

**GEOTHERMAL POWER, POLICY, AND DESIGN:
USING LEVELIZED COST OF ENERGY AND SENSITIVITY ANALYSIS TO
TARGET IMPROVED POLICY INCENTIVES FOR THE U.S. GEOTHERMAL
MARKET**

by

Christopher L. Richard

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Energy and Environmental Policy

Winter 2014

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DEDICATION

This work is dedicated to my wife, parents, brother, and most of all, my son, who will be joining us shortly. For them I am content in my accomplishments but willing to strive for greater things.

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LIST OF ABBREVIATIONS

BLM – United States Bureau of Land Management

DOE – United States Department of Energy

FERC – Federal Energy Regulatory Commission

GEA – Geothermal Energy Association

GEOFAR – Geothermal Finance and Awareness in European Regions

GeoLEC – Geothermal Levelized Cost of Energy Model

GETEM – Geothermal Electricity Technology Evaluation Model

GTO – Geothermal Technologies Office/Geothermal Technologies Program

GW - Gigawatt

INL – Idaho National Laboratory

KWh – Kilowatt Hour

LCOE – Levelized Cost of Energy

LEC – Levelized Energy Cost

MW – Megawatt

NEPA – National Environmental Protection Act of 1969

NREL – National Renewable Energy Laboratory

PURPA – Public Utility Regulatory Policies Act

REC – Renewable Energy Certificate

RPS – Renewable Portfolio Standard

ABSTRACT

At the core of the geothermal industry is a need to identify how policy incentives can better be applied for optimal return. Literature from Bloomquist (1999), Doris et al. (2009), and McIlveen (2011) suggest that a more tailored approach to crafting geothermal policy is warranted. In this research the guiding theory is based on those suggestions and is structured to represent a policy analysis approach using analytical methods.

The methods being used are focus on qualitative and quantitative results. To address the qualitative sections of this research an extensive review of contemporary literature is used to identify the frequency of use for specific barriers, and is followed upon with an industry survey to determine existing gaps. As a result there is support for certain barriers and justification for expanding those barriers found within the literature. This method of inquiry is an initial point for structuring modeling tools to further quantify the research results as part of the theoretical framework.

Analytical modeling utilizes the levelized cost of energy as a foundation for comparative assessment of policy incentives. Model parameters use assumptions to draw conclusions from literature and survey results to reflect unique attributes held by geothermal power technologies. Further testing by policy option provides an opportunity to assess the sensitivity of each variable with respect to applied policy. Master limited partnerships, feed in tariffs, RD&D, and categorical exclusions all result as viable options for mitigating specific barriers associated to developing geothermal power. The results

show reductions of levelized cost based upon the model's exclusive parameters. These results are also compared to contemporary policy options highlighting the need for tailored policy, as discussed by Bloomquist (1999), Doris et al. (2009), and McIlveen (2011).

It is the intent of this research to provide the reader with a descriptive understanding of the role of geothermal power in the United States, and to recognize that not all policy or energy technology is created equal. Further study options are provide to expand the scope and granularity of this research design to better support a growing market.

Chapter 1

INTRODUCTION

Contemporary literature and reporting, related to the geothermal industry, has identified a consistent grouping of barriers to the development of geothermal power. The importance of these barriers lies in understanding ways to improve renewable energy policy, specifically for geothermal power, and to advance market growth for the geothermal sector, which has an already competitive levelized cost (Lazard Ltd., 2009) and, more importantly, is able to provide base-load power generation. On both points, geothermal power promotes a more direct value comparison with established power systems, like coal and nuclear, and an alternative to the intermittent power of wind and solar. From the reviewed literature, multiple authors have suggested that policy should be more tailored to the unique attributes of geothermal power as opposed to a “one size fits all” approach (Bloomquist, 1999) (Doris, Kreycik, & Young, 2009) (McIlveen, 2011). In order to do this, a fundamental shift must occur in how energy policy is structured to reflect the value derived from an individual energy technology, such as geothermal. Research in energy policy, but more specifically related to geothermal power, is increasingly limited in this context and has not drawn a direct correlation between the barriers and incentives as they relate specifically to geothermal power. This research will draw on the following questions and conclusions to create a theoretical method of levelized cost analysis to apply sensitivity testing to quantify developmental barriers, and then to correlate the developmental needs with policy incentives used in the geothermal sector. It is suggested, that in following Bloomquist, Doris et al, and McIlveen, the

application of more tailored policy for the mitigation of finance and developmental risks, in the early-stages of geothermal development, will prove to be a benefit to both developers and those supporting such policy alternatives.

1.1 Research Problem:

Because geothermal power systems are able to provide stable base-load power to meet the needs of energy consumers, at a competitive levelized cost, it poses a direct clean energy alternative to coal and nuclear technologies. Since each of these technologies is engulfed by concerns of environmental emissions or safety, it is vital that cleaner energy technologies be commercialized, which are able to offer the same services to end-users. Geothermal power is uniquely positioned, as the only base-load renewable energy, which is also dispatchable to provide this energy alternative. Due to this importance in energy generation, policymakers must look to enable growth and commercialization of geothermal power to the market. Policy mechanisms can take many forms as they relate to geothermal development, but under a contemporary policy setting, the use of policy incentives has prevailed. The problem, as referenced by Bloomquist (1999), Doris et al (2009), and McIlveen (2011), finds that the current policy framework lacks suitability for a proper posturing of geothermal power within the U.S. energy market, and introduces questions related to; “why” and “how” this it known?

Policy incentives commonly used within the clean energy sector are often dependent on either direct cash or tax-based subsidies. Whether the technology is wind, solar, biomass, or geothermal there is a broad, common approach to these mechanisms. The fault in policy effectiveness that is associated with these mechanisms, finds that the rates of development, since 2000, are significantly different among each technology:

3.1% (Renewables), 5.5% (Solar PV), 32.9% (Wind), and 2.6% (Geothermal)¹.

Furthermore, when wind and geothermal technologies are compared in annual subsidies, the 2007 figures from the Energy Information Administration show an increased disparity. Those figures are as follows: \$724m (Wind) to \$14m (Geothermal) (McIlveen, 2011). There are clearly issues of suitability between technologies, as related to the use and effectiveness of subsidies. From a review of geothermal literature, as presented in Chapter 2, the problem that is most overlooked in geothermal research involves analytical qualification of the relationship between development (market) barriers and policy incentives. This requires attention to the impacts of time as a variable of development and production. Thus the research problem reflects the position of more tailored geothermal policy, and is unique in the need for a more empirical path of study.

1.2 Research Questions:

The aim of this research is to address the following question and derive a method for testing it. Based in a review of literature this research ventures to address how barriers and policy are integrated by asking; can policy incentives be tailored to more effectively address the barriers and challenges uniquely faced in the development of geothermal power? The geographic focus of this research is the United States, and the geothermal sub-technologies are classified as traditional hydrothermal. To create an original and specialized approach, the following questions are representative of this course of research:

¹ Calculations based on EIA dataset of Renewable Energy Production and Consumption from 2000-2010.

- **How are barriers to geothermal development reflected in the measurement of policy incentives?**
- **What policy options are best suited to address the unique developmental barriers expressed within the geothermal sector?**

A multi-method approach is used to establish the framework for addressing the above questions. By conducting literature reviews on multiple topics, this research provides a collection of data points that can be subjected to further quantitative analysis. This begins with a systems approach to understanding geothermal technologies and the policy landscape. Through this understanding the research will initiate a process of categorizing developmental barriers and measurement to frequency of reference. Results of which provide a more thorough definition of the barriers to geothermal development. To follow the results of the literature review, a survey method was utilized to compare those results with more contemporary views within the industry. Using a survey method also allowed for distinguishing the respective views by the role in industry served by the respondent.

Compiling the results of both reviews, the next research method introduces geothermal specific variables, as related to developmental barriers, into a modified calculation of levelized cost. This is not to create a comparable levelized cost method or calculation, but to establish precedence for the measurement of sensitivity, given variables that are uniquely associated with geothermal development. For this, a recognized levelized cost formula (OECD, Nuclear Energy Agency, 2005) is the basis, and specific assumptions are formed to create a unique assessment of the costs related to geothermal power. The measurement of sensitivity then helps to identify a correlation between the barriers to development and the more precise measures of levelized cost. These measures of sensitivity and development barriers are then used to apply policy analysis of contemporary policy mechanisms for comparative testing. Testing consists of LCOE sensitivity, which provides the viability of each policy under testable conditions

and constraints. This best allows for greater precision in recommendations on policy design. The main objective, in returning to the research problem, is to test the theoretical benefit of policy incentives during early stage development of geothermal power, and highlight the unique needs of geothermal power development.

1.2.1 Levelized Cost per Unit

The levelized cost per unit (\$/kWh) is the output of the GeoLEC² formula and modeling. It represents a levelized cost of energy that is specifically treated for qualities related to the geothermal power industry. The result of the model design is intended to create value in the effects of developmental barriers to geothermal power. This value is directly sensitive to the impact of time as a component of development costs. As policy mechanisms are comparatively tested, each will be represented by the overall reduction in LEC from the baseline values.

1.3 Research Significance:

The study of energy policy has been at the forefront of United States public policy as a result of the social impacts that have resulted from variations in the supply and cost of energy over time. Disruptions, such as the oil crises of 1973 and 1979, price shocks in the 1990's, and the economic recession of the 2000's, have each impacted the availability and access to energy needed to support and grow national economies. Energy policy is a significant area of study because, through regulations, incentives, and other policy mechanisms, the price and supply can be made more stable. This incorporates different

² GeoLEC is the method of modeling that is used in Chapter 4, and it is the result of analysis related to developmental barriers and policy mechanisms.

energy sources and technologies, but the use of that energy is the same: a means to do work. Within this greater energy policy discussion it is possible to narrow the attention to discuss individual technologies, and in this case, the research focus is geothermal power.

As is discussed in greater detail in subsequent chapters, geothermal power shares a number of qualities with both the renewable energy sector and the non-renewable energy sector. Like most fossil based energy sources (oil, natural gas, coal, nuclear), geothermal power is a resource that must be identified through geological exploration and then extracted (mined) from below the earth's surface. Although there are similarities, the power derived from geothermal resources is classified as renewable, like solar and wind power. This shared dichotomy has made for a contentious understanding of geothermal power when it comes to developing energy policy (Bloomquist, 1999) (Curtis, 2010) (McIlveen, 2011). Many broadly applied policy mechanisms also include geothermal power, and can be exemplified by both renewable and fossil energy plans. For instance, geothermal power is included in the Federal Production Tax Credit, Investment Tax Credit, Department of Energy (DOE) Loan Guarantee, and within state Renewable Portfolio Standards (RPS). These broadly applied policy mechanisms are commonly focused on the production of energy (kWh), but have limited regard for the development of projects prior to the point of production (McIlveen, 2011). It is at this point that this research focuses on the developmental barriers to geothermal power projects, and the understanding of correlations between policies and barriers.

By expanding on the positions published by a series of authors (Bloomquist, Doris et al., and McIlveen), this research is designed to provide empirical support to their individual calls for more tailored geothermal policy, but also to draw on the relationship, or lack of, between developmental barriers to applied policy. Pursuant to the research problem discussed in the beginning of this chapter, the design of this research provides

multiple offering to advance scholarly research related to the understanding of policy needs within the geothermal power sector. It should also be noted that the field of geothermal policy is largely limited to few academics, such as Dr. R. Gordon Bloomquist, and research agencies, like the DOE Geothermal Technologies Program and the National Renewable Energy Laboratories. Furthermore, the subject area of geothermal policy is often not the topic of focus, but a sectional component to more thorough discussions of geothermal power in economic, geologic, or engineering publications, by experts outside the field of energy policy (Massachusetts Institute of Technology, 2008) (Deloitte Development LLC, 2008) (Doris, Kreycik, & Young, 2009) (Sener, 2009) (McIlveen, A Geothermal Incentive Design, 2011).

It is with this understanding of the state of geothermal policy research that this study will provide scholarly contributions. First of all, the linkage between applied policy and developmental barriers remains. Since developmental barriers change over time, there is a need to assess those barriers over the development timeline, as well as by adding to it through independent study. This research serves this need by detailing developmental barriers as published, and by comparing the results of the literature review to those of an industry survey of geothermal professionals. The second contribution of scholarly significance is the development of the GeoLEC model. This is a quantitative model, which modifies the levelized cost formula used by Short et al. (1995) to include geothermal specific variables in the formula assumptions. These assumptions are based on developmental barriers, but also are used to highlight a more concise understanding of unique features associated to geothermal power projects. Lastly, the model is used to comparatively test interactions of policy mechanisms to establish a basis for policy recommendations, which are tailored to geothermal power.

The culmination of these scholarly contributions, by design, is intended to open

the geothermal policy discussion from the perspective of policy analysis, and make it the focal point of the study. Considerable material is available to introduce policy tools used by the geothermal power sector. This study supports the research problem, while adding quantitative content to the field of energy policy, generally, and geothermal policy, specifically.

1.4 Research Framework:

The research framework is an analytical design, which offers a culminated approach, using both qualitative and quantitative analyses. It begins with an understanding of the contemporary state of geothermal development, supported through an extensive literature review to collect and understand barriers to geothermal development. This process utilizes eighteen publications selected, and reviewed, to establish a contemporary understanding of developmental barriers. The outcome of cataloging the barriers establishes a ranking of categorized barriers based on publication frequency within the literature review. These results are used to design and apply a survey to test against contemporary perceptions.

With development barriers, and the respective frequencies, being identified, cataloged, and compared; this study selects, develops, and tests applied policy mechanisms using a quantitative metric. This metric is a modified levelized cost formula, called the GeoLEC. It enables the research to be modeled, based on geothermal specific assumptions, which incorporate a greater understanding of specific barriers to development identified in both the literature review and survey. As a result, a unique and specialized method is established for analyzing itemized costs related to geothermal power.

The GeoLEC model introduces both dependent and independent variables to

calculate the cost per unit (\$/kWh) value, each of these variables is subjected to a method of “one at a time” (OAT) sensitivity analysis. By conducting this method of analysis the change in output is recorded based on the individual changes of each variable. By incorporating the appropriate barrier components into the GeoLEC, it will be possible to identify those variables that offer the most efficient approach for policy implementation. The result produces a unique method for calculating levelized cost of geothermal and provides an understanding of the individual sensitivities for correlating developmental barriers to applied policies. A comparative analysis of policy mechanisms is important to identify gaps, which result from any incompatibilities of policy to barriers. Using the GeoLEC model this research quantifies the role of developmental barriers in the calculation of levelized cost. As a metric, a variety of policy mechanisms are applied, and then observed for each individual impact on a baseline levelized cost. This method of testing policies aids in identifying gaps in the existing policy structure and tests alternative options, which are better suited to the specific needs of geothermal power development in the United States. To ensure a wider applicability of policy options, each will be evaluated on the basis of levelized cost per unit (i.e. GeoLEC).

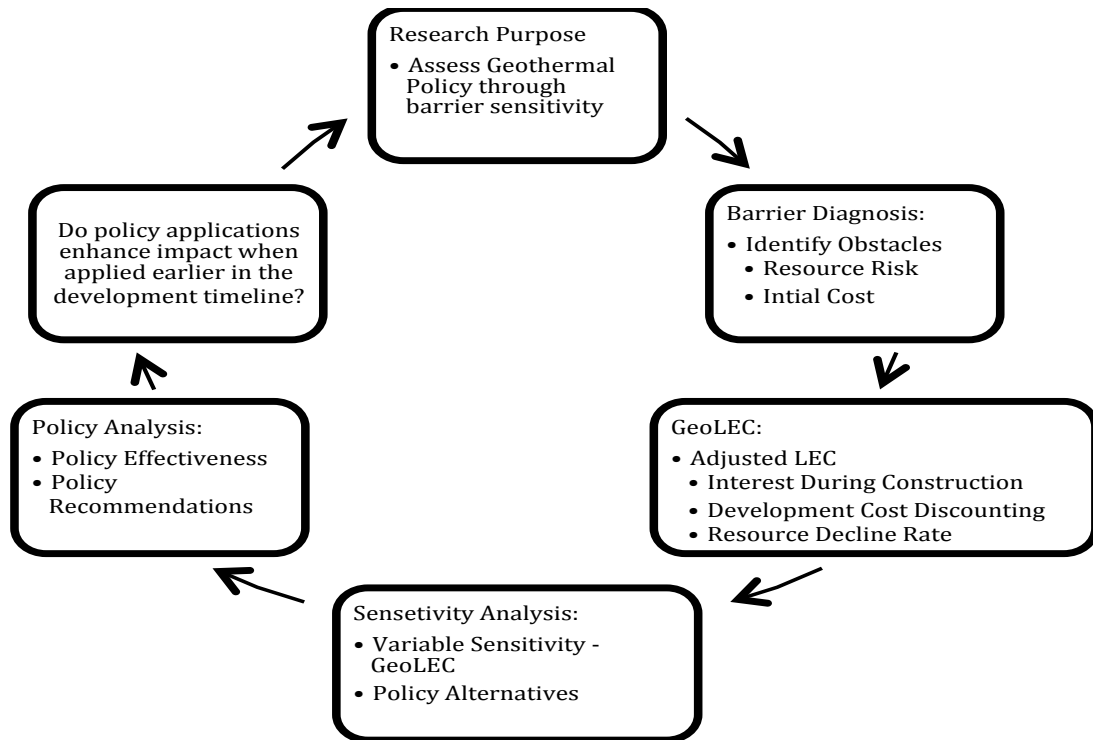


Figure 1.1: Analytical Framework

In Figure 1, the diagram shows the relationship of the methods being used. In creating an analytical research process, and by staying true to more traditional policy analysis, the entire process is cyclical in nature. This is very important, as conclusions and recommendations may encourage changes in policy mechanisms, and thus require a system of re-evaluation as the barriers to development and the geothermal industry needs change over time.

