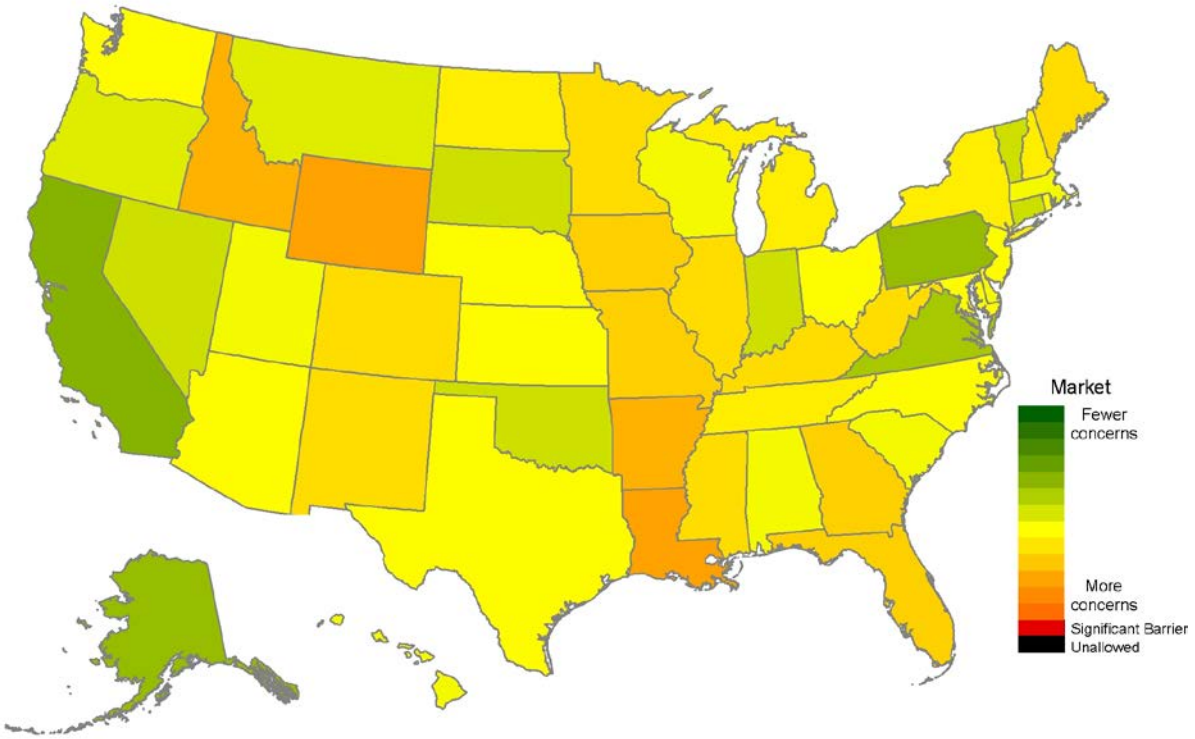


Figure 14. ***Market Attribute Summary Map.*** **This map represents the summary of all of the Market sub-attributes. The colors in the map reflect a range of scores from 6 (all three sub-attributes graded as A) to 30 (all three sub-attributes graded as E). No *unallowed* or developer-identified *no-go* situations occur for the Market attribute.**

5. Improvement Scenarios for Market Barriers

This section reviews the results of GETEM supply curve development and the ReEDS electricity generation forecasting to understand baseline deployment scenarios (i.e., business as usual) for geothermal resources as well as market improvement scenarios that may increase deployment of geothermal resources in future forecasts for 2030 and 2050.

Table 5. Improvement scenarios developed for ReEDs modeling

Scenario	Description of Potential Market Improvement	Modeled in ReEDS
BAU	• Electricity technologies (including renewables) that are competitive in current market conditions (with current policies/incentives) can be deployed.	No change from way ReEDS is currently being run: • no CPP • ReEDS represents current state RPSs • idealized future grid
SCENARIO 1: Increased Renewables	• Emissions reductions, decarbonization – *e.g., Clean Power Plan, "2 degree market," retirement of coal plants, increased state RPS*	1a: high RPS (49% throughout U.S.) from previously published study (Mai et al., 2016)
SCENARIO 2: Baseload-specific benefits	• Baseload renewables selected to provide grid stability • Baseload renewables reduce integration costs over variable renewable energy (VRE). (e.g. Caldwell and Anthony, 2016)	Run scenario three different ways: 2a: Baseload-only tax credit 2b: RPS Baseload set-aside; 2c: Transmission charge for VREs
SCENARIO 3: Geothermal-specific benefits	• Technologies are chosen based on benefits: • Geothermal power plants provide benefits to state and local communities (jobs, tax revenue, royalties)	Run scenario two different ways: 3a: Geothermal-only tax credit 3b: RPS Geothermal set-aside
SCENARIO 4: Changes in Market Conditions	• High electrification and deployment of renewables • Electric vehicles, 80% renewables	Run scenario two different ways: 4a: high natural gas prices[10] 4b: Increase electric demand due to electric vehicles[11]

5.1 Business as Usual Deployment

Before discussing potential improvement scenarios for geothermal deployment, this section provides an overview of the results of the ReEDS business-as-usual scenario. The BAU scenario considers current and anticipated future conditions, assuming no drastic improvements in technical or non-technical barriers. The BAU scenario, therefore, does not consider any market improvements and serves as a baseline to understanding the increased deployment in the potential improvement scenarios.