1.5 Research Assumptions:

The use of a levelized cost formula and model is heavily based on the use of key assumptions. These assumptions are detailed specifically for the modeling found in

Chapter 4. The reasoning behind their use is to identify and test the role of geothermal specific attributes in the model. For instance, geothermal resources should expect a drawdown on actual capacity over time (Sanyal, 2005a). This requires the drilling of make-up wells to maintain production capacity, however, even with these make-up wells there are small decreases in production capacity over time at most plants. This is not a factor in other energy production technologies, and thus is not an assumption considered in more traditional levelized cost analyses. By including this assumption in particular, this research creates a broader assumption in the study, wherein the model is unique to geothermal power only. Unlike studies and methods used by IEA (2005,2010) or Lazard (2009) to compare levelized cost, this research offers no comparability to other energy technologies or to other LCOE geothermal values. In initial calculations of the GeoLEC model the (\$/kWh) values were substantially higher, but this is accepted by the author in design of the model and the use of additional cost variables. Furthermore, these output values are of less importance than is the relationship and/or sensitivity of each variable, assumption, or policy tested.

A second assumption for the design of the GeoLEC model is in the data used. Each variable has a range of values that are used for baseline and sensitivity analysis. Because the GeoLEC baseline output is not the end result, but the point to test sensitivity, the precision of input variables is in the aggregate. All data has also been collected from publicly available sources. Specifically, to build congruency, much of the cost, development stage data, and risk perception data are collected from reporting conducted by Deloitte Development Ltd. (2009) on behalf of the U.S. Department of Energy.

These assumptions do not restrict, but are intended to shape the design and value of the research. As is discussed in the concluding chapter, further study can expand upon these assumptions to also include the independent collection of variable range data for

model inputs. This will more precisely allow the model to be compared in relation to other levelized cost studies. Since that objective is not an underlying purpose of this study, this introduction continues with a summary of the chapters.

1.6 Chapter Abstracts:

In Chapter 1, the aim is to direct the reader's attention in defining the research problem. This can be viewed in two distinct contexts relating to a macro and micro- level approach. To begin, the impetus will be placed on the larger picture of preparing and justifying the intent behind the research design and laying out how the author plans to address it. The research statement includes the research question and follow- up with an introduction to the assessment testing being proposed and a summary of chapter content.

Chapter 2 provides a concise, yet complete, review of the literature. This is to establish the most appropriate method for structuring the conceptual design that will follow in subsequent chapters. Core areas of review include defining geothermal power and its benefits and reviewing policy applications. To give purpose to the process of informing the problem, the literature review will establish the basis for the theoretical and conceptual frameworks.

In order to focus the theoretical and conceptual frameworks, Chapter 2 will also isolate three distinct publications and elaborates on each of the author's views. The theoretical base is most clearly stated by John McIlveen, of Jacobs Securities, when he states that incentives for geothermal development should be shifted to the front end of the development timeline (McIlveen, 2011). By using this theoretical base, the research takes form by defining the process by which the methods are used to culminate to define the research findings.

Chapter 3 introduces the details of research on developmental barriers. These

details will highlight multiple components of barrier analysis. The first will discuss the process of defining barriers to development. A detailed literature review provides a collection of contemporary information and data on developmental barriers. Further organization of barriers into categories allows for an assessment of frequency of use in publication, but also establishes the components used in surveying industry. To expand the results of the literature review, Chapter 3 provides the results of an industry survey on the perception of developmental barriers and policy implementation. The survey results are assessed against the analysis of barriers found in the literature review to establish accuracy. Lastly, the results of analyses this chapter will aid in determining parameters and assumptions to be applied in the GeoLEC model used in Chapter 4.

Chapter 4 extends upon the barrier diagnosis by developing a mathematical model for assessing levelized cost and variable sensitivity. There is an introduction to levelized cost and a discussion of understanding levelized cost analysis based on methods detailed by Short et al. (1995). This formula is adjusted to reflect very specific assumptions found in geothermal power. These assumptions are included in Short et al's formula to create the GeoLEC formula, a tailored approach to geothermal cost analysis. It is structured to allow for the analysis of individual variables, discounted over time. Sensitivity analysis is then applied to the formula to assess unique properties of each of the variables used in the GeoLEC.

Chapter 5 expands the analytical methods to assess individual policies in a contemporary and future state. This analysis utilizes the results of the previous chapters to identify policy options that should be tested. Contemporary policy options are used to establish the current impact of policy incentives on levelized cost. Alternative policy options are taken from the literature review material to establish a basis for options found globally and in theory. The aim of this chapter is to compare the effects of current policy

against those more tailored to the specific barriers to geothermal power.

Chapter 6 will provide a summary of the overall results and their implications. An expected result is that not all policy alternatives will provide improved options for policy application, but the key is to identify those that do. Based on the findings, this chapter will provide the reader with a set of recommendations. Also included in this chapter is a discussion of paths for further study.

1.7 Summary:

Policy created specifically to address the needs of an industry, in this case geothermal power, follows a simple logic. This position is, and has been, advocated for by industry professionals and academics in a variety of disciplines, lending credence to its validity. However, this is short on empirical research. In Chapter 1 the research problem and design are introduced to help the reader better understand the significance and role of the work in the following chapters. Summaries of those chapters was discussed, and as the audience follows this research the analytical framework bring us back to the beginning by testing policy, as reflected in the analysis of developmental barriers. There is a need for more empirically based research to support the position of more tailored geothermal policy mechanisms. The following chapters are written to support this need.

Chapter 2

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

This research design requires, and is ultimately based on a solid foundation of knowledge. Geothermal power should be understood in context as not only an individual energy technology, but also as a functional part of the U.S. energy market. To expand the approach discussed in chapter 1, this chapter begins by presenting a review of current literature in the field of geothermal markets to develop a theoretical framework for studying the objectives defined here within the research. Subsequent chapters will highlight the quantitative and qualitative findings of the study, and are will be based on the foundation of material that follows. In addition to providing an adequate foundation for further study, this chapter provides the reader with a greater understanding of the market and policy research, relevant to geothermal power in the United States. This chapter will present an introduction for “geothermal specific policy”, define the technologies, and provide a history of relevant policymaking as background material. This process begins with a theoretical framework and problem statement. The problem statement is maintained from Chapter 1, as the foundation for developing the appropriate research questions and design that is the subject of subsequent chapters.

2.1 Theoretical Framework:

The beginning of this chapter details a collection of knowledge, which is representative of several research areas focused on geothermal energy. A theoretical framework, as detailed in Fig. 2, organizes the network of knowledge on the subject, and provides a mapping of the process by which the research objective is derived. This

framework is intended to aid the reader in following each of the author's assertions in building a detailed research design for scholarly relevance. Each component of the framework is discussed and follows a procedural process of development.

With most research endeavors, the most important acknowledgement is to begin with a defined topic area. This study is focused on geothermal power, and its relationship with contemporary energy policy. The larger topic of geothermal energy is compartmentalized by end use; with each option structured under a different revenue stream. Power applications are measured in energy capacity (MWe), while other forms of geothermal (e.g. direct-use, heat pumps) are represented in thermal units (MWt) and are applied to measuring thermal displacement. The framework, as represented, is only applicable to the power sector of geothermal. Therefore, regardless of shared qualities or characteristics, this study is not to be confused with direct use or heat pump applications.

The topic area and the definition of sub-technologies are discussed informally within the framework and literature review, so as not to distract the readers from the study's main objective. With that being said, a detailed review of interdisciplinary literature is provided in this chapter to familiarize the reader with industry, market, and policymaking variables that are relevant to this study. Industry research brings an understanding of the technological, geological, and development attributes, which are specific to the geothermal industry. Market research and analysis provide macro-level relationships of geothermal power within the greater energy sector, by giving awareness to developmental barriers and installed capacities. The remaining research area (e.g. policy analysis) is a review by which the interaction of policymakers, industry and market data, and resources are inner wound.

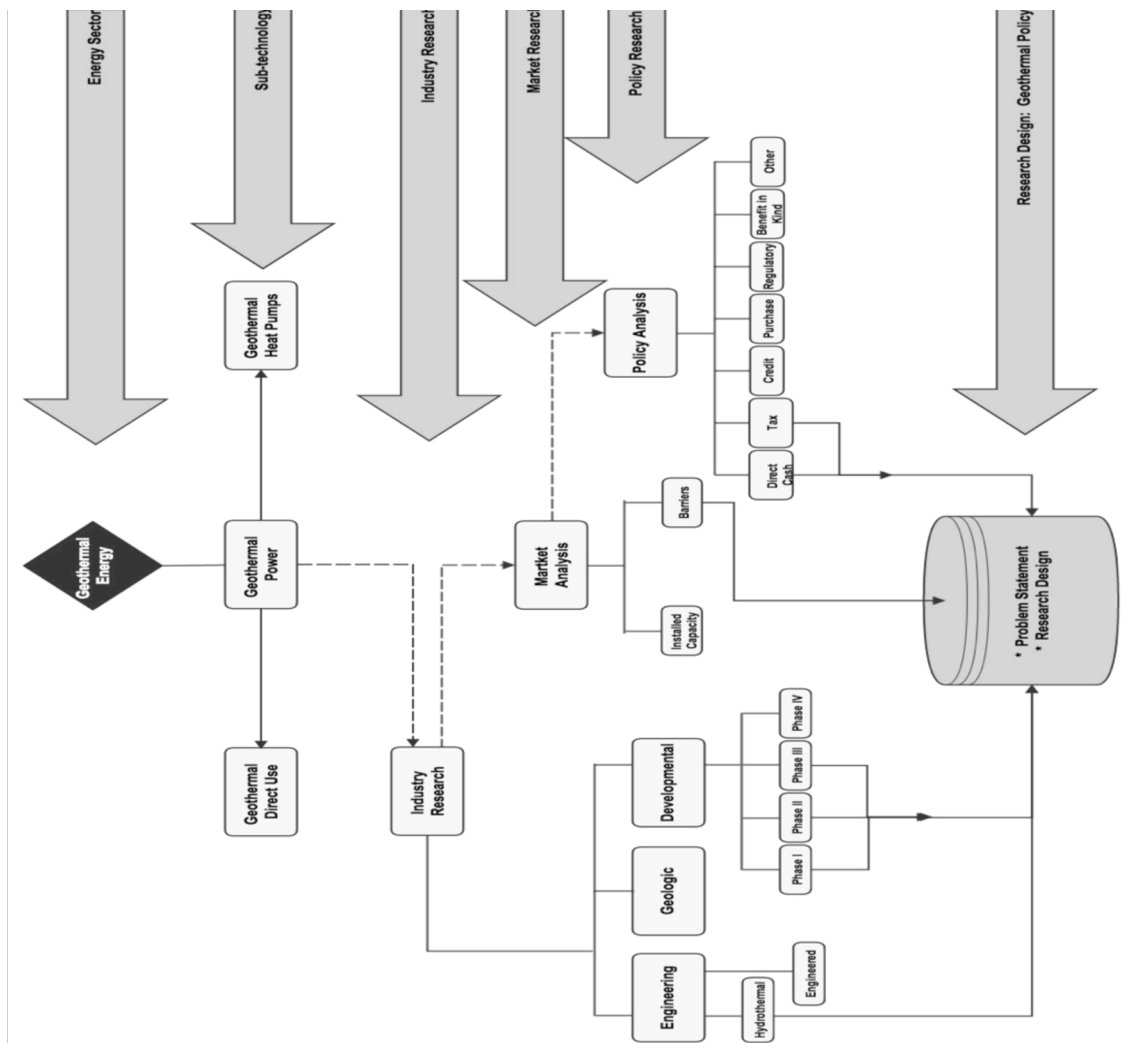


Figure 2.1: Theoretical Framework

2.2 Why Geothermal?

Globally there is a clear need for dependable, base-load electricity. Of the common renewable energy sources only geothermal represents these characteristics of dependability and base-load capacity (Richter, 2008). John McIlveen makes an even more direct statement, by saying, “You cannot replace a coal plant with any other renewable (besides geothermal) and still meet base load requirements” (McIlveen, 2011,

p. 1). Richter continues by stating that within the geothermal sector, political support needs to grow, but the key arguments used to support geothermal energy development focus on: predictability, sustainability, reduced environmental impacts (compared to fossil fuels), security, and lastly, competitive costs (Richter, 2010). Data suggests that the economic benefit derived from the geothermal sector far exceeds the investment, with every dollar of investment; geothermal energy's resulting growth of output to the U.S. economy is \$2.50, which is a return of 250% (Kagel, 2006) (Geothermal Energy Association, 2009). This output can be observed directly in jobs, wherein 95% are permanent and the majority of those are full-time. Jobs data from 2004 shows that within the industry 4,583 direct jobs and 6,877 indirect jobs (Kagel, 2006) are represented, and as installed capacity increases so should the sector's employment levels. Jobs data from 2010 supports this with 5,200 direct and 7,900 indirect jobs (Jennejohn, 2010). More contemporary data, published by the US Department of Energy (DOE) and the Geothermal Energy Association, shows that jobs per megawatt (MW) installed are substantially greater than those for natural gas development. Construction jobs per installed MW are 4.0 (geothermal) and 1.0 (natural gas), while operation and management (O&M) jobs per installed MW are 1.7 and 0.1 respectively. That represents nearly 11x the total employment produced by geothermal power compared to natural gas (Geothermal Technologies Program, 2006) (Jennejohn, 2010).

Recognizing this breadth of impact supported by the energy sector, the key characteristic of geothermal power is the long-term stability and dependable power curve. Valued by both utility and grid operators for base-load conditions, geothermal plants have no issues of intermittency with a capacity factor greater than 85% (Massachusetts Institute of Technology, 2006). This characteristic is significant when comparing the capacity factor of geothermal (85-90%), and as high as 95% (McIlveen, 2011), to that of

wind (35-45%) and solar (21-32%) (Gelman, 2010). With 40,000MW (including EGS – Enhanced Geothermal Systems) of potential capacity, in the US alone, and a levelized cost very competitive with other energy sources (Lazard Ltd., 2009) (Richter, 2009) (McIlveen, 2011), geothermal is a very attractive energy option.

Although not exempt from emissions, because the reality is that all technology produces emissions throughout their lifecycles, the emissions from geothermal are significantly lower than that of fossil based energy systems. Other environmental impact comparisons, such as plant area (e.g. footprint) are much lower due to the high capacity factor and base-load characteristics, which is the amount of energy (MWh) produced per acre. This is substantially less for geothermal than wind, solar, or coal, according to an analysis from Jacobs Securities (McIlveen, 2011).

2.3 Geothermal Utilization and Development:

Geothermal energy is subject to geographic confinement, not only in the United States but also around the world. The most prominent regions, globally, for geothermal exploration and development are located in the landmasses, which encircle the Pacific Ocean, and may be better known as the “Ring of Fire”. Although geothermal resources are certainly not limited to only this region, it is within this region that the most viable resources have been discovered in the United States. To better understand the potential benefit of geothermal energy, the current and potential states of development in the United States will be discussed.

At present fifteen (15) states have been identified to contain known geothermal resource areas (KGRA). However, only eight (8) of which make up the 3187MW of total U.S. installed capacity in 2012 (Geothermal Energy Association, 2012). Ongoing development in the remaining states is expanding the use of traditional hydrothermal

resources, while introducing advanced technologies to produce energy from enhanced geothermal (EGS), low temperature, and geopressed systems beyond the traditional western states.

2.4 Geothermal Technologies:

The choice of geothermal technology for producing power is subject to the resource characterization, and other logistical matters (i.e. transmission), that make up vital components for determining the project's economic feasibility. Dry steam, flash power, and binary systems are the dominant geothermal power technologies. Determining temperature, pressure, and fluid density are key factors distinguishable of each type.

In 2008, the U.S. Geological Survey (USGS) conducted a national resource potential assessment for geothermal. The result of this study supports the use of a variety of surface (power plant) technologies, by defining the estimated resource potential at P5, P50, and P95 probabilities. For traditional hydrothermal resources, the focus of this research, identified resources at P50 are estimated at 8,356MWe. The P95 to P5 range for such resources is 3,675MWe to 16,457MWe. Undiscovered hydrothermal resource estimates resulted in the 7,917MWe, 23,739MWe, and 73,286MWe - at P95, P50, and P5 respectively. These estimates do not take into account the resource potential of EGS technologies, which are considerably higher at 345,100MWe, 507,000MWe, and 727,900MWe; again representing P95, P50, and P5 estimates (Williams et. al., 2008). Based on these potential resource estimates the applicability of surface geothermal technologies is broad. The following section will detail each technology.

2.4.1 Dry Steam:

The most sought after resources in geothermal electric generation are called "Dry

Steam”. Surface temperatures at extraction are above 235°C and a resource pressure of 30 bars (Glassley, 2009) mean that dry steam resources are extracted in a full steam state and are directly used to power a turbine. This process requires no separation of resource content, because of its pure steam form (Geothermal Energy Association, 2009). Once cycled through the turbine, the steam is condensed and returned to the reservoir to replenish the resource stock, as shown in Fig. 3. An alternative method is to simply allow the steam to evaporate, but this requires a more substantial resource to produce an equivalent power capacity (Dickson & Fanelli, 2004). Condensing the steam, although more costly in process, is more resource effective as the stock is more sustainably maintained. To condense the steam back into a liquid form, plants utilize either air-cooling or water-cooling towers. In cases where the water-cooling is used, steam is released as a by-product into the atmosphere (Geothermal Energy Association, 2009). This is a point of concern to some, as particulate matter is emitted. Because of the immense heat resource that can be extracted the capacity factors of dry steam plants are typically above 90% (Glassley, 2009).³

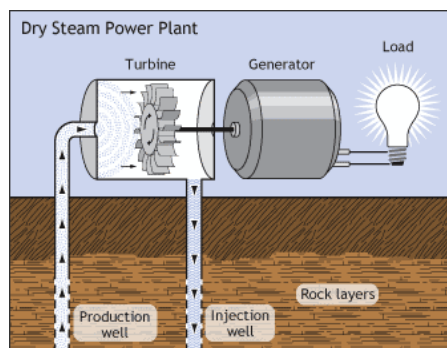


Figure 2.2: Dry Steam (Cross & Freeman, 2009)

³ Cross & Freeman (2009) is a publically sourced publication contracted by the U.S. Department of Energy’s Geothermal Technologies Office.

2.4.2 Flash Power:

When super-heated water rises to the surface under immense pressure, it must be “flashed” (reduction of pressure) (Glassley, 2009) to create steam to power the turbine. This method of geothermal generation uses pressurized steam, like Dry Steam systems, but must incorporate an additional step to ensure separation of “brine” (resource fluids) and pressured steam for optimal use (Geothermal Energy Association, 2009). The “brine” can be used in direct heating, but ultimately will be returned, with the condensed steam, to the resource reservoir in a closed loop cycle. The type of resource available determines this technical distinction in generation. Condensing steam in a flash plant follows a similar process as that of direct steam (see Fig. 4). In addition, both dry steam and flash power plants have minor amounts of emissions of carbon dioxide, nitric oxide, and sulfur (Shibaki, 2003). Open loop systems and allowing steam to evaporate into the atmosphere are the leading contributors to these emissions, but are negligible compared to those of fossil fuels.

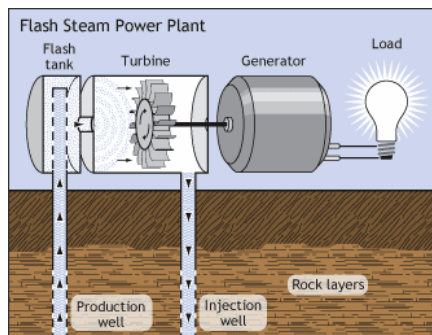


Figure 2.3: Flash Power (Cross & Freeman, 2009)

2.4.3 Binary Power:

Advancements in geothermal technology have allowed resource temperature requirement to decrease and broaden the effective range of viable temperatures. Applications using binary technology extract low-temperature resources (<150°C) and utilize processes, like the Organic Rankine Cycle (ORC)⁴ (Geothermal Energy Association, 2009). Since the majority of hydrothermal resources are within the range of 75°C and 180°C, the operating application of binary technology has the widest range of use (GEOFAR, 2009). The application of Binary cycles heated, but lower temperature resources through a closed loop system to heat a secondary liquid, with a significantly lower boiling point to water or brine. Typically used within binary cycles, the secondary liquid used is often isobutane or pentafluoropropane (Geothermal Energy Association, 2009), and in the Kalina cycle an ammonia/water mix. As the secondary liquid boils the steam is pressurized and fed through a turbine. Since the system loops are closed, the geothermal brine is returned to the reservoir and the secondary liquid is condensed and repeatedly cycled. A great benefit of binary plants is that any concerns over environmental emissions become reduced to near zero (GEOFAR, 2009) (Geothermal Energy Association, 2009). With a completely closed loop system for both the primary and secondary working fluids, neither is exposed to the environment (see Fig. 5). Even more so, the use of ammonia as a secondary working fluid, in the Kalina binary cycle, is chosen because it is environmentally benign and has shown increased efficiency over the ORC. This is not a clear separation of the two technologies, as ORC offers greater

⁴ The organic rankine cycle is a binary turbine technology that uses a secondary working fluid to power a steam turbine in the creation of electricity. The primary working fluid is harvested from the sub-surface and the heat is extracted through the use of a heat exchanger. Ormat Technologies developed this method.

capacity $>150^{\circ}\text{C}$ and Kalina stands on greater low-temperature efficiencies (GEOFAR, 2009). Binary applications are limited by maximum temperature ($<175^{\circ}\text{C}$) and economics, as the efficiency is lower compared to flash and direct steam applications.

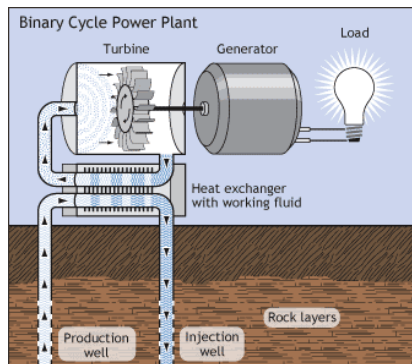


Figure 2.4: Binary Power (Cross & Freeman, 2009)

2.4.4 Dual Flash/Binary Systems:

Utilizing the technologies noted previously, flash power and binary power could together be combined to harvest a greater portion of the resource capacity. Once the steam is cycled through the flash turbine it is condensed as a heated liquid and cycled through an adjacent binary system. This liquid causes the secondary liquid to flash, powering a second turbine before being condensed again and returned to the resource reservoir. The Geothermal Energy Association describes this process by noting that the steam exiting the backpressure turbine, at the first stage, is then condensed and used to supply the binary turbine in the second stage (Geothermal Energy Association, 2009).

2.4.5 Enhanced Geothermal Systems (EGS):

In 2006, the Massachusetts Institute of Technology (MIT) led efforts to publish a report detailing the state of Enhanced Geothermal Systems in the United States. This work has since become an integral source of information on the topic. Enhanced Geothermal Systems, also called Engineered Geothermal Systems, (EGS) are commonly defined, by the U.S. Department of Energy, as the economic extraction of engineered hydrothermal resources to produce power (Massachusetts Institute of Technology, 2008). The afore mentioned MIT report, however, broadens this definition to include any geothermal technology, not currently in production, and in need of enhancement or stimulation (Massachusetts Institute of Technology, 2008). Based on this context other technologies are included, such as co-generation with oil and gas extraction and geopressured resources. The MIT report's definition of EGS is important as the report covers each distinctly. In other cases EGS is also referred to as "hot dry rock". With the success of Ormat Technologies Desert Peak II reservoir stimulation (Ormat Technologies, 2013), EGS applications can be further distinguished as "greenfield" and "in-field". A greenfield project is understood as one which requires full concept development, where as in-field EGS is the stimulation of a resource within, or near, an active hydrothermal reservoir to improve permeability.

EGS utilizes drilling technologies to access resources deep within the Earth's crust, generally from 3,000 to 10,000 meters. Because the heat is dry, EGS applications must create the reservoir by pumping water into the sub-surface, to enhance permeability, so as to extract the resulting steam to power a turbine. Therefore, after accessing a resource, the resource is stimulated in a process called hydro shearing. This process introduces water, under pressure, to create fractures in the subsurface and improve permeability. With a viable, engineered hydrothermal system, heat can be extracted to

power a binary system (Geothermal Energy Association, 2009). This technique greatly expands the geographic viability of geothermal power, as drilling will eventually reach dry thermal manifestations at varying depth around the globe. This is, however, an optimistic view of the EGS application, since specific geologic formations are necessary to engineer such a system (Massachusetts Institute of Technology, 2008). The benefits of EGS allow for greater flexibility in siting (closer to demand, transmission) and enable geothermal applications in geographic locations outside those of traditional hydrothermal development. The authors of the MIT report concluded that the potential electric capacity of EGS was near 100,000MW_e by 2050 (Massachusetts Institute of Technology, 2008).

Compared to traditional hydrothermal technologies, EGS applications have strong benefits. Addressing the issue of resource restriction for siting is a significant advantage. There are, however, some restrictions present in the EGS applications as well. The most notable of these is the risk of induced seismicity. Although it is referenced as a manageable risk, the authors of the MIT report note that its direct impact is in public perception (Massachusetts Institute of Technology, 2008). Siting of projects is likely to be most impacted as developers weigh the economic risks associated with the possibility of sub-surface risk (e.g. resource location, viability, longevity). Of similar environmental concern there remains uncertainty in the potential flow of fracturing liquids in use with EGS methods. Fluid loss is being studied relative to fracturing and reservoir flow near fluid channels and the cooling of associated rock (Massachusetts Institute of Technology, 2008). The surface application resembles that of a binary turbine, as shown in Fig. 5.

2.5 Geothermal Development Stages:

The development of geothermal resources is defined in stages. Each stage represents a different layer in a functional foundation toward a fully operational

geothermal plant. A categorization of activities, risks, costs, and time is required to be able to differentiate an assortment of potential obstacles. A review of the literature presents a relatively consistent determination of requirements for each stage, and is discussed thoroughly in the following. Here these stages are discussed with reference to multiple sources, but within those references it will rely heavily on the Geothermal Energy Association's (GEA) terms and definitions for reporting of geothermal capacity. These reporting requirements are comparable to those presented in Canada, Australia, and Europe, and are used in direct association to the analytical scope of later research.

2.5.1 Phase I - Resource Procurement and Identification:

In the initial stage of development several facets of preparation are needed prior to early-stage development, in the form of exploration and drilling. The GEA's reporting requirements find that the resource procurement and identification process includes the identification of resources, securing the rights to the resource, pre-drilling exploration, and the completion of an internal transmission analysis (Geothermal Energy Association, 2012). More formally, the reporting code stipulates a categorical qualification process, as follows (Geothermal Energy Association, 2010):

- Literature Survey, Geologic Mapping, or Geochemical/physical surveys (Min 2/3); and
- Internal Transmission Analysis; and
- Land rights and permitting process underway.

Other authors have provided additional details for this stage of development. Alexander Richter classifies legal work, concessions, and permitting within this initial stage of development (Richter, 2010) (GEOFAR, 2009). Deloitte Development, LLC suggests a similar stage in the development process, and is labeled as identification. The Deloitte assessment provides specific cost and time values for the range, and estimates

the probability of success (Fig. 6) for this process: US\$385,000 - \$1million, 3-6 months, and ~ 9-10% (Deloitte Development LLC, 2008). For quantitative purposes the data supplied by Deloitte are used throughout modeling efforts in Chapters 4 and 5.

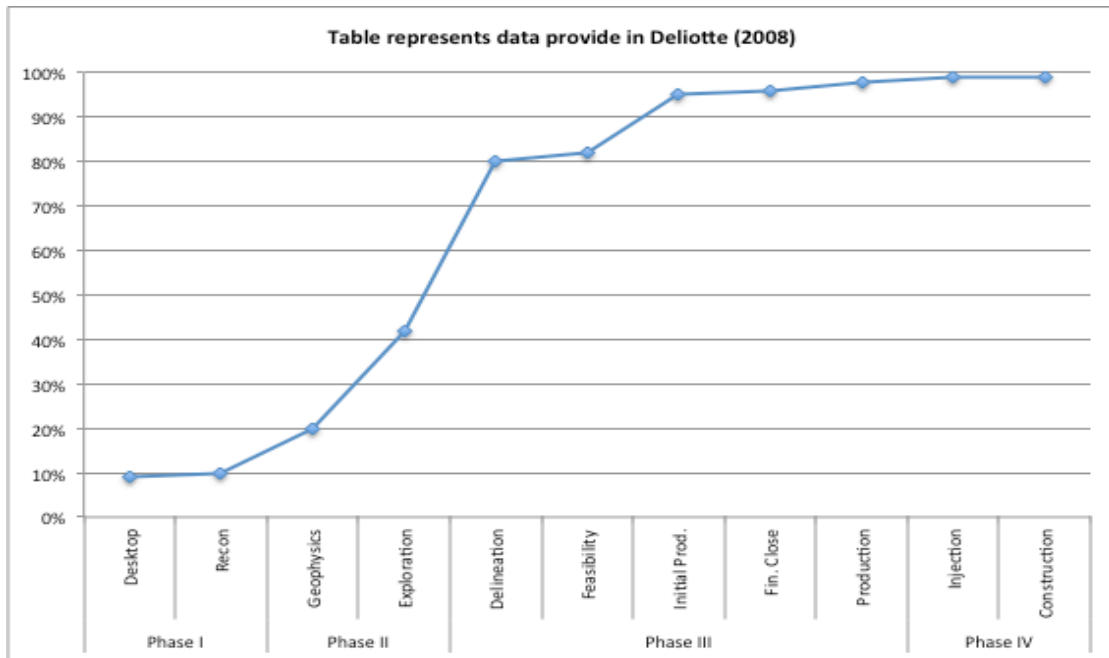


Figure 2.5: Probability of Success by Phase

2.5.2 Phase II - Resource Exploration and Confirmation:

Once the project design and preparation is in place the next stage of development is exploration and confirmation of the resource. The GEA reporting code states that the following conditions must be met (Geothermal Energy Association, 2010):

- Temperature Gradient Holes, Slim Hole Drilled, or Full Size Discovery Well Drilled; and
- Interconnection application or Transmission Feasibility Study; and
- Slim Hole Drilling Permit or Production Well Drilling Permit.

Richter (2010) also includes temperature gradient drilling, but identifies geophysical surveys and geochemical assessments, which can be applied in Phase I of the GEA code. In addition to the initial exploration, further permitting will take place as the project becomes more viable and the business model is adapted for resource compliance (Deloitte Development LLC, 2008). As part of this stage of permitting an environmental impact assessment is undertaken to establish the local implications of the project. Deloitte estimates that the value ranges for this stage are US\$5-10 million, with a project timeline of 1 to 1.5 years (Deloitte Development LLC, 2008). As the project progresses through the stages the probability of completion increases, but the resource exploration risk is greatest in the initial drilling stages. Although a substantial amount of preparation must take place to this point, the risk of drilling a dry well is a leading concern. The aggregate of successful wells to dry wells is estimated at 20% according to GEA (Geothermal Energy Association, 2009), while the U.S. Department of Energy reports that only 20-25% of test wells are viable and 60-90% of production wells support production (Geothermal Technologies Program, 2009). This exploration risk can lead to issues of investor uncertainty. The probability of success for a project at this stage of development is estimated to range from ~ 20-42%, depending on tasks completed (Deloitte Development LLC, 2008).

The National Renewable Energy Laboratory (NREL) published material on development stages to complement other literature. NREL's position, however, addresses development through analysis of financing. This is further categorized by the stages "Exploration and Drilling" and "Construction and Operation" (Salmon, Meurice, Wobus, Stern, & Duaiame, 2011). The "Exploration and Drilling" stage of financing incorporates the traditional development stages being discussed from Start- Up to Feasibility. Associated costs of resource identification are estimated by NREL to be US\$ 14/kw

installed and the rise significantly to US\$300/kw installed for evaluation (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). Risks are also represented in the NREL report and show an inverse relationship to time and investment percentage.

2.5.3 Phase III - Permitting and Initial Development:

Drilling test wells incorporates much of Phase III activities. Based on the GEA reporting code, it is very important to have operational wells for production or injection, or to be able to establish a sustainable reservoir capacity for the project (Geothermal Energy Association, 2010). Other phase requirements involve interconnection studies on feasibility and facility, transmission request, impact studies, plant permitting, power purchase agreements, and secured financing. The following provides further explanation (Geothermal Energy Association, 2010):

- Minimum of 1 full size production well operational, 1 full size injection well operational, or Reservoir characterization completed and sustainable reservoir capacity determined (Min 2/3); and
- Interconnection feasibility complete, System impact study, Interconnection facility study, or Transmission Service Request Submitted (Min 2/4); and
- Plant permit, Power purchase agreement, or Financing secured (Min 2/3)

Richter (2010) describes a focus on exploration of primary resource areas and the collection of data needed to assess the value of resource capacity in geothermal application. Resource assessments will include reserve estimates and flow characteristics (Richter, 2010). Deloitte's analysis combines Pre-feasibility and Feasibility stages under the heading of "Drilling". Much of the categorization of drilling is a leading process of testing, permitting, and proceeding toward a production well. This stage, although combined, is estimated at US\$35-50 million (Deloitte Development LLC, 2008) and requires a significant investment to proceed. NREL finds a "moderate" chance of reaching production, since identification of a resource is often the riskiest part of the

development process (Salmon, Meurice, Wobus, Stern, & Duaine, 2011), and Deloitte estimates the success probability to range from ~ 80- 98%. Note the significant jump in probability once the project reaches Phase III. At US\$169/kw installed (Salmon, Meurice, Wobus, Stern, & Duaine, 2011) and a timeline of 1-2 years (Deloitte Development LLC, 2008) establishing a viable project to extract and produce geothermal power is substantial.

Development of test wells is assessed on a basis of resource and economic viability. Deloitte's cost analysis also holds for this stage at, combined, US\$35-50 million (Deloitte Development LLC, 2008). NREL introduced well field development at an installed cost of US\$1367/kw with lower risk at production and a more significant investment demand (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). Further resource analysis is needed to structure primary design, secure Purchase Power Agreements (PPA) and final permitting. Deloitte includes in their drilling assessment that workforce and drilling expertise may be in a competitive shortage at this stage due to market pricing of resources in the oil and gas industries (Deloitte Development LLC, 2008).

Financing of geothermal projects through this stage requires a greater balance of equity to debt. Salmon et al. (2011) show an interesting distinction in the methods of applied finance for early stage development projects. The implications of their report introduce a variety of finance methods prior to and following the economic downturn of 2008. Prior to 2008, much of the early stage financing was supported largely through private groupings of investors. With limited appetite for tax incentives and the increased investment risks across most sectors, most investment opportunities dried up (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). Rebounding slightly following the global economic crisis in 2008, developers were able to introduce more innovative methods to secure financing. These options include securing private equity in project portfolios;

exchange traded corporate equity, and balance sheet financing (Salmon, Meurice, Wobus, Stern, & Duaiame, 2011). The reason for emphasizing finance is to recognize the applied finance methods at various stages of development.