The ReEDS model assumes a current (2016) installed capacity of 2,685 MW. Under the BAU scenario, the model forecasts total deployed capacity for identified and undiscovered hydrothermal geothermal resources to be 4,100 MW by the year 2030 and 5,940 MW by the year 2050, as shown in Figure 15.

[10] Data taken from AEO 2015 High Growth case (EIA, 2015)

[11] The high electrification scenario uses a national economic value assessment of plug-in electric vehicles (Melania et al., 2016) and an 80% RPS scenario taken from NREL's set of standard scenarios (Cole et al., 2016).

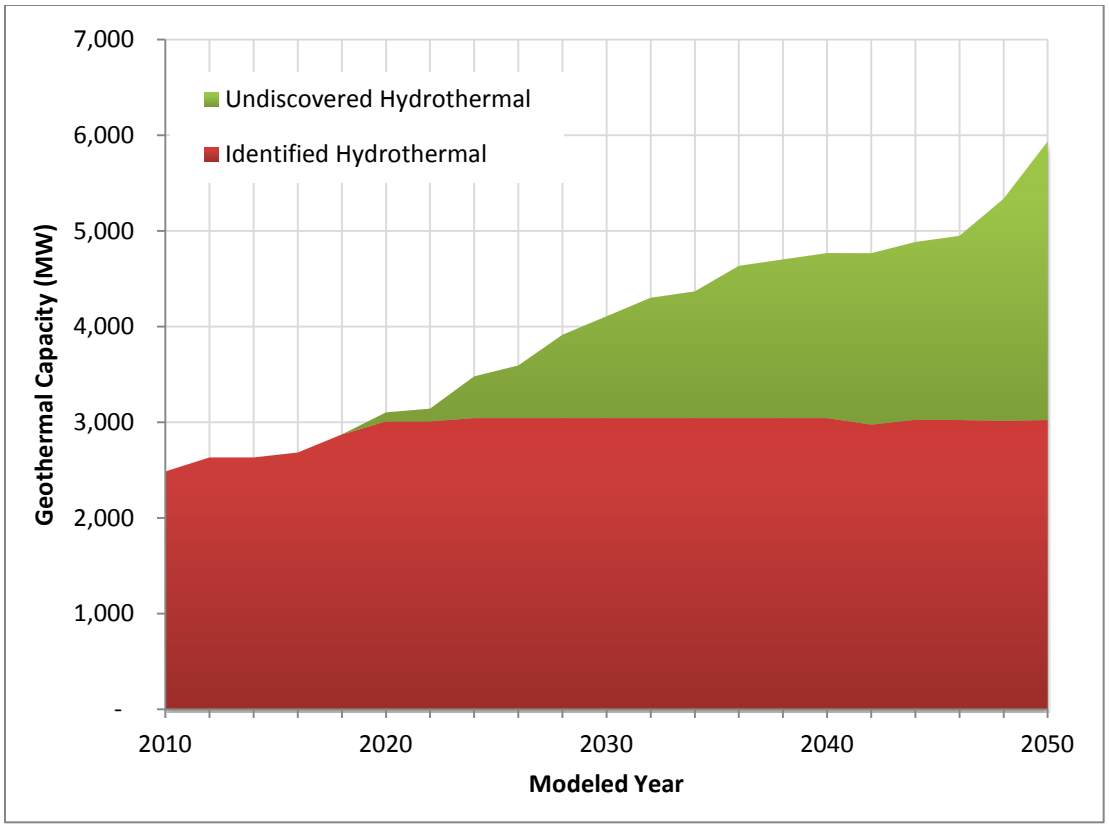


Figure 15. ***Business As Usual Deployment Curve for Hydrothermal Geothermal Resources.*** **The graph reflects ReEDS model outputs for forecasted hydrothermal geothermal resource deployment through 2050 under business as usual assumptions.**

In addition, the ReEDS model forecasts larger levels of geothermal deployment due to enhanced geothermal systems (EGS) in scenarios analyzing improved technology impacts. These scenarios deploy cost-competitive EGS beginning in 2024. For the impact of timeline improvements under these scenarios, see Young et al. (2018).

5.2 Scenario 1: Increased Renewables

A 2016 NREL report (Mai et al., 2016) examines a future scenario where RPSs are expanded, which assumes that nearly all states adopt an RPS with relatively aggressive targets. In the BAU scenario, renewables (including hydro) reach 26% of total U.S. electricity generation by 2030 and 40% by 2050. Under the High RE scenario, renewables reach 35% by 2030 and 49% by 2050.

The analysis examines changes in electric system costs and retail electricity prices, which include all fixed and operating costs, including capital costs for all renewable, non-renewable, and supporting (e.g., transmission and storage) electric sector infrastructure; fossil fuel, uranium, and biomass fuel costs; and plant operations and maintenance expenditures. This scenario is included here, but with updated geothermal data, to look more specifically at the impact to geothermal deployment. The model shows limited increase in geothermal deployment relative to

the baseline case, with the increase in renewables coming instead from utility-scale and distributed photovoltaics (PV).