2.5.4 Phase IV - Resource Production and Power Plant Construction:

The final phase of development, as referenced by the GEA, is the production and development process. A project at this point of development has an identified resource capacity, secured financing, and is likely to have a PPA in place to secure a revenue stream. The probability of success is estimated at this stage of development by Deloitte (2008) as ~ 99%, which represents the lowest level of unknowns in the project timeline. It is not, however, without any risk since the project has to be proven sustainable over time. To meet the qualifications of Phase IV development a project must have the following (Geothermal Energy Association, 2010):

- Plant Equipment Order, Plant construction underway, or Production and injection drilling underway (Min 2/3); and
- Interconnection Agreement Signed, and Transmission system service request studies completed; and
- Approved plant permits, EPC contract signed, and PPA secured.

Once through the preceding stages of development the developer will be able to plan, design, and construct a plant to best utilize the confirmed resource capacity. Richter's classification of this stage takes the existing well formations to develop more production and injection wells for operation. Civil works and plant construction commences (Richter, 2009). It is important to note a direct correlation between plant size and confirmed resource capacity. Financing can be very challenging if development exceeds the resource capacity. Overall financing is significantly reduced in risk, due to the completion of a PPA. Deloitte reports that further permitting is required for long-term operation, with plant construction being the most costly portion of development (Deloitte

Development LLC, 2008). NREL estimates the installed cost/kW at US\$1800 with greatly reduced risk (Salmon, Meurice, Wobus, Stern, & Duaine, 2011), while Deloitte estimates US\$75-85 million for a 50MW plant, which is \$1500-\$1700/kW. During the construction and initial operational stages of production, the developer and operator will continually analyze and test the resource for sustainability, salinity, and temperature gradients to establish a long-term projection of resource viability and capacity (Deloitte Development LLC, 2008). Project financing progresses through the stages of development differently. Bridging the development from exploration and drilling to construction many projects require mezzanine financing. NREL indicates that this financing option requires higher financing costs, as compared to equity financing. There are also limitations for applying this type of financing, such as a drilling contract and a minimum of one production well (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). Given the reduced investment risk of development just prior to entering the construction phase, it is believed that many developers will incur additional debt to proceed. Mezzanine debt should not be confused with traditional project financing, which becomes readily available at the construction phase.

Traditional project financing becomes applicable once the development project has secured a level of equity to secure the debt. Cost of financing is reduced significantly, but like mezzanine debt, securing the project equity is vital. NREL reports that traditional investors (insurance companies, investment banks, etc.) are likely lenders, whom require a long-term resource assessment, PPA, and 50-80% of production wells drilled (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). These long-term financing contracts over options of limited liability to the developer and allow application of many investment driven policies.

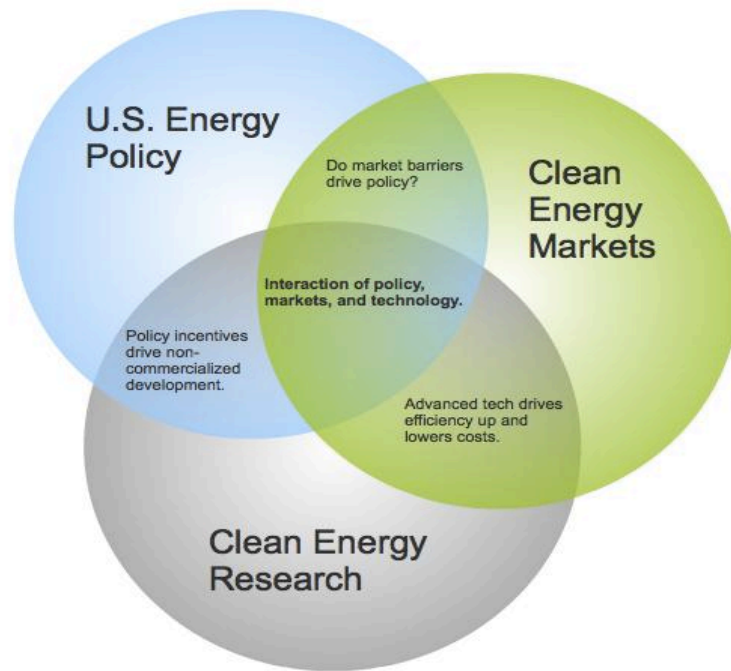


Figure 2.6: Role of Energy Policy

2.6 Why Energy Policy?

Following a strong argument for geothermal power, enhancing the development process and options becomes significantly important. R. Gordon Bloomquist makes a strong correlation between policy and development, he suggests that policy must lead development, therefore the education of policy-makers regarding geothermal is needed to further develop the sector (Bloomquist, 1999). His emphasis is directed toward the education of policy makers, but the intent is clear, and the US DOE Geothermal Technologies Program (2009) suggests the same, finding policy as an important factor for expanding a market centered on geothermal power. Figure 7 shows this representation more clearly. Since geothermal energy is the only real renewable capable of base-load generation, there is a need for both political and policy support (Massachusetts Institute

of Technology, 2008).

Government policy is reflected in nearly all aspects of project development, from cost to time and regulation. Bloomquist (1999) emphasizes this by noting that it begins with permitting and issues of access; and follows through the lifecycle to end with decommissioning or site restoration. Furthermore, he continues by recognizing that the role of the policy maker is vital in developing geothermal power, with comparable importance traditionally given to geologists, drilling supervisors, reservoir engineers, and power plant designers as it relates to successful development (Bloomquist, 1999). Blair et al. (1983) introduce policy in analyzing investment decisions for commercial development of geothermal energy. Their framework of policy and regulatory measures accounts for a variety of policy areas where geothermal projects are dependent. Types of policy application, regarding geothermal energy, are separated into seven categories of subsidy: direct cash, tax, credit, purchase, and regulatory, as well as benefit in kind transfers and other miscellaneous government action (Blair, Cassel, & Edelstein, 1982).

2.6.1 Direct Cash Subsidies:

A subsidy of this nature is considered a direct cash payment, provided by the government, to support the economic needs of both energy producers and developers (Blair, Cassel, & Edelstein, 1982). These types of subsidies can have a high potential cost to government, but are easy to target and can have positive impacts on the relative higher capital costs of geothermal energy. A contemporary example is the 1603 Cash Grant program, which awarded cash payments to projects in lieu of the production tax credit or investment tax credit from 2009 to 2011 (GPO, 2011).

2.6.2 Tax Subsidies:

Government programing and incentives are commonly dependent on the level of tax revenues collected to formulate budgetary capabilities. Tax based incentives, or subsidies, offer energy producers and consumers the opportunity to reduce their tax liability, thereby increasing their net revenue. With an adequate tax-liability appetite, investors are drawn to these types of incentive programs, but there are often limits on smaller firms. Blair et al. (1983) caution that tax-based incentives can create windfall opportunities for investors that would otherwise have no need for the subsidy. This places an additional strain on taxpayers without truly being able to forecast fiscal impacts (Blair, Cassel, & Edelstein, 1982).

2.6.3 Credit Subsidies:

The government can support development projects by intervening in loan transactions. This type of government action provides the borrower with reduced developmental costs, while also reducing the financial risk incurred by the lender (Blair, Cassel, & Edelstein, 1982). The reduction in costs and default risk for geothermal projects benefits distributed energy projects more than centralized systems, but it also highlights the need, and access, to traditional lending sources (Blair, Cassel, & Edelstein, 1982). Salmon et al. (2011) find that as a result of the economic conditions, post-2008, the access to traditional financing options have been reduced. Therefore, larger firms are utilizing balance sheet financing, while smaller firms have found success with IPOs (Initial Public Offering) or portfolio financing (Salmon, Meurice, Wobus, Stern, & Duaiame, 2011). Blair et al. (1983) suggest that credit subsidies are often not an attractive option for larger development firms, also supported by Salmon et al., lending support to the idea that credit subsidies have a more restricted audience.

2.6.4 Purchase Subsidies:

As uncertainty is a driving component of energy pricing, the baseload production of geothermal energy and relatively high capacity factor give utilities greater access to stable consistent power (Blair, Cassel, & Edelstein, 1982). Subsidies based on purchase pricing place the government entities under contractual obligation for purchase of geothermal energy. These contractual specifications are given as a price and quantity. The benefit of such policies is to lower overall cost by establishing a revenue stream. Indirectly, the benefits of purchase subsidies are well recognized by investors and lending agencies as a reduction of perceived risk (Islandsbanki, 2011) (McIlveen, 2011). A non-governmental form of this type of subsidy is the Power Purchase Agreement (PPA).

2.6.5 Benefit in Kind Transfers:

To qualify as a benefit in kind transfer, there must be an implicit cash transfer for government products or services, which are below the present market value (Blair, Cassel, & Edelstein, 1982). An example of this type of benefit is the leasing of federal or state lands, for a specific duration and rights to royalties on energy sales.

2.6.6 Regulatory Subsidies:

Government regulatory actions, which create an environment that benefits one technology over another, is defined as a regulatory subsidy (Blair, Cassel, & Edelstein, 1982). The promotion of technologies based on renewable vs. non-renewable classifications, or the uses of renewable portfolio standards (RPS) are examples of this type of subsidy. RPS statues create state obligations on utilities to provide a stated percentage of power from renewable sources. The Public Utilities Regulatory Policy Act of 1978 (PURPA) made way for access of distributed generation, including geothermal

energy, by requiring utilities to purchase non-utility generation.

2.6.7 Other Government Actions:

Although the preceding policy categories apply to most geothermal incentives, there is also a need to include those incentives that fall outside their purview. The most recognized incentives that are considered “Other” have to do with research, development, and deployment (RD&D). Advances in technology and technological processes, create reduced risk and improved economic environments by increasing efficiencies and reducing costs. The display in Figure 8 represents the relationship of each policy type with its respective point of implementation in the geothermal development cycle.

Prob. Success	Subsidy Type	Example
Phase 1 (9.5%)		
Phase 2 (31%)	Benefit in Kind Subsidies	BLM Federal Leases
Phase 3 (90%)		
Phase 4 (99%)	Tax subsidies	Property Tax Reduction
	Credit Subsidies	1705 Loan Guarantee
	Purchase Subsidies	PPA Contracts FITs
	Regulatory Subsidies	RPS PURPA
Production (100%)	Direct Cash Subsidies	1603 Cash Grants
	Tax subsidies	Property Tax Reduction PTC
	Other Gov't Subsidies	GTO Grants/Awards ARRA

Figure 2.7: Incentive by Life Cycle Phase

2.7 Defining “Geothermal Specific Policy”:

Policy issues in geothermal development can take a variety of forms and be viewed from as many perspectives. With an intricate network of technical and non-technical disciplines engaged in the development process of bringing geothermal power to the grid, the public looks to geologists, engineers, business developers, and the like to formulate valued positions on the course energy policy should take. Given the nature of the literature available for review, there are a variety of positions that one can take with regard to designing a research model. But at last, there must also be refinement. It is through this process of refinement that this research will produce a common statement, shared by multiple authors with varied backgrounds. This position is paraphrased as; ‘geothermal power requires more tailored policies to enable development’ by offering more support to the needs of the industry (Bloomquist, 1999) (Doris, Kreycik, & Young, 2009) (McIlveen, 2011). This point is considered as the bridge connecting each of the components in the theoretical framework, discussed later in this chapter. The individual roles found within the development process are relevant to defining one’s individual perspective. It is believed, by the author, that a person’s role in the industry informs the interpretation of policy benefits.

R. Gordon Bloomquist, PhD discusses a need for geothermal specific policy, in an article, entitled “Making the transition to geothermal educating policy makers” (Bloomquist, 1999). While the intent of this publication is to focus on creating a process to better educate policy makers on the benefits of geothermal power, there are multiple comments that recognize a need for more tailored policy. He comments directly on the role of the policymaker in geothermal development as a key stakeholder, much like the geologist, and project engineer. Bloomquist follows by recognizing the lack of awareness to geothermal technologies in education and academia. Thus in creating a report with

policymakers in mind, the industry will need to be able to relate directly to the policymaker's existing, and possibly limited, foundation of knowledge and experience (Bloomquist, 1999). In light of this he refers to the examples of oil and gas in particular, and mining in general, to draw on a pre-existing knowledge base. These points suggest that the underlying issue is a lack of geothermal awareness in policy making. From this interpretation, a more tailored approach to policy is needed. This is not, however, the only occurrence wherein Bloomquist suggests a gap in how policy is applied to geothermal technologies.

Six years later Bloomquist details a history of U.S. geothermal policies in, "The Evolution of U.S. Policy Designed to Encourage Geothermal Development Provision of Access and Encouraging Project Development" (Bloomquist, 2005). . He identifies that the risks in developing geothermal resources have a direct and inverse effect on the access to modes of conventional financing. At the time of this article's publication, 2005, Bloomquist makes a strong case that past policy initiatives are as valuable today as when active in 1980, with the passing of the Energy Security Act (Bloomquist, 2005). Examples of these types of policies include the User Coupled Confirmation Drilling Program, Feasibility Study Loans, and Loans for Geothermal Reservoir Confirmation Program, with each being targeted to early-stage geothermal development and exploration. As is discussed later, resource exploration and sustainability are a unique attribute within the current renewable energy portfolio to geothermal power.

More recently, in 2010, Bloomquist makes a correlation between development and investment risk, but is more intently focused on the barriers to market entry. Without adequate access to the market, developers are unable to raise the initial capital required for early-stage development. Even with access to the market and the required resources, the financing needed is limited due to a comparatively higher risk, as compared to other

renewable energy, involved in exploration and discovery (Bloomquist, 2010). Although it is discussed in the context of global geothermal applications, the national level commitment to developing “indigenous” resources must also include a method for risk mitigation and cost reduction (Bloomquist, 2010). In Chapter 3, the identification of development barriers identifies which barriers to development are unique and substantial to geothermal as an independent renewable technology.

There is no direct statement advocating for a tailored approach to geothermal policies by Bloomquist, but he does identify specific challenges that suggest the need for such a resolution. This is interpreted by the author as a need for improved market access throughout the development pipeline, and requires a more thorough understanding of how policy is able to aid this process. Bloomquist reflects on past policy to make this point, albeit indirectly, by focusing on the alignment of past policy to meet the challenges faced within the current industry.

These pieces of literature allow for an interpretive approach, and as a whole are believed by this author to reach a deeper meaning. Bloomquist is not the only author whom targets this theme. He does bring several decades of experience in the industry and academia as support for his position. Other contemporary authors are also highlighted in this position.

In 2009, the National Renewable Energy Laboratory (NREL) published an intriguing and thorough report entitled, *Policy Overview and Options for Maximizing the Role of Policy in Geothermal Electricity Development*. Written by Doris et al. this report “explores the effectiveness of the historical and current body of policies in terms of increased geothermal electricity development” (Doris, Kreycik, & Young, 2009, p. 7). Relevant to the discussion at hand, the findings presented in the report show that existing policies are neither sustained or complete in a way that spurs development. This is

because they “lack focus on the special needs” of geothermal power, “lack adequate financing” for market development, and may focus on the wrong audience (Doris, Kreycik, & Young, 2009). Furthermore, as is also suggested by McIlveen, policy mechanisms have a tendency to lump resources together (Doris, Kreycik, & Young, 2009) (McIlveen, 2011). Doris et al (2009) are referencing direct versus indirect usages of geothermal resources and McIlveen (2011) considers renewable energy technologies as a whole, but the point is the same. The Doris et al. report also substantiates key points in the discussion of development barriers by noting that geothermal development projects have longer development cycles, higher initial cost, and higher risk to be carried by the project investors.

In the remainder of their report, Doris et al. also review four policy attributes that they suggest are critical in the development of geothermal energy policy. These lead into a discussion by the authors on gaps in geothermal development policy. The policy attributes are initial costs, geographical resource policy, incentive sizing, and awareness of geothermal benefits (Doris, Kreycik, & Young, 2009). It is through these policy attributes that the authors believe policy design should be focused. Due to a lack of comparative market penetration for geothermal, the observation is offered that: geothermal policies are not focused directly on the geothermal market, which means they are not optimized to facilitate the sector’s development by funding its growth. (Doris, Kreycik, & Young, 2009). Therefore the gaps in the current policy structure can be limited to the following areas, the first of which is to provide tailored policies for geothermal, such as RPS carve-outs. This, they suggest, would improve the state of current policies, but would further require consistency, adequate funding, appropriate audiences, state-level permitting, and more innovative policies and programs (Doris, Kreycik, & Young, 2009). As these points are echoed throughout the report, there is a

nagging question that is materializing after reviewing both Doris et al and Bloomquist. If, as Doris et al (2009, p.28) state, “the role of policy is to drive development of these resources by furthering technology development, reducing barriers and risk, and bringing down the price of development”, then how are policymakers able to properly identify those barriers that must be mitigated to further development? With the question of “what” being supported in the literature, there remains the question of “how”.

John McIlveen, of Jacobs Securities in Toronto, makes the statement that the current method of subsidizing geothermal projects is inappropriate to stimulate new projects. Given the nature of the current subsidies being loaded on the back-end of development, they fail to properly navigate the bottleneck in the front-end of the geothermal development cycle, which includes various barriers (McIlveen, 2011). In this article McIlveen is structuring a framework to support his overall position, to modify policy mechanisms to the needs of the geothermal industry. Because the current structuring of policy incentives caters to rapid deployment, the proportional break down of subsidy funding per MWh is more than 20:1. This is low compared to coal, solar PV, and wind power, and represents only \$0.92 per MWh for geothermal and more than \$20 per MWh for the other energy technologies (McIlveen, 2011). These calculations are provided on data from the Energy Information Administration (EIA). Keep in mind that this is based on the ability to produce power as a function of subsidy funding. Even within just the renewable energy sector the disbursement of 81% Investment Tax Credit (ITC) funds go to the wind industry, while only 3.8% are subject to geothermal projects (McIlveen, 2011). This is further disproportionate, when one considers that pre-construction costs for geothermal projects can easily be in the millions of dollars, compared to wind and solar, which are typically only in the thousands of dollars (McIlveen, 2011). These issues are fully inline with the Doris et al report, when they

stated that the barriers to development are time, initial cost, and resource risks (Doris, Kreycik, & Young, 2009) (McIlveen, 2011).