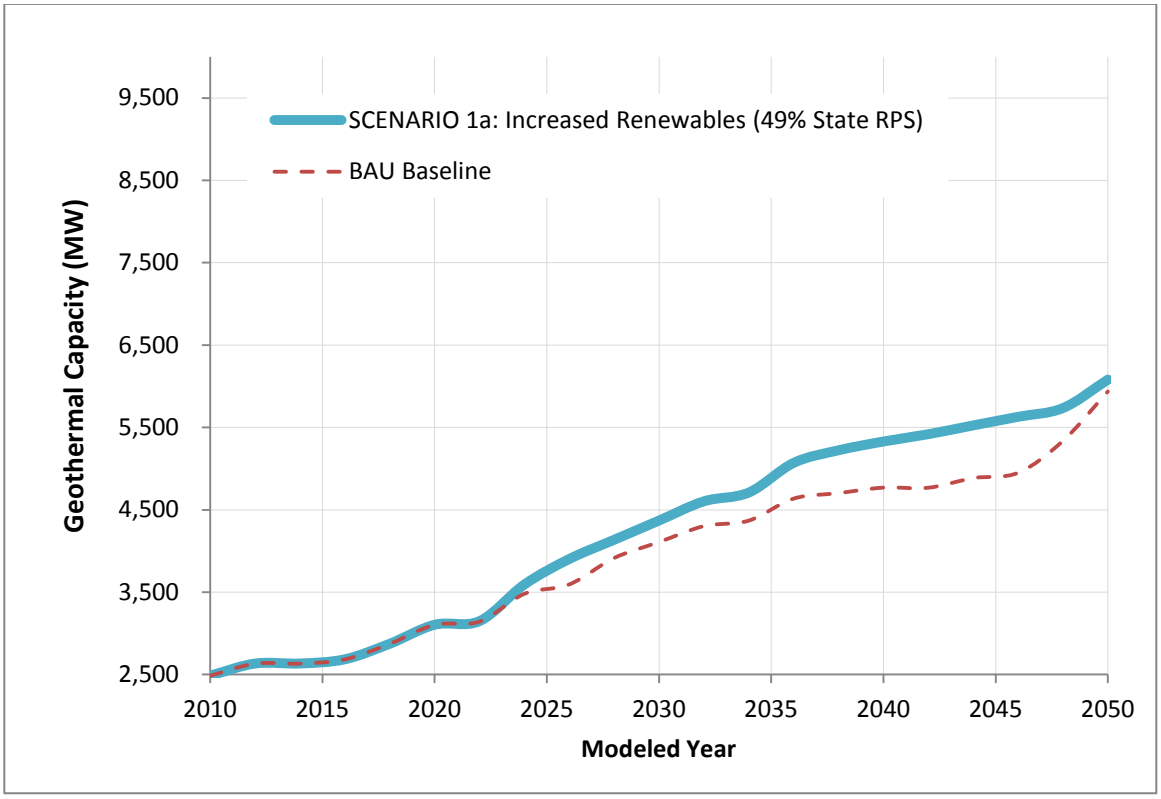


Figure 16. Modeled deployment of federal RPS. The model shows limited increase in geothermal deployment relative to the baseline case, with the increase in renewables coming instead from utility-scale and distributed photovoltaics (PV), suggesting the business-as-usual of geothermal costs are not competitive in current power markets with other renewables.

5.2 Scenario 2: Baseload Benefits

An April 2017 memo (Perry, 2017) by Secretary of Energy, Rick Perry, requested a 60-day investigation into the merits of baseload energy. Questions being addressed included whether wholesale energy and capacity markets are adequately compensating attributes such as on-site fuel supply and other factors that strengthen grid resilience and the extent to which continued regulatory burdens, mandates, and tax and subsidy policies are responsible for forcing the premature retirement of baseload power plants. Young et al., 2017 provides a more detailed discussion of geothermal and the electricity grid.

States such as California and Arizona, have been recognizing that the MWh-based approach used by traditional RPS policies does not differentiate between each renewable MWh based on its value to the grid or for reducing fuel consumption. These states are experiencing challenges as renewable energy production during certain times is beginning to provide diminished value in terms of reduced fuel consumption or capacity contribution (e.g., Denholm et al., 2015 and Figure 17). Both states have discussed using Clean Peak Standards, which build upon the RPS

construct by adding a requirement that a certain percent of energy delivered to customers during peak load hours must be derived from clean energy sources. (California AB1045; Huber and Burgess, 2016).