These risks in comparison are controllable in the development and costing of wind and solar projects, making it more challenging for geothermal developers. The difference in power quality between geothermal and other renewables is that, as a baseload provider, geothermal can directly replace coal-fire plants without issues of intermittency and the comparable load requirements (McIlveen, 2011).

Each author, or publication, referenced in the preceding section carries a common position: Geothermal development requires policies that are tailored to the needs of the industry and technology. Policy incentives created by, among others, the Energy Policy Act of 2005 and the American Recovery and Reinvestment Act of 2009 have been broadly applied to a variety of technologies defined as renewable, or clean. However, as Bloomquist, McIlveen, and Doris et al. point out, this only marginally supports the unique needs of the geothermal sector. Therefore policy incentive should enter a state of assessment and design to best support growth in the U.S. geothermal industry.

2.8 Problem Statement:

Using the premise provided by reviewing works by Bloomquist, McIlveen, and Doris et al. the following question arises; if geothermal technologies need tailored policy, how should that policy best be tailored? Market analysis can be used to target specific barriers development and growth. The author believes these barriers allow for the identification of technological, scientific, and economic characteristics, specific to geothermal power, present in the literature review. There is then a question of how well does contemporary policy address these barriers related to geothermal development? If the position held by Bloomquist, and others, are accurate, then it is also appropriate to

develop an analytical metric to test this premise. From the literature reviewed this is believed to be a missing component to a more robust analysis of policy applied to geothermal power. Therefore, this study will target the questions found through review of the literature and model analytical metrics to measure the results.

2.9 Summary:

In this chapter the components of the theoretical framework are connected under a common position. Bloomquist (1999), Doris et al. (2009), and McIlveen (2011) offer a sound position, which calls for a more tailored approach to geothermal policy. With this in mind the literature review introduces a foundation for understanding the technical, economic, and social factors of developing geothermal power. It offers improved emissions, as compared to fossil fuels, and is safer over time than nuclear power. Thus to promote market growth for geothermal technologies, research is needed that focuses on the problems identified above. Analysis of developmental barriers is covered in the following chapters, and expands on the need for tailored policy.

Chapter 3

BARRIER ANALYSIS

A more thorough understanding of each variable, unique to developing geothermal power projects, can be provided through assessing the industry's barrier characteristics through literature and survey. The literature published in recent years represents a significant part of the contemporary understanding of the challenges faced within the industry. Geothermal agencies, like the Department of Energy's (DOE) Geothermal Technology Office – formerly the Geothermal Technologies Program – (GTO), the National Renewable Energy Laboratory (NREL), and the Geothermal Energy Association (GEA) have all presented findings within a larger context of geothermal technologies. Understanding the developmental barriers allows for the industry to monitor value related change as exhibited throughout the sector.

Reviewing literature on the topic of barriers is the first step in establishing a better understanding of the ongoing relationship between developmental barriers and applied policy. This chapter highlights a collection of publications in the form of an annotated bibliography, which provides each source its own summary. This information is then organized, based on the creation of a categorized grouping of barriers. Once completed this allows the study to assess each barrier by frequency of use. To validate the results of the literature collection, the previously identified selection of barrier categories, are used to survey industry professionals. Survey results are compiled and compared, in this Chapter, to market literature on the barriers to development, which determine consistencies over time.

The diagnostic method of this research combines the literature review of barriers

with the results of a survey to provide guidance for determining the structure and input variables to be used in analytical modeling. This chapter will detail the problem definition, the collection of data and the processes for both categorization of barriers and the assessment of survey results.

3.1 Problem Definition and Barrier Review:

The distribution of barriers suggests it is clear that certain barriers are more frequently agreed upon than others, however, the terms of defining them vary by author. Slight variations are present in how specific barriers are defined and/or identified. This, therefore, suggests that for proper analysis, a method of categorizing development barriers is needed. Some barriers carry across multiple stages of development, such as “government support”, and are quite broad in application from local to federal levels. Ultimately, the need for government support stems from an awareness by policymakers to the needs of geothermal development following a similar path as has already spurred development in other renewable energy technologies, such as wind and solar.

3.2 Research Process:

Describing this approach will briefly, but concisely, offer a progressive method in assessing the relevant barriers to geothermal development and the policy applications in place. This is broken down into steps and stems from information collected in a review of the literature on barriers.

- I. Log the barriers, as discussed by each author, and taking note of overlapping terms;
- II. Define groupings of barriers with parent terminologies;
- III. Identify market issues by category, to subsequently be used in the assessment of individual barriers;
- IV. Quantify the use of each parent barrier by frequency;
- V. Use the frequency to rank barriers; and
- VI. Assess current policy impacts with the highest ranked barriers.

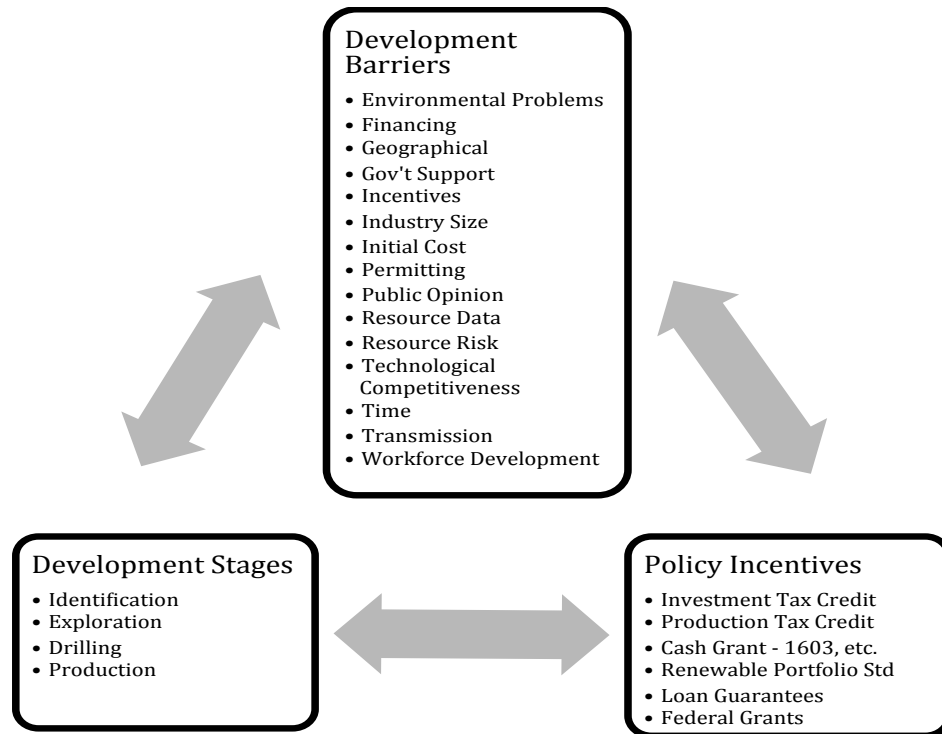


Figure 3.1: Diagnostic Framework

To convey the proper understanding of barriers that are common to the development of geothermal power, a thorough review of the sources is needed to aid the reader. This goes beyond the details of the literature review presented in Chapter 2 as the analysis here focuses on the intents and purposes behind the challenges faced within the geothermal industry (Fig. 9). While each publication is directed toward a much larger discussion than development barriers, to minimize tangential and redundant topics each summary is focused on the context of developmental barriers in geothermal power.

3.3 Development Barriers by Selected Literature

In conducting an analysis that supports the statements made by other authors,

such as Bloomquist, McIlveen, and Doris et al., the selection of published materials is of high importance. For clarity, the stated position targets policy better suited to the needs of geothermal technologies. With this in mind, the publications are itemized into specific barriers found throughout the development and deployment of geothermal power in the United States. The collection of publications is sought from accessible sources and is dominated by institutions and authors under contract to the U.S. Department of Energy. There are multiple sources that are published from non- U.S. sources. For example, Islandsbanki, formerly Glitnir, in Reykjavik, Iceland, which has published annual reports on the United States Geothermal Energy Market. Due to its annual release the use of three editions is aimed at observing both consistency and variability within the industry. Also, while discussing Europe, the GEOFAR reports reflect more of the global conditions that U.S. developers are also facing. For this reason, it is felt that the information within should not be overlooked.

The remaining reports and publications used are uniquely focused on the development of geothermal power in the United States. While each is authored differently, there is a consistency in institutional sourcing. These publications are selected from the ranks of the U.S. DOE Geothermal Technologies Program, the National Renewable Energy Laboratory, the Geothermal Energy Association, the United Nations, and the World Bank as sponsoring agencies to ensure the highest source qualification. The contemporary nature of the publications is part of a constantly changing environment of politics and economies seen in geothermal development since 2008, with several sources predating this point.

Finally, the summaries that follow will try to reflect the overall purpose of each report. Due to the extensive nature that each may, or may not, provide, it has been decided that a limited discussion of each is most appropriate to target directly the

challenges and barriers faced in the industry. In several cases these challenges are not explicitly stated and require more attention to detail their importance. From the following publications the rest of the model to be presented will identify which barriers are most recognized by the geothermal community.

United States Geothermal Energy Market Report, Islandsbanki (2011)

The report provided by Islandsbanki, provides a concise annual review of the respective state of the United States market for geothermal power. The authors highlight the need for more adequate financing options for early stage and drilling operations and the relative delays that result (Islandsbanki, 2011). These delays are subject to the securing of financing and the availability of the drilling rigs, thus contributing to a much higher cost of capital for each project. There is also an issue of risk perception that is identified in respect to the process of financing. Islandsbanki provides a clear representation this as a figure, by detailing the actual versus the perceived probability (Islandsbanki, 2011). To visualize this, as a project proceeds through the development stages the actual probability to completion is much higher in the earlier stages of development than is actually perceived by investors. This may be attributed to the failures of individual projects, but the report thus concludes that barriers to investment are the industry size, long lead times, and high up-front capital costs (Islandsbanki, 2011).

Geothermal Policy Maker's Guidebooks, National Renewable Energy Laboratory (2011)

To promote a more streamlined assessment and process for the structuring of geothermal policy, NREL has compiled an online procedural tool to help policymakers address geothermal electricity generation. The key area of this summary is reflected in the last stage of policy implementation. In this documentation, the authors identify

technological maturity, project timeline, and development risk profile as specific issues to identify when considering a geothermal policy (National Renewable Energy Laboratory, 2011).

Elaborating further, the discussion of technological maturity is focused on the application of EGS (Enhanced Geothermal Systems) and is less relative to co- production and conventional hydrothermal applications (National Renewable Energy Laboratory, 2011). Because this method of geothermal development and technology is still largely in the research and development phase, its application is much more novice, in terms of technological maturity. Project timelines for geothermal projects are comparatively longer than those of sister technologies, with typical scenarios to vary from 4-7 years (National Renewable Energy Laboratory, 2011). The last barrier discussed by NREL, covers the considerable risk that is experienced in the early stages of geothermal development (National Renewable Energy Laboratory, 2011). With a risk profile that is tied directly to the successful location and management of hydrothermal resources, each project can expect to encounter significantly higher risk in the earliest stages of development, with a substantial decline as the project nears production.

As listed in the documentation by NREL, the importance of these development variables is to identify the barriers that policymakers are most likely to encounter when implementing geothermal policy for electric generation projects. The process itself concludes with implementation, but follows as: identify potential, identify challenges, evaluate policy, alternative policy, and implement policy to lead to increased development of geothermal power (National Renewable Energy Laboratory, 2011).

Guidebook to Geothermal Power Finance, Salmon et. al. (2011)

In the Guidebook to Geothermal Power Finance, the authors, Salmon et al., review

the following theme as it relates to geothermal power. They find that given the impacts of the global recession in 2008, financing practices for geothermal development have changed, especially in the early stage financing. This guide looks at the current state of financing and addresses policy tools such as RPS, ITC, PTC, and DOE Cash Grants (Salmon, Meurice, Wobus, Stern, & Duaine, 2011), but it also identifies a series of barriers that are specific to geothermal power.

The authors find that in comparison, geothermal, is less attractive to investors due to the unique financing timeline (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). Add to this, longer development horizons and permitting restrictions, the benefits of baseload generation and a 50+ year operational cycle diminish for investors (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). The core position that is held by the authors is to reflect on the lack of “utility” level investment in the development of geothermal power.

Barriers to Geothermal Development, Jennejohn, D.⁵ (2011)

This document is based on a presentation to a Senatorial committee by a Geothermal Energy Association researcher. Although not formally published, it does provide a broad assessment of the barriers that are common in geothermal power development. Jennejohn categorizes the barriers into the following groups: Exploration and Drilling Technology, Project Finance, Project leasing and Permitting, Transmission, and Workforce Development (Jennejohn, 2011).

Exploration and drilling technologies are not definitive in their methods for

⁵ Jennejohn (2011) references a congressional presentation made with direct regard to non-policy barriers to geothermal development. Although the literature does not reflect government support the author and GEA share the same position.

identification and extraction of resources and according to the United States Geological Survey (USGS) the majority of hydrothermal resources are yet to be discovered (Jennejohn, 2011). These contemporary methods carry higher risk profiles for both the identification and technology applications of the proper resources.

Project financing is also subject to the resource risk as it introduces a significant barrier to market entry. High up-front costs and risk are difficult to align with the investor demanded returns (Jennejohn, 2011). This process of investor decision-making is difficult to justify, as project lead-times and return on investment are directly reliant on risk uncertainties (Jennejohn, 2011).

The lead-times are also associated to permitting and leasing barriers for geothermal development. Progress has been made in the streamlining of the regulatory processes, but lead times are still a determining factor in project stage development and economic viability. Furthermore, Jennejohn identifies that even under National Environmental Protection Act (NEPA), there are a series of regulatory hurdles that can hold up a project, and these hurdles must be overcome to secure stable financing packages for development (Jennejohn, 2011).

Not only is the identification of potential resources a geographic barrier, but the location and cost to connect to the transmission grid is a considerable barrier presented by the author (Jennejohn, 2011). Recent successes have been made to support transmission projects to remote power plants, but more policy support is needed to better connect potential sites. This will, according to Jennejohn, require more interstate coordination and planning (Jennejohn, 2011).

As growth in the industry is expected in the foreseeable future, the last point that is discussed here is the need for additional workforce and development programs. Jennejohn cites an aging workforce and job transfer to and from oil and gas as key points

in the identification of the development barrier. He lists opportunities, such as the National Geothermal Academy, as moving in the right direction, but questions if there is adequate support for these programs federally (Jennejohn, 2011).

Although there are a series of barriers that are discussed in this presentation, the author closes with an optimistic point. He states that even with this variety of barriers to the development of geothermal power, the annual amount of installed capacity has risen (Jennejohn, 2011), indicating that these barriers are not stopping the progress of development only slowing them.

Federal Interagency Geothermal Activities, U.S. Dept. of Energy (2010)

In order to bring a concise knowledge base of policy related to geothermal power, the authors, acting as an interagency working group, have compiled this report to enable all stakeholders in geothermal power an overview of the state of programs and policy as of 2010. There are a variety of topics and discussions held in the report. The one of greatest interest is that under the heading of “Challenges to Geothermal Development”. This discussion is structured under the subject areas of technical, market structure, and policy and regulation (U.S. Department of Energy, 2010).

Technical challenges to geothermal development are focused on exploration, drilling, and environmental activities. The authors suggest that exploration requires improved exploratory and surface mapping, while drilling activities require reduced costs and more accessibility to rigs (U.S. Department of Energy, 2010). Environmental impacts and challenges are then summed under issues of water use and accessibility, and the impacts of seismicity from project operations (U.S. Department of Energy, 2010).

As a leading challenge in the market structure, the authors of this report are aware of issues that stem from the relationship of investment and risk (U.S. Department of

Energy, 2010). Since finance and investment activities and needs are functional throughout the development cycle, understanding this system of risk carries great importance. Further data assessment for EGS technologies and resources must be researched and are expected to aid in reducing the risk perceptions held by investors (U.S. Department of Energy, 2010). Also impacting the market structure the report identifies transmission access and the labor force as challenges that will require further attention to support growth and development (U.S. Department of Energy, 2010).

To close the discussion on development challenges, the authors choose to address issues in policy and regulation. In this an important element is that, “emerging technologies often face policies and procedures that were developed for other resources and technology deployments” (U.S. Department of Energy, 2010, p. 15). With this mindset, they also state that the production tax credit (PTC) is challenging, but may be the most important policy for geothermal development and that the permitting process needs to be improved on the federal level (U.S. Department of Energy, 2010). For states there is a suggestion that more focus be made on assessing the lessons learned through early adoption of technology (U.S. Department of Energy, 2010).

Geothermal Market Report, Curtis (2010)

To assess the barriers of development in geothermal power projects, Curtis can be understood through the following statement, “The disconnect between a robust project pipeline and actual plant startups reflects the industry’s challenges over the last 20 years, but current project development trends reinforce its ambition and exceptional growth potential” (Curtis, 2010, p. 5). For one, Curtis (2010) recognizes the barriers that impact the industry as long development timelines, high exploration cost and risk, and high capital costs, with long paybacks on investment. On the geographic and policy side, there

are limitations due to resource discovery and location, as well as a lack of support through policy at the federal level, when compared with similar industries (Curtis, 2010).

Curtis also elaborates on the challenges faced by developers. For instance, he recognizes that the distance from identified resources to transmission routes is impeding access to the grid and driving up the cost of geothermal development (Curtis, 2010). Additionally, factoring in challenges with technology and regulatory barriers in permitting (Curtis, 2010), it appears that Curtis has correctly identified reasons that limit the direct, and accurate, comparison of geothermal to other energy sources.