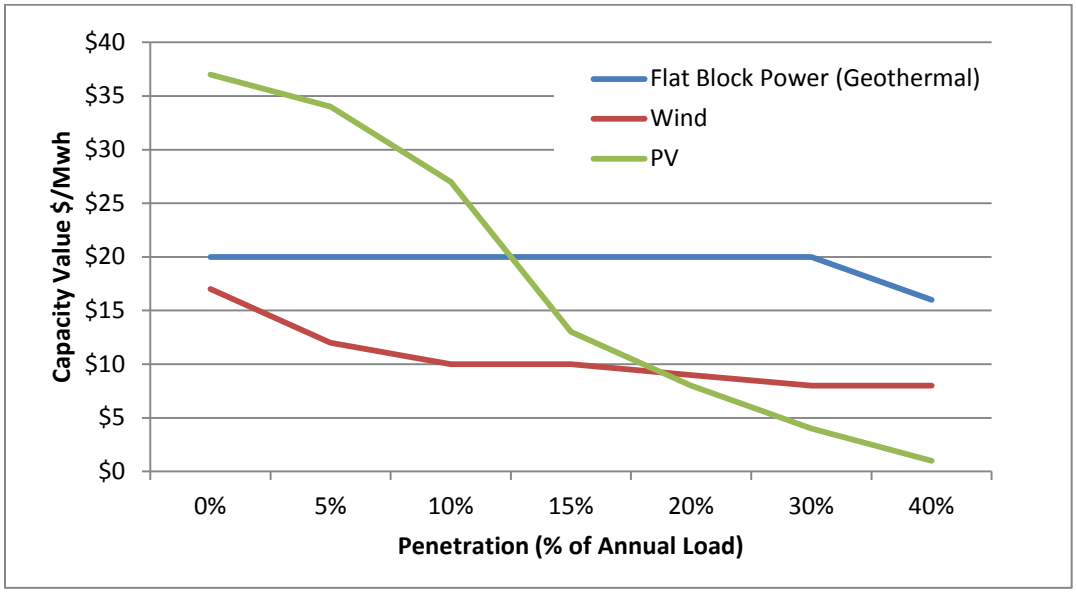


Figure 17. Marginal economic value of geothermal. Flat Block Power (Geothermal) delivers a constant amount of electricity on a 24x7 basis. Marginal value is calculated as the sum of capacity value, energy value, day-ahead forecast error, and ancillary services (Mills and Wiser, 2012). For more information, see Young et al., 2017.

Additionally, California had proposed a bill in which 20% of remaining RPS needs to be filled with baseload renewable energy (California Bill AB 920).[12]

Three scenarios were run to model increased benefits for baseload renewables:

2a. Federal-led baseload benefits: Creation of a 30% tax credit for baseload renewables only. Currently, wind and solar are eligible for a 30% tax credit for the PTC and ITC respectively (*see* 26 USC § 48 and Consolidated Appropriations Act of 2016). Phase-outs for current PTC and ITCs for wind and solar remain as planned (as discussed in Section 3.4). This improvement scenario analyzes the potential impact of extending the ITC at 30% through 2050 for geothermal and other renewable energy baseload technologies[13] that have yet to reach significant deployment as a mechanism for diversifying the renewable energy generation portfolio.

[12] This bill has been modified since the initial draft of this paper was written and ReEDS scenarios were run, but these models still provide insight into the impact such a scenario might have on geothermal deployment.

[13] Marine hydro kinetic, off-shore wind, biomass, concentrating solar power (CSP)

2b. State-led baseload benefits: Creation of a 20% set-aside for baseload renewables in current projected State RPS levels. Recently proposed legislation in California proposed that 20% of remaining RPS be filled with baseload renewables.

2c. Utility-led baseload benefit: Creation of a 30% increase in integration costs (not total project costs) for variable renewables using current projected state RPS levels. Though there are no bills that we are aware of that directly support a 30% increase in integration costs, there are laws and regulations that require utilities to procure energy storage. Adding energy storage to a variable renewable project can increase total project costs by 33% or more (Bade and Maloney, 2017).

The results of these runs are shown in Figure 18.

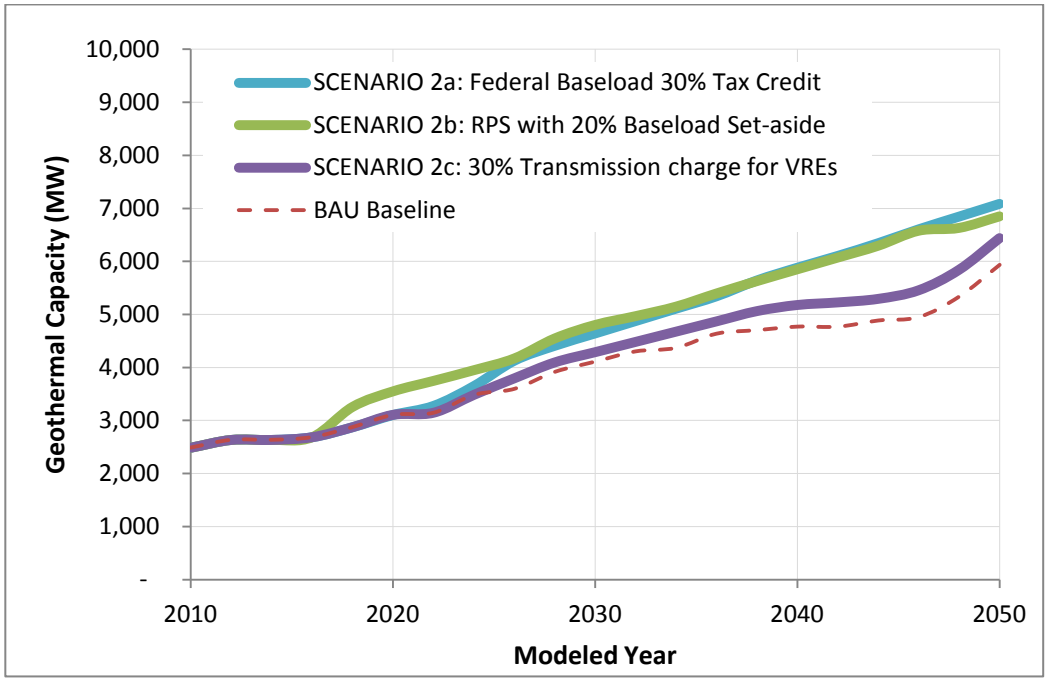


Figure 18. Modeled geothermal deployment projections for the three baseload benefit scenarios. The Federal baseload tax credit and state baseload set-aside have approximately the same impact on geothermal deployment over the BAU case, with approximately 1 GW of added geothermal.