Financial Instruments as Support for the Exploitation of Geothermal Energy,
GEOFAR (2009)

The core focus of this report is European finance and investment. Despite the departure from U.S. markets there are a number of points identified as barriers to geothermal development, which translate globally. Geothermal has comparatively higher up-front costs, but lower operational costs. This is suggested to be because of the costs associated with exploration and drilling (GEOFAR, 2009)⁶. In development processes the risks associated with drilling are identified as an important barrier in geothermal, and directly impact the costs of the project (GEOFAR, 2009). It is also suggested by the authors that traditional financing methods are too risk adverse during these early development stages and thus the projects must rely on policy incentives to reduce the overall cost of development (GEOFAR, 2009). Further, more direct, assessment of barriers is illustrated in the discussion by Table E. The authors identify high up-front

⁶ Author's note: Reports from GEOFAR are focused on the market primarily in Europe. It has been included for its concise nature and analysis.

costs, geologic risk, and long pay back periods, with higher investment costs and lower outcomes (GEOFAR, 2009). The table also recommends financial instruments that exist to assist in the mitigation of these barriers, but even those are limited. These instruments are reflected in GEOFAR's member countries (all European), but none are able to support or provide the full range to address each barrier (GEOFAR, 2009).

United States Geothermal Energy Market Research Report, Richter (2009)

In reporting the state of the United States Geothermal Energy Market, Alexander Richter authored Islandsbanki's annual report in 2009. This report covers many topics regarding the state of the geothermal market, as well as a brief discussion of the technology and application. Most important is the discussion provided in the table on page 24 titled, "Opportunities and Challenges in the U.S. Geothermal Market" (Richter, 2009). In this table Richter identifies several challenges.

The lack of both debt and equity are first identified in the midst of the global constraint on funding options that resulted in 2008 onward. In this case, Richter also suggests that smaller development entities are finding it difficult to finance projects within a restrictive investment environment. Pricing fluctuations are possible factors that will impact operational profitability for some, but he suggests that outside of investment, the failures of EGS projects (Basel, Switzerland) are proving to be negative for all geothermal. In more general terms, Richter also discusses the lack of longevity in policy incentives and the need for risk mitigation tools in the U.S. market (Richter, United States Geothermal Energy Market Report, 2009).

Policy Overview and Options for Maximizing the Role of Policy in Geothermal
Electricity Development, Doris et. al. (2009)

In a review of the policies that impact the rate of development of geothermal power, Doris et al. offer a thorough and thoughtful overview to the relationship of geothermal development and policy. Since the focus is squarely on policy, as opposed to development or investment, the tone and process of this report are unique among the rest of the literature. Throughout the course of the discussion the theme is related to the impacts of policy application, with little clear definition of the challenges or barriers that face the industry and its development. With this in mind, the following will be based on an interpretive assessment of the suggested solutions and the underlying needs for them. This should serve as a compilation of respective challenges for the purpose of study.

As an introduction to the state of policy for geothermal development, the authors suggest needing more robust environments focused on adequate financial support (Doris, Kreycik, & Young, 2009). The focus thus should not only be on the needs of geothermal, as a specific energy technology, but also be geographically based to support state specific needs (Doris, Kreycik, & Young, 2009). The authors also recommend that the process of permitting be streamlined and the distinction between direct and indirect technologies be removed (Doris, Kreycik, & Young, 2009). As part of the report conclusions, Doris et al. further recommend that federal support be focused on the need for “technology improvement, price reduction, resource assessment, and drilling assistance” as part of research and development (Doris, Kreycik, & Young, 2009, p. 28).

From the preceding paragraph, and unlike the intended bibliography, the solution/recommendation approach provided by the authors can be used in assessing industry challenges. For instance, government support, in the form of policy, is recommended that it be expanded, but also focused on the industry. This suggests that the

method of policy (e.g. federal) support is ineffective at the macro-level. Permitting, as a development task, is complicated and drawn out, making the progression of development projects contingent on the flow of bureaucracy. As a unique position, the report suggests that geothermal be addressed for both direct and indirect technological uses, and thus may reflect the industry size and associated impact potential. Research and development policies recognize that there are deficiencies in technology, costs, resource assessment, and drilling, which can be translated into stated challenges, such as, technological maturity, high costs, and resource risk.

Although this summary diverges from the method used for other sources, the content that can be ascertained within should not be overlooked. The purpose of this report is very much in line with the goals of this research and therefore it was strongly felt that it was important to include.

Non-Technical Barriers and the Respective Situation of the Geothermal Energy Sector in Selected Countries, GEOFAR (2009)

In a second report surveyed, GEOFAR has provided a very direct and concise discussion of the barriers that impede the development of geothermal power. Although the selected countries are predominately from Europe the assessment and outcomes are held as quite relevant in discussing the U.S. development sector for geothermal. The authors of this report, like others, categorize the barriers and in this case further limit the discussion to “non-technical”. They review several categories: economic and financial barriers; legislative and regulatory barriers; and awareness, acceptance and willingness (public) barriers.

The economic and financial barriers discussed by the authors are limited to high

up-front cost, geologic risk, and long pay back timelines (GEOFAR, 2009). Furthermore, the lack of adequate finance options are directly linked to the viability of each of these barriers. The high up-front costs are due to the need for exploration and discovery of resources, which then are tied to the geologic risk associated with those activities (GEOFAR, 2009). With the lack of finance options available, especially in the early stages of development, the inconsistent variety of policies found in studied countries is also found to be a challenge. Some countries have feed-in-tariffs, others loan programs, and so on.

Legislative and regulative barriers are subject to the myriad of administrative and permitting requirements associated in project development, and thus also carries extended time variables (GEOFAR, 2009). The authors also note the lack of resource definition as a legislative hurdle, as well as issues that arise from defining ownership. Further assessment of barriers to geothermal development is focused on the indirect variables, such as public opinion, political will, and environmental problems (GEOFAR, 2009). These barriers are defined under the category of awareness, acceptance, and will.

Geothermal Tomorrow, U.S. Department of Energy (2008)

This report brings together a variety of contributors, from each of the national energy laboratories from around the United States to discuss the future of geothermal power. Due to the vast nature of research areas and topics there are multiple sections to the report, with a range of discussions from EGS to finance and pricing of geothermal power. As a much smaller component of the report there are several statements that reflect challenges faced by the geothermal industry.

To introduce the report and put it into context, Ed Wall, from the DOE Geothermal Technologies Program, writes, “Despite great potential, geothermal energy

faces several barriers to growth. These issues include limited geothermal siting opportunities, inadequate technology, and high startup costs” (Geothermal Technologies Program, 2008, p. 2). Further into the report the commentary by the authors identifies geothermal power as specifically susceptible to these higher cost factors. The first finds that regional aggregation and local transmission constraints are comparatively weak and second, the lack of stable pricing for fuel forecasting, R&D, and most of all policy are a significant motivator for the energy sector as a whole (Geothermal Technologies Program, 2008).

United States Geothermal Energy Market Research Report, Richter (2008)

To identify the respective source of information, this report is an earlier precursor to the Islandsbanki and Richter reports summarized for 2011 and 2009, respectively. Glitnir was renamed Islandsbanki in 2009. In this report the author, Alexander Richter, covers a broad discussion of the state of the U.S. geothermal energy market in 2008

As the geothermal industry in the U.S. finds the potential for rapid development and growth, Richter identifies the challenge of resource logistics and expertise in the geothermal sector (Richter, 2008). As this development continues, the relationships across the development timeline must be strengthened to support the stability needed to drive down costs, since the sector remains fragmented in funding and development (Richter, 2008). He also notes that the political support needed to move the sector forward must grow, but also the duration of support must become more long-term to foster confidence (Richter, 2008). This support is suggested in the form of incentives, which he feels would best be able to help reduce the risk associated with geothermal development projects (Richter, 2008).

Geothermal Risk Mitigation Instrument and Incentive Program, Bloomquist et. al. (2007)

In their report for the World Bank, Bloomquist et al. look at an international⁷ collection of programs designed to mitigate risks in geothermal development projects. The stated goal of the report is to research each of the selected programs and understand their incentive toward the development of geothermal power. Within this discussion the authors also cite several challenges for the industry that are the basis for their study. These challenges are: the high-risk associated with exploration and reservoir confirmation drilling for geothermal projects, and the costs associated to well field development and plant construction (Bloomquist, Petty, & Wagner, 2007).

Based on these challenges the authors continue commenting on the financing constraints that projects are then presented with.

An Assessment of Geothermal Resource Development Needs in the Western United States, Fleischmann (2007)

As the development potential for geothermal power is geographically located in the western most states of the continental United States, the Geothermal Energy Association compiled a report on identifying and addressing the needs in those states. In this report the review of needs also identifies the challenges faced in development and each is clearly detailed by the author.

Fleischmann begins by discussing the need to close the gap of information

⁷ International geothermal development presents its own challenges, but is also able to leverage development funding from organizations such as the World Bank, International Finance Corporation, and KfW Development Bank to spur progress in the developing world.

regarding geothermal resource exploration, potential, and discovery. He suggests that there needs to be greater resource characterization, more public awareness toward geothermal resources, and an institutional database for information storage and access (Fleischmann, 2007). Beyond informational needs, the states also require adequate government support. Due to the high up-front costs of development projects, he recommends that there be more responsive programs in place at the federal, state, and university levels, which would also include a method of outreach (Fleischmann, 2007).

Government support can also be related to adequate incentives structures, but is also more than just policy incentives. Regulatory issues are also discussed, with specific attention given to water issues, federal land leasing, and environmental reviews (Fleischmann, 2007). This is exemplified by water use in western states with the delicate balance of resources with the demand. Transmission access and distribution issues are also identified in the report as they are related to the power markets and the needs faced specifically in those states (Fleischmann, 2007). Fleischmann concludes his list of challenges and needs by acknowledging a linkage between direct and indirect technologies in the geothermal sector.

Further discussion in the report stresses the author's concerns over the state of the market in general. Fleischmann, like other authors, states that there is a difference in the technological maturity of geothermal processes and experience when compared to the oil and gas sector (Fleischmann, 2007). This lack of maturity, and government support are important to establishing programs for risk mitigation. As incentives reduce risk, up-front costs, and encourage investment, Fleischmann believes that more rapid development is possible (Fleischmann, 2007). Historical precedence is then placed on the relationship between government incentives and the ability of developers to secure financing.

Geothermal Risk Mitigation Strategies Report, Deloitte (2008)

Touting the benefits of geothermal power, while recognizing the weaknesses and challenges in the industry, the authors at Deloitte Development thoroughly assess the U.S. Geothermal Market and look to strategies in risk mitigation. A core component of this process is the recognition and discussion of key challenges, or hurdles, to more widespread development. The authors also bring about an introduction of various market penetration strategies that are also common with other renewable energy technologies.

The core barriers discussed in the Deloitte report identify four key areas of challenge for the industry. First, they have identified the need for better access to the transmission infrastructure (Deloitte Development LLC, 2008), as it is understood that the geographic location of hydrothermal resources is often not close to the point of end use. Next are the limitations present in not having an adequate (reliable) system for resource information (Deloitte Development LLC, 2008). A system of available geologic resource data would allow the industry to gain a more in-depth understanding of the process of exploration and discovery of resources. Third, the level of risk present in geothermal development, especially in the early stages of development, are inadequately mitigated and can better be dealt with through mechanisms that mitigate said risk (Deloitte Development LLC, 2008). The authors also identify the lack of a stable policy framework to support the development of geothermal, through incentives and regulatory processes (Deloitte Development LLC, 2008).

Other issues that the authors focus on include barriers common throughout the renewable energy sector. So as not to repeat similar barriers, the authors recognize the high-perceived cost of projects, lack of qualified personnel, and remote geographic resource locations as more common for a variety of energy technologies, but also concerning to geothermal development (Deloitte Development LLC, 2008). The report

continues by focusing on policy, transmission, and informational barriers specifically.

Financial Risk Management Instruments for Geothermal Energy Projects, Combs (2006)

Due to the financial requirements involved in the development of geothermal power, Jim Combs, at the behalf of the United Nations, wrote his report detailing risk management instruments for financing geothermal energy projects. The section of this report that is the most relevant addresses the key risks/barriers in geothermal development. Combs identifies four key areas of risk, while indirectly referencing several additional challenges throughout the report. The key barriers are as follows: drilling expense and risk; exploration risk; technical failures; and long lead times (Combs, 2006).

In the case of drilling expense and associated risk, he details several scenarios, but primarily focuses on cases of well blow out. The exploration risk has a variety of factors ranging from dry wells to sustainable flow rates and temperatures, any of which can make a project economically non-viable. Technological failures in equipment are listed for several cases, with Combs' example being a pump breakdown or malfunction. He also provides a broad understanding of the project risks associated with long lead times and specifically focuses attention on land access and permitting (Combs, 2006). Through the remainder of the report, Combs identifies high up-front capital costs as a timeline barrier, with the associated risk tolerance found acceptable by investors and financiers.

Within the closing section, the author provides a series of recommendations for risk mitigation in geothermal development. It is stated that better transmission access, transportation, information database, and a system of cost sharing would greatly assist the process of investment in the development of geothermal power (Combs, 2006).

Geothermal Technologies Program Strategic Plan, NREL (2004)

In a review of the strategic plan for the DOE Geothermal Technologies Program, a strong case for geothermal power is established in support of the program's three main objectives. Those objectives are as follows: reduce the levelized cost of geothermal power to below \$.05/kwh, increase the viable resource potential of geothermal to 40,000 MWe, and reduce EGS levelized cost to \$.05/kwh (National Renewable Energy Laboratory, 2004). In the further discussion of these strategic goals the authors devote a section to "institutional barriers", which is important for this discussion.

The institutional barriers that are identified in this report are focused on the challenges that are beyond the benefits of geothermal power. They find that, compared with other energy technologies, the public less understands geothermal power in terms of awareness, perception, and support (National Renewable Energy Laboratory, 2004). Project delays, related to permitting and regulatory processes, create longer lead times and drive up the cost of project development. It is found that this too is relative to external awareness of geothermal processes (National Renewable Energy Laboratory, 2004). To counteract this, the Department of Energy has initiated the "GeoPowering the West" program to better inform stakeholders and to help identify more specific barriers to development and work to overcome them for more robust development (National Renewable Energy Laboratory, 2004).

Other programs set forth in this strategic plan are aimed at more specific challenges. For instance the authors discuss the "Exploration and Resource Characterization" component as a means to maximize drilling success and minimize costs (National Renewable Energy Laboratory, 2004). The "Drilling and Reservoir Management" component shares similar challenges, but also identifies a need for accessible information on geologic data and technological improvements in the drilling

process (National Renewable Energy Laboratory, 2004).

Geothermal Financing Workbook, Battocletti (1999)

The nature of this report focuses on the variety of risks that are associated to the development of geothermal power, and is specifically dedicated to issues in finance. To be included in this series of publications as the oldest piece of literature is not by accident. Although there is a thorough discussion of different risks, the following statement by the author is most revealing. Battocletti states, “All of these, except the resource risk, are common to all other types of power projects; therefore, financial institutions are familiar with them and have developed mechanisms to assess and mitigate them. By contrast, geothermal resource risks, being relatively unfamiliar, have been the subject of intensive investigation in recent years...often as a condition of financing” (Battocletti, 1999, pp. 13-14). It is not only the unique role of resource risk that is important but also the interaction of that risk on financing and its external awareness.

3.4 Analysis: Development Barriers

For the course of analysis, each of the publications must be cataloged. The bibliographic summaries above have drawn attention to the precise challenges or barriers brought forth by each author and report. As recognized in the beginning of this chapter, the cataloging process will define the terms of each category and will reflect those challenges. The analysis itself is the process of identifying those barriers based on frequency. At this point the reader is reminded of the reason for this process. While other authors have suggested that geothermal policy needs to be catered to the needs of geothermal development, these statements themselves lack empirical support thereby limiting them as opinion. If one were to utilize this position in the formulation of policy,

it would need to be proven that this is not in line with the current state of policy structuring. For this reason, a measurable output is proposed in later chapters to assess the barriers to development and policy design. This is an isolated application to the discussion of geothermal policy and will inform on the rest of this research. Let us begin with the cataloging of barriers by each author.

In the preliminary log of the sources and their subsequent barriers, there is a substantially longer list of topics. The logging of each source was done in a chronological order, representing newest sources first. Included in the preliminary information is also an identifier of each source based on its respective source topic and can be determined as: investment, development, policy, and non-technical. As each source was added, the specific challenges were added to the list and identified for that source specifically. Table A represents the data as entered in the initial state.

The next step in the analysis process is to define groupings of barriers. Since each of the initial barriers may share characteristics across publications, or simply be titled differently, creating common barrier themes is a direct approach for grouping likeness. Each of the barriers was identified into common categories. The following is the list of informal parent categories initially used: Risk, Cost, Technology, Policy, and Other. It is important to realize that there is potential for overlap in each of these categories. For example, “investment security” could be interpreted as an issue of “Risk” or “Cost”.

- “Risk” is defined in a geologic sense and includes all subsurface risks.
- “Cost” relates to any barriers or challenges that are directly associated with the cost of development. (i.e. Cost of Capital, Cost of Debt/Equity)
- “Technology” categorizes any challenges that are related to engineering and/or technical processes, and include both surface and subsurface applications.
- “Policy” identifies any challenges that are legislative or regulatory in nature.
- “Other” includes all barriers that cannot otherwise be categorized within one of the previous definitions.

systematic process of categorization.

Table 3.2: Development Barriers

Risk:	Cost:	Policy:
Exploration Risk	High Capital Costs	Lead Time
Drilling risk	Investment Cost	Equivocal Legislation
Geological Risk	Long Payback	Admin. Requirements
Early-stage Risk	Investment Security	Geothermal Definition
Limited Siting Opportunities	Perceived High Cost	Resource Ownership
Lack of Mitigation tools	Financing Gap	Political Will
Developmental Risk	Relative Policy Incentives	Stable/Clear Policy
	Drilling Cost	Permitting
Technology:		Life-cycle Support
Transmission Access	Other:	Federal Land Rights
Reliable Resource Data	Industry Size	Developmental Timeline
Inadequate Technology	Public Opinion	
Access to Rigs	Environmental Problems	
Technological Maturity	Workforce Development	

Table 3.2 represents the barriers, as categorized. Referring back to the to the previous statements regarding identification and wording by authors, within each category the barriers are then reduced into simpler forms as identified by their respective categories.

For the categorized list of barriers that have been identified, further division is required within each categorization. The goal of this process is to create the appropriate grouping for under each heading. To begin, “Risk” has been identified under the definition of risks of a geologic nature. Those barriers that have been identified under the heading of “Risk” include: exploration risk, drilling risk, geologic risk, early-stage risk, lack of mitigation tools, development risk, and limited siting opportunities. Of these it is clear that the majority can be grouped into the premise of early development risk, and includes all but the limited siting opportunities.

While addressing the issue of financing, Salmon et al. do focus on what is defined

as “early-stage” by recognizing the development tasks involved. For the purposes of their reporting they have included: resource identification, resource evaluation, and test well drilling (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). Islandsbanki and GEOFAR identify a similar grouping of development stages by recognizing exploration, pre-feasibility, and feasibility as the sections of the development timeline before the reservoir has been proven (GEOFAR, 2009) (GEOFAR, 2009) (Islandsbanki, 2011) (Richter, 2008) (Richter, 2009). Therefore, although exploration and drilling risk, for example, are very much different, there is a shared state of development of both, as the level of perceived investment risk has not reached production viability (Islandsbanki, 2011). Therefore, to group the different barriers defined under “Risk”, the perceived investment threshold is used to validate the grouping. The remaining barrier that fails this grouping of risk is then identified individually as a geographic barrier to development, “limited siting opportunities”.

A similar method is used for each of the remaining categories. Regarding “Cost” there are ten barriers that have been added to this category. The same perspective is applied to identify grouping structures within the “Cost” designation. There are common themes among certain barriers and, through initial observation, two can be readily identified: initial cost and financing. Continuing with the same process, as was done for “Risk” it is found that under the heading of initial cost, three barriers are identified. These barriers are: high capital costs – up front, high-perceived costs, and drilling costs. Under the alternate identification heading of financing, all but one of the remaining barriers can be grouped. This includes the following: investment cost, long pay back, investment security, financing gap, and access to financing. The idea behind this method of grouping is that by identifying a more generalized barrier, the process of applying a solution will have both direct and indirect impacts on a variety of barriers. This is preferred in this

study, since a very isolated approach may only be able to address one very isolated barrier. The remaining barrier that does not align with initial cost or financing is listed in “lower relative policy incentives”. It is possible to also categorize this under the “Policy” category, but for the purposes of this study it was important to focus on the cost component listed within the barrier.

Technological barriers cover a range of topics from informational to grid access. This range is the core reason why the “Technology” category requires more than two areas of separation. In this case, the scale and type of the application is an accurate method of justifying each meta-barrier. To recognize scale, the barriers are identified as either macro-level or micro-level. Transmission access, although site and project specific, is a macro-level application. The remaining barriers are more project specific, therefore, “transmission” is defined as a general barrier. Of the remaining barriers there is a clear distinction between informational technology and engineering technology. This allows the grouping to be made according to those that are of one or the other. “Technological Competiveness” will include the engineering technology barriers, while “Resource Data” will address informational resource barriers.

Due to the variety of issues that are related to “Policy” there are cases where a selected barrier may be cross-listed for multiple categories. For the purposes here, that is believed to have a potential to alter the results of the study based on the design. Therefore, any barriers that have the potential to be cross-listed will be identified in a sole general barrier. This can also be the case within the category of “Policy”, since a general designation of “Government Support” will be used to recognize all barriers that do not fit squarely within an alternate policy barrier. Given the list of identified barriers, it appears that there are multiple barriers that address “time” or specifically “permitting”. For this reason each will be used to form specific policy barriers, with the remainder being

identified as “government support”. The barrier of “Time” will include: lead-time and development timeline, while “Permitting” includes: administration requirements, geothermal definition, resource ownership, permitting, and federal land rights. In the case of permitting, much of the discussion relates to the functionality of the process, wherein the definitions relating to the process of permitting have created a desire for streamlining. The remaining policy barriers are more general and relate directly to the macro-level policy framework and its support of geothermal power.

To wrap up the categorization of barriers, an “Other” category is included to identify more unique, but worthy, barriers that should not be grouped, or are not able to be grouped. Because only four barriers remain, each is identified independently in the study. Briefly each will be discussed. Multiple authors identify industry size as a limiting factor for the geothermal sector (Doris, Kreycik, & Young, 2009) (Islandsbanki, 2011). Islandsbanki specifically identifies that the size of the industry is restrictive to external investments (Islandsbanki, 2011). Public opinion is also discussed by one third of the authors as an issue of industry and technological knowledge and comfort with geothermal power. This is disruptive to bridging the gap in perceived and real development risk (Islandsbanki, 2011) (Deloitte Development LLC, 2008). Project developments and plans also have barriers due to environmental constraints, and can involve a wide range of variables. The last barrier to be categorized is that of workforce development. One in six publications identify the need for qualified personnel for the industry to grow. This model of categorization allows the study to identify barriers as general themes, while acknowledging those that are more specialized.

Through this process of barrier identification and categorization, the goal is to provide a structure and order to the method of cataloging. For greater definition each of the barriers is summarized in the following and then incorporated into Table 3.3.

3.4.1 Barrier Definitions:

- Environmental Problems: Any issues that require mitigation or resolution that involve impacts on the natural environment.
- Financing: This covers a broader area than other barriers, but is all inclusive of barriers related to the financing duration, rates, and access for geothermal projects. Each of these factors has an inverse effect on the overall cost that is associated to finance.
- Geographical: Geographic limitations on siting and discovery of hydrothermal resources.
- Government Support: Stable and consistent policy and legislation is needed for long-term project completion.
- Incentives: Application of policy incentives favors other renewable energy sources when compared to geothermal (Curtis, 2010).
- Industry Size: Comparative level of installed capacity and number of developers, with regard to other energy technologies in the U.S.
- Initial Cost: The initial costs relate to actual and perceived development costs, as well as drilling.
- Permitting: An all-encompassing legislative barrier involving the access, use, requirements, and definition of land, but is focused primarily on federal lands.
- Public Opinion: Perception and opinions held by the public and the need to have a better-established understanding of geothermal power.
- Resource Data: Collecting and availability of current geologic and development data for geothermal resources to aid in future development efforts.
- Resource Risk: Any subsurface, or geologic, risk including the need for risk mitigation associated with geothermal development activities.
- Technological Competitiveness: Ensuring access to drilling equipment within development timeline and establishing more advanced methods of exploration and production to reduce costs and development timelines.
- Time: This accounts for any implication of duration for project development and includes lead-time and development timeline.
- Transmission: Factoring the associative costs of remoteness and resource discovery and development, with accessible means of transmission and distribution of power.
- Workforce Development: Requiring the adequate level of workforce support to drive anticipated development of geothermal power into the future.

It can be seen in comparing Table C and Table D that the process of categorization and cataloging of the barriers allows for a much more streamlined approach. This streamlining of the barriers also creates the opportunity for the selected authors to speak in a more universal language when defining challenges and barriers to

geothermal development. In addition to the more defined collection of data, it is possible to rank each barrier by frequency, from highest to lowest. In the next paragraph a more detailed account of the frequency process is provided.

After defining the barriers above, each of the barriers is categorized appropriately and the frequency is determined of each. For this study the method of determining frequency is simply: $f_i = \frac{n_i}{N}$. Wherein (n_i) is the number of references for each barrier and (N) is the sum of reference items. The criterion for frequency reflects how often each is referenced within the larger sample of literature. Please review the table for the results of this process.

Table 3.3: Barrier by Reporting Frequency

Literature Review: Geothermal Market Barriers (Compiled 01/11/2012)		Year	Resource Risk	Initial Cost	Time	Technical Competeness	Government Support	Financing	Permitting	Public Opinion	Environmental Issues	Transmission	Resource Data	Workforce Development	Geographical	Industry Size	Policy Incentives
Islandsbanki (2011)	2011																
NREL (2011) - Policymaker's Guide	2011																
Salmon et al. (2011)	2011																
Jennejohn (2011)	2011																
Geothermal Technologies Program (2010)	2010																
Curtis (2010)	2010																
GEOFAR (2009) - Financial Instruments	2009																
Richter (2009)	2009																
Doris et al. (2009)	2009																
GEOFAR (2009) - Europe	2009																
Geothermal Technologies Program (2008)	2008																
Richter (2008)	2008																
Bloomquist (2007)	2007																
Fleischmann (2007)	2007																
Deloitte LLP (2007)	2007																
Combs (2006)	2006																
NREL (2004)	2004																
Battocletti (1999)	1999																
Frequency (%):			72%	67%	44%	44%	39%	39%	33%	33%	28%	28%	28%	17%	11%	11%	6%

As it is presented in the table, each of the barriers is ranked from left to right in order of frequency. While Curtis was the only author to reference “policy incentives”, the process of categorization supported much higher frequencies for the other barriers.

Reflecting solely on “policy incentives” the fact that it was not a shared concern by any of the other authors reviewed would indicate an overall level of content with the state of the incentives at the time of each publication. This could be seen as counterintuitive to this process of study, since policy incentives are to be specifically correlated with the results of the barrier analysis. Although this may be an interpretation, a more important question to be asked is; if there is a higher level of content with the policy incentives in place, what barriers are being interacted with?

Most barriers are referenced two or more times in the collection of publications, and although there is a certain level of frequency for each, only two of the barriers are referenced in more than 50% of cases sampled. The goal in targeting those barriers that are more commonly referenced is to determine if, and where, consistency occurs in defining market barriers. It is also important to note that because a barrier is common, it may or may not carry a significant weight as a market limitation. This point will become more apparent in a latter portion of this chapter.

None of the barriers, as defined, is unanimous in their selection, but this is suspected to be a response to variations in themes throughout the collection of sources. To proceed forward there is no need to assess all of the barriers and their respective frequencies. To better refine the results 50% is referred to as an appropriate threshold to move forward with the next stage of analysis; therefore, the two most common barriers listed are “Resource Risk” and “Initial Cost”, with 72% and 68% frequency respectively. Each of these barriers was established, as a grouping of like barriers and thus it is understandable that they would be more frequently referenced, but with this point aside, their respective importance is directly addressed by individual authors. For example, Doris et al finds that geothermal development incurs high initial cost and risks for initial investors over a longer timeframe (Doris, Kreycik, & Young, 2009). An important take

away from this analysis is that the barrier “resource risk” is only relevant for geothermal when compared to other renewable energy applications and is shared when considered with oil and gas. Battocletti’s statement referenced in the summary of her report identifies “resource risk” as being unique and unknown in comparison to traditional developmental methods and players (Battocletti, 1999). This creates a strong identity between geothermal power and resource risks. It can also be said that these risks are directly represented in the financing and cost structures found in geothermal development and are therefore linked to high initial costs. It is important to recognize that each barrier is part of an intricate network of factors that impede development and industry growth.

3.5 Comparative Survey: Design and Analysis

The literature clearly focuses attention on the role of risk and initial costs as the preeminent barriers to developing geothermal power. Further confirmation, or refutation, is necessary to properly guide the remaining research. The results and conclusions of the previous literature review and analysis are to now be used to guide a survey on industry perceptions toward developmental barriers. This process is addressed with the following: a structured survey, the collection of results, and finally a comparison of barrier frequency analysis.

Structuring the survey requires that the intent of the research method not be biased. For proper comparison the definition of barrier perceptions is directly carried over from the analysis completed earlier in this chapter. Since a method has been established to categorize and catalog the data entries from the literature, definitions and categories of developmental barriers will remain the same, for congruency. The survey method, however, will have multiple components: a disclaimer, industry role, barrier identification, policy perceptions, and general commentary.

The disclaimer, which also serves as a summary statement, ensures that the purpose of the survey is stated, while also establishing the rights and responsibilities of the respondent. It includes a statement that the survey is voluntary, part of the author's doctoral research, responses are anonymous, and that the Geothermal Resources Council (GRC) is not a sponsor. The latter is to note that although the GRC assisted in the administering of the survey, both at the 2012 GEA Expo and digitally, they have no responsibility for the content or purpose of the survey method. Below is the statement in its entirety:

“Survey Description: This research is a voluntary survey of industry professionals on perceived developmental barriers to geothermal power. The survey is a supplement to doctoral research at the University of Delaware’s Center for Energy and Environmental Policy. Survey responses are anonymous, and each respondent is free to answer the survey in full, in part, or may discontinue their responses at anytime. The Geothermal Resources Council is not a survey sponsor, and the research here within is solely that of the author.”

This summary statement, with the rest of the survey, can be found as part of Appendices at the end of this study. After discussing the previous statement, the next part of the survey will identify the role within industry of the respondent. This is to allow for the observation of patterns of perception related to industry role. As a result of the literature review on barriers, the perception of barriers is related to the area within industry that the respondent serves. To prevent identification, this process is generalized into multiple options, but is intended to represent the core faculties that represent the geothermal power industry. The survey options available are: Geology/Science, Engineering, Business Development, Public Policy, and Other. There is no request to further identify “Other” in this part of the survey.

Identification of perceived barriers to geothermal development begins with a list of barriers. Using the analysis presented by categorizing barriers, as presented earlier in

this chapter, the survey includes the barriers listed by definition above. The purpose of using these barriers is to establish consistency in terms and definitions for later comparison. A category of “Other”, with a write-in option, is included to broaden the survey options. This provides 14 choices for respondents to consider. Each barrier is listed alphabetically, with “Other” representing the final option. For review each option is listed in the following table:

Table 3.4: Survey Categories – Barriers

<input type="checkbox"/>	<i>Environmental Problems</i>	<input type="checkbox"/>	<i>Industry Size</i>	<input type="checkbox"/>	<i>Resource Risk</i>
<input type="checkbox"/>	<i>Financing</i>	<input type="checkbox"/>	<i>Initial Cost</i>	<input type="checkbox"/>	<i>Technological Competitiveness</i>
<input type="checkbox"/>	<i>Geographical Government Support</i>	<input type="checkbox"/>	<i>Permitting Public Opinion</i>	<input type="checkbox"/>	<i>Time Transmission</i>
<input type="checkbox"/>	<i>Incentives</i>	<input type="checkbox"/>	<i>Resource Data</i>	<input type="checkbox"/>	<i>Workforce Development</i>
<input type="checkbox"/>	<i>Other</i>				

This section of the survey asks the respondent to select any barriers that, at present, limit the development of geothermal power projects in the United States. Definitions of each barrier are provided and are represented by previous analysis. There is no request for ranking, and the number is not limited to reflect the methods used in collecting data from the literature review on barriers. Responses from the literature review range from three (3) to ten (10) barriers to development per source. The conclusion of Question 1 of the survey allows the respondent to define “Other”, if selected, and to provide comments.

Two appendices are included to represent the two survey formats used for this method. The first is the paper survey that was administered on Oct. 2nd, 2012 at the GEA Expo in Reno, NV as part of that year’s annual GRC Meeting. This survey includes a

second question, focused on policy perceptions, which is not included as part of this research. Following the close of the Annual Meeting and Expo, the GRC distributed a digital version of the survey (only question 1) to the attendees of the Annual Meeting as part of the final wrap-up. A copy of this version of the survey is noted within the Appendices. Although two survey processes are used to collect the data found within, the content used is relevant only to a very precise question on industry barriers. This is stated to avoid any confusion as to the relative nature of more than one survey, and method, in the compilation of comparative data that will follow.

The second question, only presented in the paper survey, goes beyond the intent of the literature review to include a process of identifying policy applications that offer mitigation to development barriers. For the purposes here the responses rely on the knowledge and experience of the respondent with issues related to policy. Each respondent is asked to provide any policy mechanisms or options that they feel support the mitigation of barriers identified in question 1. Answers are by write-in only. This commentary is included to provide context only and is not part of the current research design.

3.5.1 Survey Analysis:

To analyze the survey data it is important to process it in a way that allows for comparable analysis with the results of the literature review. In order to fulfill this need the results must be collected in similar fashion for both processes. Since the metric used in the literature review is to determine frequency, the survey data will do the same, but also assesses the level of significance for each barrier, as viewed by the respondent. This process treats each response as an individual result – much like that of each publication/source – to build a frequency table. Number will identify each response, with

additional conclusions being able to be drawn from the relationship of industry identifiers and perceived barriers.

The collection of the survey data represents a contemporary assessment of the perceptions of the geothermal industry. Each barrier will be tallied to determine based on survey data. Like the data from the literature review the same process will be used to calculate frequency: $f_i = \frac{n_i}{N}$. Wherein (n_i) is the number of references for each barrier and (N) is the sum of reference items. Further comparison is provided with the use of visualization techniques.

3.5.2 Survey Data:

Due to the nature of the second survey method (digitally administered) the compilation of data is delayed to allow for varied response times. In this case, two months has been allowed, and has resulted in 28 responses. Eighteen of which are from the paper survey and 10 were received as a result of the digital version. To support the legitimacy of the response data, the author's target was for 30 responses in total sampling. Here the number of responses is near enough to the target number that 2 additional surveys would not skew the results presented as follows.