The results show that relative to BAU levels in 2050, a 30% federal baseload tax credit has the potential to increase geothermal deployment by 1.15GW (19%), a 20% baseload set-aside under current RPS levels increased geothermal deployment by 900 MW (15%), and a VRE integration charge could increase geothermal deployment by 500 MW (8%).

Both the federal and state policies result in relatively similar deployment, though the baseload set-aside[14] appears to increase geothermal deployment more immediately and then tapers off, while the federal baseload tax credit deploys geothermal more steadily.

5.3 Scenario 3: Geothermal Benefits

Rationales for geothermal-specific benefits include diversification of renewable energy resources to support grid services and system reliability (discussed previously) and state and local economic benefits. A recent NREL study (Young et al., 2018) looked at long-term local economic benefits of various energy projects. The project-specific impact can vary by project and location within a state. Nevertheless, the results of this analysis can offer some perspective regarding the relative impact of certain projects based upon technology. The results of this analysis suggest that geothermal offers the most long-term jobs (Figure 19) and provides more local operations and maintenance (O&M) spending than other technologies analyzed (Figure 20). This greater local benefit is a result of a larger proportion of geothermal costs coming from O&M spending relative to the other technologies (Figure 21).

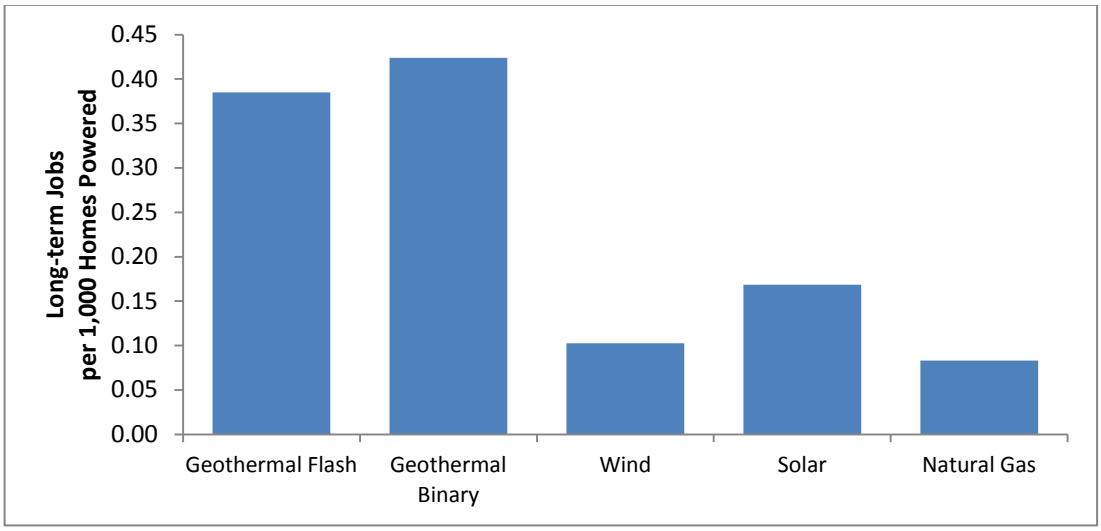


Figure 19. Comparison of local O&M spending per 1,000 homes powered by certain generation sources. Data varies geographically, and is shown for California plants. (data from NREL JEDI analyses for Young et al., 2018)

[14] The 20% baseload set-aside scenario (with BAU assumptions) predominantly builds CSP to satisfy the baseload set-aside, with smaller, relatively equal amounts of geothermal, hydropower and biomass plants.

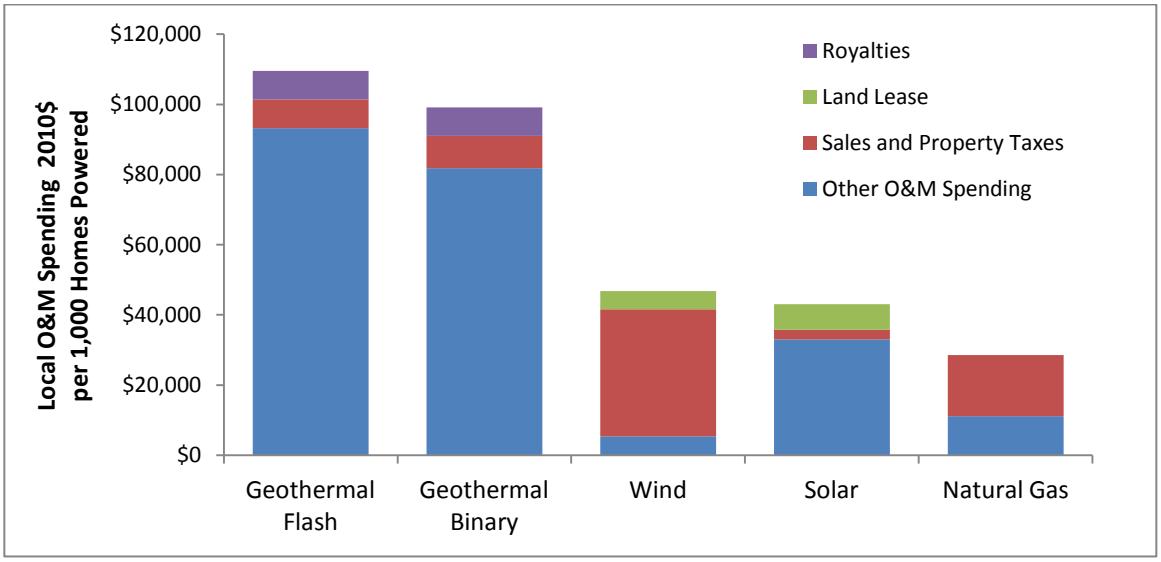


Figure 20. Comparison of local O&M spending per 1,000 homes powered by certain generation sources. Data varies geographically, and is shown for California plants. Though both wind and solar use large amounts of land (hence, wind's large spending on taxes), California currently offers a property tax break for solar. Royalties shown are for plants developed on federal lands and include portions disbursed to state and local entities; additional royalties are paid to the federal treasury. Royalties for development on private land is generally higher than shown and is paid to local landowners. (data from NREL JEDI analyses for Young et al., 2018)

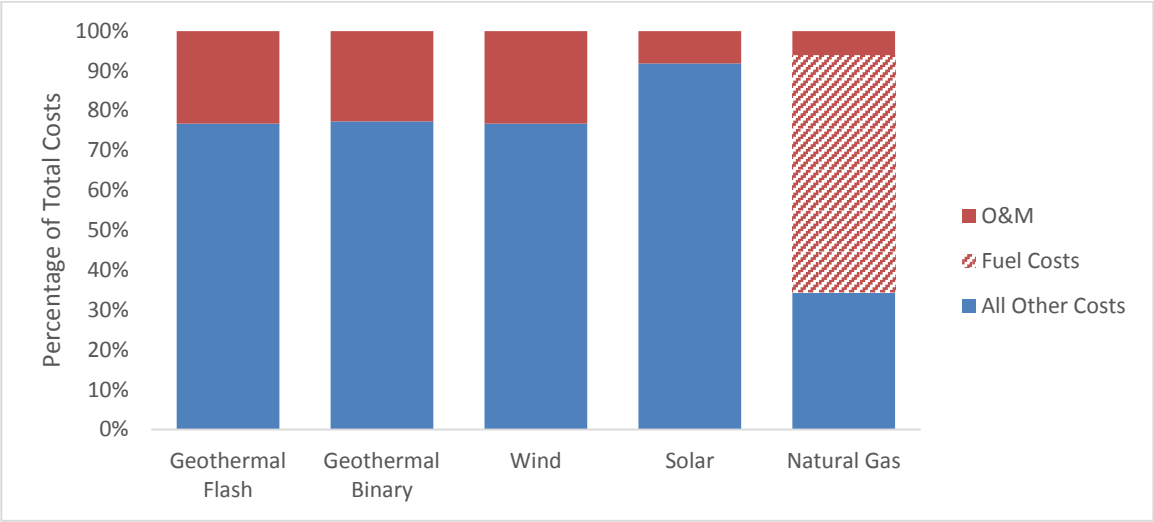


Figure 21. Comparison of O&M spending by technology as a percentage of LCOE. The high percentage of O&M spending on geothermal plants means increased local economic benefits for communities in which geothermal is developed. Fuel for natural gas is called out separately because it is not considered to be sourced locally and is not included in Figure 20.

Policymakers interested in leveraging possible geothermal benefits in relation to other technologies could consider policy prescriptions that boost geothermal development including favorable tax credits or technology set asides. Two scenarios were run to model the impact of favorable policies on geothermal deployment:

3a. Federal-led geothermal benefits: Creation of a 30% tax credit for geothermal, a level equal to current solar ITC (*see* 26 USC § 48 and Consolidated Appropriations Act of 2016). Phase-outs for current ITCs for wind and solar remain as planned. As discussed in *Section 3.4 Barrier 4: Incentives*, incentives including the federal ITC and PTC are helpful in making renewable energy projects financially viable. The ITC is currently at 10% for geothermal and is being reduced to 10% for solar projects not commencing construction by 2022 (26 USC § 48). This improvement scenario analyzes the potential impact of extending the ITC at 30% through 2050 for geothermal as a mechanism for diversifying the renewable energy generation portfolio and increasing local jobs and spending.

3b. State-led geothermal benefits: Creation of a set-aside for geothermal power. A set-aside for geothermal development has previously been proposed in the California State Legislature; in the 2013-2014 California Senator Ben Hueso (D) proposed SB-1139. This was a bill that would have created a 500 MW set-aside for geothermal development by the end of 2024 (SB-1139). SB-1139 would have required each "retail seller"[15] to procure a proportionate share of the 500 MW based on the forecast retail sales for 2018 as determined by the California Public Utilities Commission (SB-1139). SB-1139 also included a provision preventing the California Public Utilities Commission from approving any PPA that would have resulted in a cumulative increase in the average rate of retail electricity by one percent or more (SB-1139). SB-1139 was passed in the California State Senate, but ultimately failed to receive the necessary votes to pass the California General Assembly (SB-1139).

The results of these runs are shown in Figure 22.

[15] "Retail seller" means an entity engaged in the retail sale of electricity to end-use customers located within the state, including any of the following:
(1) An electrical corporation, as defined in Section 218 of the California Public Utility Code.
(2) A community choice aggregator. A community choice aggregator shall participate in the renewables portfolio standard program subject to the same terms and conditions applicable to an electrical corporation.
(3) An electric service provider, as defined in Section 218.3 of the California Public Utility Code. The electric service provider shall be subject to the same terms and conditions applicable to an electrical corporation pursuant to this article. This paragraph does not impair a contract entered into between an electric service provider and a retail customer prior to the suspension of direct access by the commission pursuant to Section 80110 of the Water Code.
(4) "Retail seller" does not include any of the following:
(A) A corporation or person employing cogeneration technology or producing electricity consistent with subdivision (b) of Section 218.
(B) The Department of Water Resources acting in its capacity pursuant to Division 27 (commencing with Section 80000) of the Water Code.
(C) A local publicly owned electric utility.
(k) "WECC" means the Western Electricity Coordinating Council of the North American Electric Reliability Corporation, or a successor to the corporation. California Public Utility Code, Article 16, 399.12(j).

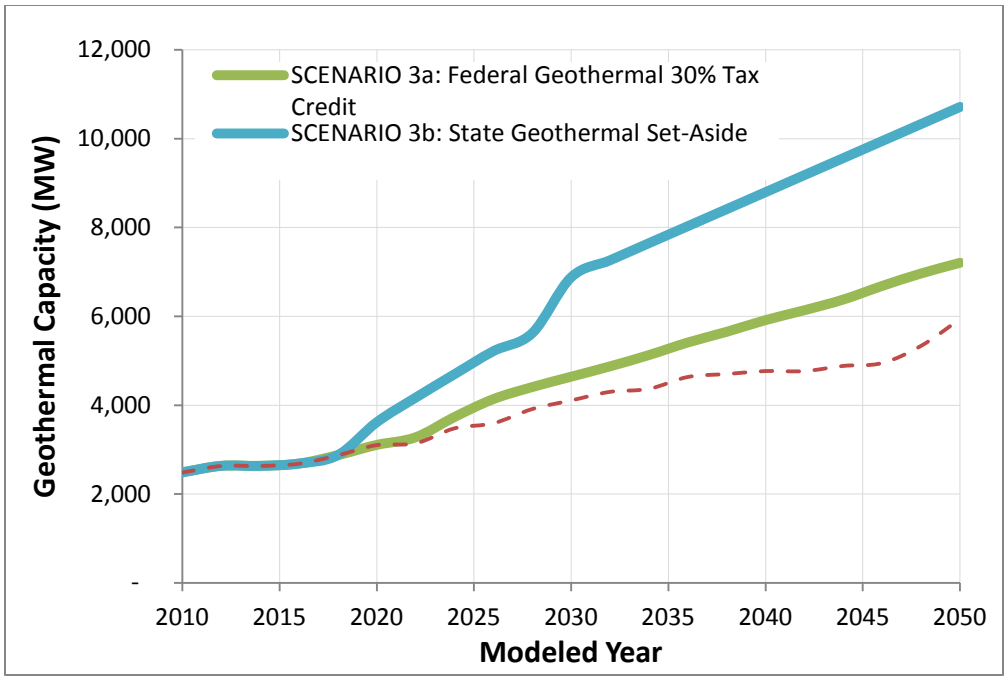


Figure 22. Modeled geothermal deployment projections for the two geothermal benefit scenarios.

The results show that relative to BAU levels in 2050, a 30% federal geothermal-only tax credit has the potential to increase geothermal deployment by 1.26 GW (21%) and the geothermal set-aside could increase geothermal deployment by 4.77 GW (80%). Geothermal deployment under the baseload tax credit (Scenario 2a) and the geothermal-only tax credit (Scenario 3a) are relatively close. We did not run any scenarios that mimic oil and gas tax credits for geothermal. This may be an area for future analysis.

We found the geothermal set-aside scenario to be highly sensitive to two parameters. First, high RPS levels stimulate deployment of engineered geothermal systems (with currently significantly high costs in the ReEDs model). Second, deployment under these set-asides was highly dependent on the rate of discovery of undiscovered resources (set to 1% per year in the BAU case). This suggests that if states were interested in developing geothermal set-asides, it is important for them to carefully consider the amount of set-aside relative to geothermal resource available in the state, and to be sure there are appropriate RD&D funds (from any source) to identify geothermal resources in the state for development to meet the RPS. Scenario 3b presented deploys near-field EGS, but does not deploy any deep EGS geothermal projects.

5.4 Scenario 4: Changes in Market Conditions

Predicting future market conditions is not an exact science. Therefore several scenarios were run with varying future market conditions to understand and illustrate potential impacts market conditions may have on geothermal deployment.

4a. High Gas Prices. The 2016 NREL Annual Technology Baseline (ATB) data on long-term prices of natural gas shows the potential for relatively little change in natural gas prices between 2016 and 2040 in a low natural gas price scenario, with natural gas prices rising

approximately 2 percent by 2040 (NREL, 2016). The mid-case natural gas price scenario shows an expected rise from $3.31/MMBTU in 2016 to $5.45/MMBTU by 2040, a roughly 65% increase in natural gas prices. However, if natural gas prices rise over this period of time from the low-case scenario of $3.28/MMBTU by 2040 to a high-case natural gas price of $9.40/MMBTU by 2040, natural gas prices could see close to a 300% increase over the next 25 years.

Using the 2040 mid-case natural gas price as a baseline, this could change the LCOE for natural gas combined cycle power plants running at average capacity (48%) from $66/MWh by 2040 in the mid-case scenario to $91/MWh in the high-case scenario and combined cycle power plants running at high capacity (87%) from $54/MWh in the mid-case scenario to $79/MWh in the high-case scenario. Geothermal power does not require a fuel source and as such could be viewed as a hedge against rising natural gas prices. This scenario discussing the impact high natural gas prices could have on geothermal deployment by 2030 and 2050.

4b. High Electrification. Research suggests that the U.S. electricity system could operate economically and reliably on clean fuels like nuclear and renewables (NREL, 2012). At the same time, such a system could be robust enough to extend the benefits of clean power to a much broader swath of the U.S. economy, such as building heating and cooling systems, electrified transportation, and industrial processes. The adoption of plug-in electric vehicles (PEVs) can reduce household fuel expenditures by substituting electricity for gasoline while reducing greenhouse gas emissions and petroleum imports.

The results of these runs are shown in Figure 23.

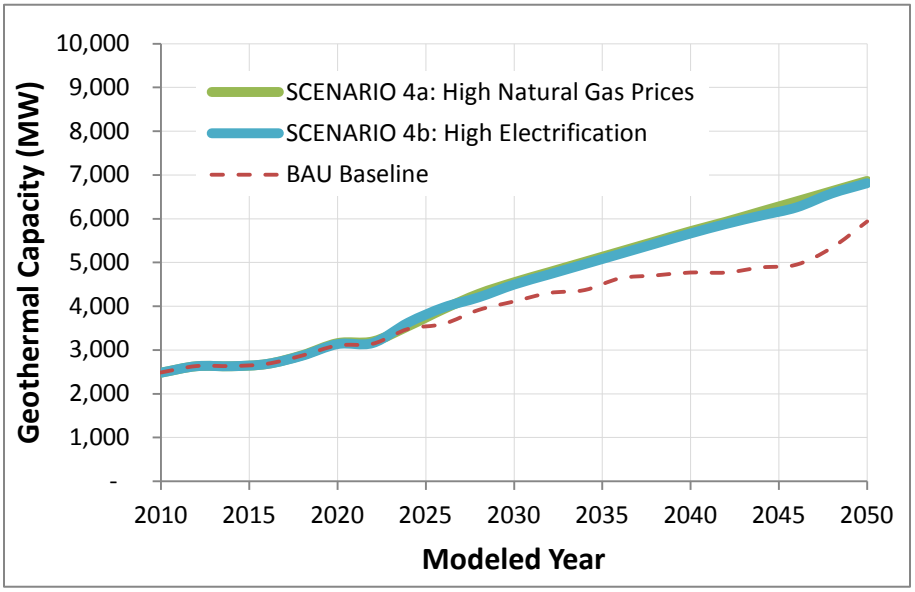


Figure 23. Modeled geothermal deployment projections for the two market condition scenarios. Both modeled scenarios increase geothermal deployment by about 1 GW (~16% increase over BAU).

The results show that relative to BAU levels in 2050, high natural gas prices have the potential to drive geothermal deployment – in this scenario, the modeled increase is 930 MW (16%). This is

similar to the impact on geothermal deployment in the modeled high electrification market, showing an increase of 870 MW (15%).

This high electrification scenario assumes PEVs achieve very high market share, the electricity grid continues to be decarbonized due to increased renewable generation capacity, and both PEVs and competing gasoline vehicle technologies experience strong technology progress in terms of reduced upfront costs and improved fuel economy (Melaina et al., 2016).

6. Discussion

This paper highlighted many of the identified geothermal barriers associated with selling geothermal power in the electricity market. While these market barriers reduce the ability to sell geothermal power into the market, the improvement scenarios illustrated above have the potential to greatly reduce the impact of the market barriers on the geothermal deployment.

The market improvement scenarios in this report assume no improvement in geothermal technology. They provide a baseline discussion of these market improvement scenarios, which shows that set-asides and tax credits, such as those that have benefited wind and solar, can significantly influence deployment. Grid reliability features and economic benefits of geothermal deployment outlined in this report may drive similar such set-asides for geothermal. Additional benefits of increased geothermal deployment (e.g., emissions, water use, land-use footprint, jobs, local spending) will be discussed in the forthcoming DOE GeoVision report.

Table 6. Summary of ReEDs model results showing market penetration levels under various market scenarios.

Scenario	Scenario	2050 Modeled Deployment in 2050	Improvement over BAU
BAU	BAU Baseline	5,940 MW	N/A
SCENARIO 1: Renewable Benefits	**1a:** Increased Renewables (49% State RPS)	6,080 MW	140 MW (2%)
SCENARIO 2: Baseload-specific benefits	**2a:** Federal Baseload 30% Tax Credit	7,090 MW	1,150 MW (19%)
	2b: RPS with 20% Baseload Set-aside	6,850 MW	900 MW (15%)
	2c: 30% Transmission charge for VREs	6,440 MW	500 MW (8%)
SCENARIO 3: Geothermal-specific benefits	**3a:** Federal Geothermal 30% Tax Credit	7,200 MW	1,260 MW (21%)
	3b: State Geothermal Set-Aside	10,710 MW	4,770 (80%)
SCENARIO 4: Changes in Market Conditions	**4a:** High Natural Gas Prices	6,870 MW	930 MW (16%)
	4b: High Electrification	6,810 MW	870 (15%)

2050 deployment for these market scenarios were presented as singular improvements. As part of the GeoVision study, many of these scenarios were run in combination. For example, a

scenario that includes improvements in permitting, such as categorical exclusions (Levine and Young, 2017), and improvements in market, such as a federal geothermal 30% ITC (this paper) suggests increases in 2050 geothermal deployment in excess of 100% over the BAU. In addition, these non-technical barrier improvements (land access, permitting, market) were run in combination with improved technology scenarios, which also show significant geothermal deployment potential. For the comprehensive report, see Young et. al, 2018, where cumulative scenarios are discussed in detail.

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