The collection of survey results is provided in Appendix of this study. In the table below the results of individual usage frequency are given for each barrier and then sorted from highest to lowest. The results show that, like the literature review, the dominant barrier to geothermal development is "Resource Risk". It is followed by "Financing" and "Permitting". "Initial Cost", which was second to resource risk in the literature review, is fifth in the survey results. A possible explanation for this and the rise of "Financing" as a barrier in the survey is the obvious relationship between the two in financial terms. Although an attempt was made to distinguish the two, it is possible that respondents

recognized each as part of the other. Another explanation resides in the significance of financing as a barrier in industry news in recent years and thus it's undesirable correlation to increased development costs for geothermal projects. In either case the results are informative and offer a reasonable amount of resonation in the study of literature on the subject.

Table 3.5: Comparative Survey Data

	Development Barriers															
	Resource Risk	Financing	Permitting	Incentives	Initial Cost	Environmental Problems	Government Support	Time	Transmission	Public Opinion	Resource Data	Geographical	Industry Size	Technological Competitiveness	Other	Workforce Development
Survey	64%	57%	46%	39%	39%	36%	36%	25%	25%	21%	14%	11%	7%	7%	0%	0%
Lit Review	72%	39%	33%	6%	67%	28%	39%	44%	28%	33%	28%	11%	11%	44%	NA	17%

Compiled: 12/23/12

The barrier, which offered the most significant change from the literature review, is “Permitting”. Prior to the administering of the survey, feedback on the results of the literature review questioned the relative insignificance of permitting as a development barrier. Based on actual, and contemporary, survey results the role of permitting, as a barrier to geothermal development cannot be denied. With nearly half of all respondents acknowledging the role that permitting delays play in slowing geothermal development more attention should be given to this barrier than is reflected in the literature review. It is also the reasoning behind the survey request for industry role. While thirteen (13) of the twenty-eight respondents identified permitting as a barrier only two identified himself or herself as Business Development (1) or Public Policy (1). This accounts for less than 15% respectively of those supporting permitting and only 7% of all respondents. On the

other hand, however, both Geology and Other received four (4) citations for permitting, making up 61.5% of permitting and 28.6% of the whole. From the author's perspective this suggests that certain barriers do not have the same level of resonance among industry performers (i.e. financiers are less concerned about permitting than geologists). As a final note the actual proportion of respondents in Business Development or Public Policy was much lower than that of the others. These two industry roles only accounted for three of the total 28 respondents.

A comparison between the results of the literature review and survey data should also include a brief discussion of significant discrepancies, and not solely recognize those barriers that are consistent between datasets. When comparing the frequencies of each barrier the role of policy incentives is quite notable. In the survey results "Policy Incentives" is recognized as a significant barrier, with 39% of respondents agreeing. However, the results of the literature review only find 6% of the sources in agreement. "Government Support" is largely consistent at 35-40% frequency, which does not explain possible similarities associated with "Policy Incentive" barriers. From the author's perspective, it does represent a shifting principle in public policy that the existing incentive framework lacks the level of compatibility for market growth in geothermal. This is a matter of opinion here, but is correlated to the basis of this research. In a contemporary sense, the growing recognition of policy incentives as barriers within the industry suggests that the role of said incentives is also growing in importance, or has become unbalanced in comparison with other energy technologies. In either case its role should not be ignored, and is used in this context to support the research design.

3.6 Survey Assessment:

The purpose of identifying, and confirming, specific barriers in the development

of geothermal power is to provide a more narrowed focus on those barriers that are most relevant to structuring effective energy policy. It is obvious that all barriers have an impact on the growth of the industry and the advancement of geothermal technologies, but it is also unrealistic to provide policy actions for each. This would neglect the direct and indirect attributes associated among similar barriers, and would create inefficiencies. In the same regard, this is why a successful policy option for (e.g. solar or wind) does not directly hold for geothermal. Even policy structures within the geothermal industry must be tailored to the variety of technologies defined as geothermal (e.g. geothermal power vs. geothermal heat pumps). To carry this thought to the conclusion of this chapter, the outcome will isolate three (3) barriers to be carried on into the next chapter as functional components of the remaining study.

To isolate which barriers are most appropriate for further analysis, a fundamental question is asked: “which barriers are unique to geothermal?” This returns the premise back to the discussion presented in Chapter 2. The aim is now to combine the perspective of industry with the attributes, which distinguish geothermal from its sister energy technologies. It is with this in mind that resource risk, permitting, and financing/initial cost are further distinguished.

Resource Risk: Unlike other renewable technologies, geothermal power shares more commonalities with the oil and gas industry in relation to risk associated to the exploration, confirmation, and exploitation of geologic resources in the production of energy. This similarity is unique to geothermal, and has substantial effect on time and costs. In both the literature review and survey, this barrier was unquestionably the most agreed upon by the vast majority of respondents and sources. It is also by default a development component that is not shared across the renewable energy spectrum.

Permitting: Due to the geologic nature of geothermal resources, there has always

been contention regarding the rights and regulation of land and resources in the development of power projects. Additionally, the process of permitting can slow a project's progress and lead to over-runs on cost and time. As a regulatory process, permitting is a barrier that is externally controlled through bureaucratic processes at all levels of government. Although the conclusions drawn from the literature review and survey highlight varying views on the significance of permitting as a development barrier, the role of permitting in geothermal projects is far more complicated than those related to other energy technologies, and even qualifying the rights of a resource vary by state.

Financing/Initial Cost: In both the literature review and survey, financing and initial costs are treated as independent barriers. Following the analysis of the comparative results, the level of independence is much less obvious. It is believed that survey respondents were not able to distinguish between each, and especially for those outside the financial industry perspective the differences remain quite subtle. This provides an opportunity to expand on the initial framework and broaden the interactions of costs and economics in the modeling of levelized cost in Chapter 4. Reflecting on the effectual extent of both resource risk and permitting on costs, this is an opportunity to provide modeling results, which highlight the level of sensitivity exhibited both directly and indirectly.

These three development barriers are unique to geothermal in both nature and extent. In support of the underlying thesis in this research, the role of energy policy is in question as to the current suitability of policy mechanisms to the geothermal market and its technologies. By using the results of this chapter, the following chapters will use quantitative modeling to analyze the accuracy of contemporary policy used in the development of geothermal power projects and then recommend alternative options for

policy makers to consider in the future. These barriers will be applied directly within the model to represent unique characteristics associated with geothermal power projects.

3.7 Summary:

The objective of this chapter was to provide a method, and means, to highlight the significance of development barriers for geothermal power and its industry. In each section it has provided the reader with a comprehensive review of contemporary literature on the subject of geothermal markets and technologies, established a methodology for cataloging those results, introduces an industry survey, and lastly compares the datasets and results from the literature review and survey to select barriers for further modeling. The literature review and analysis identify resource risk and initial cost as the most substantive barriers to geothermal development, while the comparative results of the survey provide mixed results. The survey agrees on resource risk, but puts less reliance on the role of initial cost by favoring financing barriers instead. An assessment concludes that the differentiation of financing and initial cost may be over estimated and that the role of permitting as a market barrier is overlooked within the literature review. The results found within lead to the conclusions that resource risk, permitting, and financing/initial cost are the most representative, and relevant barriers in modeling levelized cost for geothermal power. This conclusion rests largely on the unique nature of each barrier to the geothermal market and its technology.

Chapter 4

LEVELIZED COST OF ENERGY

As part of a robust toolbox used by energy and policy analysts, there is a need for quantifying the cost of energy related to its role as a market commodity. In energy, this commodity is standardized in units as kilowatt-hours (kWh). This unit is produced by utilities, and consumed by end users. It is therefore natural to strive to identify the costs related to the production of a kWh, and from the analyst's toolbox, levelized cost can be used to calculate the cost per kWh (\$/kWh), with respect to the time value of money (OECD, Nuclear Energy Agency, 2010). In describing this procedural method, the research will introduce a form of levelized cost analysis, the role of assumptions, and then produce a modified levelized cost formula, based on those assumptions used in the study.

4.1 Quantitative Methods

Levelized cost is commonly used when looking at the comparative, projected costs between energy technologies. Before introducing examples of applied research and reporting on the method, it is best to provide a clear understanding of levelized cost. For reference, this is best represented by the International Energy Agency (IEA), Nuclear Energy Agency, and Organization for Economic Co-operation and Development (OECD) in a report titled "Projected Costs of Generating Electricity", published 8 times since 1983, and most recently in 2005 and 2010. Since levelized cost is the core component of the report's analysis, the definitions and discussions are quite relative to the research and

analysis that follows. In the 2005 edition, the report defines levelized cost as a calculation of “electricity generation costs related to the net power supplied to the station busbar⁸” (OECD, Nuclear Energy Agency, 2005). Furthermore the levelized cost methodology incorporates discounting of costs to their present values, defined as the discounted cash flow method (OECD, Nuclear Energy Agency, 2010) (OECD, Nuclear Energy Agency, 2005). The basic form of the formula used is found below:

Equation 1: Levelized Cost of Energy A⁹

$$LEC = \sum_{n=1}^N \frac{\frac{I_n + M_n + F_n}{(1+r)^n}}{\frac{E_n}{(1+r)^n}}$$

(OECD, Nuclear Energy Agency, 2005)

Short et al. (1995) provide a more granular look at calculating levelized cost. Combined with the method presented by the IEA, NEA, and OECD, this work also provides a LCOE method, which includes the after-tax total life cycle cost (TLCC). According to Short et al. the calculation of TLCC is at the heart of further LCOE estimates. The recommended use of LCOE is ideal in ranking comparative energy systems for investment decisions (Short, Packey, & Holt, 1995). The following chapter will provide the mathematical foundation for modeling the foundation of this study, the Geothermal LCOE (GeoLEC). It is also on this basis that LCOE was selected as a modeling metric. Its value as a comparative tool for policy makers and financiers makes

⁸ Busbar costs are all costs incurred prior to the transmission and distribution of electricity.

⁹ Beginning on page 117, each variable is defined in greater detail.

it among the most commonly used metrics for energy-cost analysis. Because LCOE incorporates discounting, cash flows, fixed and variable costs, and expected energy production, there are a sufficient number of variables, which can be studied in comparative sensitivity analysis of policy options. This comparative method is a basis for developing this study as original research.

The first equation to be discussed represents the total life-cycle cost for after tax depreciation. This configuration of TLCC is ideal for commercial and industrial systems (Short, Packey, & Holt, 1995), such as a power plant but not a utility. Represented in the equation are the present values of depreciation and O&M expenses, as a function of the tax rate. This is annually subtracted from the initial investment costs (I). (1-T) is used to reflect the after tax value of O&M expenses annually. In simpler terms this provides the analysis with time-valued cost of the energy system at time “0”. The difference between Short et al. and the LCOE used by the OCED/NEA is the explicit use of deprecation after taxes. For developers and operators this is an important factor in calculating a more accurate levelized cost of geothermal power.

Equation 2: Total Life Cycle Cost

$$TLCC (pre - tax) = \sum_{n=0}^N \frac{I - (T * PVDEP) + PVOM(1 - T)}{(1 - T)}$$

(Short, Packey, & Holt, 1995)

The calculation of levelized cost for the energy system stems from the appropriate formula for TLCC. Without addressing the others, the pre-tax depreciation revenue requirement is most appropriate for modeling the development costs of geothermal power. Modified Accelerated Cost Recovery System (MACRS) is used to represent the

applied depreciation technique, with respect to a 5-year timeline for the property class that includes solar, wind, and geothermal projects. Here the asset is expected to depreciate its qualified capital costs in the following annual schedule: 20%, 32%, 19.2%, 11.52%, 11.52%, and 5.76% over 6 years (Internal Revenue Service, 2012).

With an additional modification to the TLCC, it is possible to understand how Short et al. (1995) have calculated levelized cost. This represents the annually discounted value of TLCC over the life of the project. Short et al. begin discounting at time period (1) one and treat the investment cost as the combined overnight costs for project development.

Equation 3: Levelized Cost of Energy B

$$LCOE = \frac{TLCC}{\sum_{n=1}^N \frac{Q_n}{(1-d)^n}}$$

(Short, Packey, & Holt, 1995)

Equation 4: Levelized Cost of Energy B – Expanded

$$LCOE = \frac{I - (T * PVDEP) + PVOM(1 - T)}{\sum_{n=1}^N \frac{Q_n}{(1-d)^n}}$$

(Short, Packey, & Holt, 1995)

To best explain the formula for LCOE, the values in the denominator provide the discounted value of energy. This is determined by taking the plant’s nameplate power (kW), multiplied by the capacity factor and the number of hours annually. The result is the annual expected output of the plant in kWh. Summing these annualized values is then divided into the total life-cycle cost. In this case, PV and $\sum_{n=1}$ carry the same meaning.

Although these cost estimates do not reflect the actualities of energy development, it does give a balanced means to remove development uncertainty for a comparative output (OECD, Nuclear Energy Agency, 2010). Sanyal defines levelized cost as “the initial capital investment plus the cumulative present value of future costs discounted by the cost-inflation rate, divided by the cumulative power generation over the project life (Sanyal S. K., 2005b) (Sanyal & Morrow, 2010). This indicates that in alternative research applications the levelized cost analysis carries a similar context. The key to the respective differences is the list of assumptions made in the formulation of the formula. Many of these assumptions are applied to provide a standardized approach across technological applications (OECD, Nuclear Energy Agency, 2010) (OECD, Nuclear Energy Agency, 2005). It is on this premise that this study articulates specific assumptions to be used in analyzing levelized cost for geothermal specific policy design. Each of the assumptions used has been selected to represent and measure a specific barrier to development, as noted in Chapter 3.

4.2 Levelized Cost Assumptions:

Various assumptions are used in the calculation of levelized cost. Because these calculations are used to typically compare different energy sources on a level plane a number of variables must be controlled. A prime example in comparing these costs is to include the cost of fuel. Across different energy technologies this can be assumed in a variety of ways. For example, coal must be mined and transported, natural gas must be extracted and shipped via tanker or pipeline, and for most renewable energy sources there are no assumed fuel cost because the fuel is naturally renewable. The latter case is true for geothermal but would not be the case for biomass, which requires a fuel stock. In the section that follows a number of assumptions are used to more specifically define

geothermal attributes. These assumptions are not in any way intended to allow for cross comparison with alternative energy technologies, although some may remain applicable.

4.2.1 Discounting Development Costs

Levelized cost incorporates investment costs, i.e. capital costs of development, but treats those costs as overnight costs. Another way to understand this is to calculate overall project costs without any duration of development. Comparatively high initial costs are a significant barrier to the development of geothermal power, as noted in Chapter 3. By discounting the value of initial cost to the beginning of development, the model can isolate the effects on these costs over time and apply policy for mitigation. Because geothermal projects have longer lead times, in comparison to other energy projects, this allows for the model to be uniquely tuned to a defining characteristic of geothermal projects. Also, since the permitting process can cause delays in project development, the associative economic value of investing in geothermal, versus alternative options, should not be disregarded. In addition to, and possibly more so, the barrier of initial cost/financing is reflected in the calculation of a discounted capital cost. It is, however, not subject to a flat estimation of the over all capital costs of the project, but a cumulative value over time. As will be discussed, the role of Assumption 2 will be vital in this process.

Equation 5: Discounted Capital Costs

$$LCOE = \frac{\sum_{n=0}^N I - (T * PVDEP) + PVOM(1 - T)}{\sum_{n=1}^N \frac{Q_n}{(1 - d)^n}}$$

To appropriately determine the value of development at time-zero (n=0), it is

necessary to reverse the time value of money to include variations in development time and cost, as represented in each phase of development. Under this application the duration and associated cost of development is excluded for the cost calculations. In the case of geothermal, the development timeline is a common barrier to development (Figure 4.3). Therefore the first assumption to be included is to calculate the present value of the project from the beginning of development. This is a variable range, but based on a study from the Geothermal Energy Association, it is estimated to be from 3.25 to 6 years for a 50MW plant (Deloitte Development LLC, 2008). A model can properly formulate this variability and the change in cost that is associated with it, thereby allowing for a more accurate representation of geothermal power development and its barriers. In fact the US Department of Energy is designing a similar model for calculating the geothermal levelized cost called GETEM – Geothermal Electricity Technology Evaluation Model (Augustine et. al., 2012). This model uses a method of adjustable discount rates by development year to estimate the financial risk associated at different stages of development, which is inline with how the capital costs are discounted in the GeoLEC. Another factor that is related to the development timeline and costs is the capitalization of interest during construction. It is common in the development of geothermal projects for initial investment to be made as equity. This is understood as “ownership” in the project, as compared to debt financing, which is strictly a loan. To better conceptualize where this method is going, it is important to discuss, briefly, the differentiation of development stages for geothermal power projects.

4.2.2 Geothermal Development Stages

The development of geothermal resources, for power production, progresses through a series of stages. Each stage represents a different foundation toward a fully

operational geothermal plant and the production of electricity. While each stage incorporates a categorization of activities, risks, costs, and timelines, the understanding of each is required to identify each of the assorted factors posing as barriers. This reference is made to the literature review in Chapter 2, where each development stage is defined with respect to the Geothermal Energy Association’s reporting guide (Geothermal Energy Association, 2010). Cost figures and supporting data from additional sources are included in the description of each.

Table 4.1: Aggregated Capital Cost by Phase¹⁰

“C _n ”	\$2007	Aggregate Values
Phase I	\$8-\$20	\$14
Phase II	\$100-\$200	\$150
Phase III	\$700-\$1000	\$850
Phase IV	\$1500-\$1700	\$1600
Overnight Costs:	\$2308-\$2920	\$2614

In relation to the economic value of time, the isolation of each development stage allows for a more direct identification of the sensitivities exhibited. The selection of permitting as a barrier is directly related to the value of time, and then indirectly it reflects the actual economic variations that are subject to capital costs. Like the assumption discussed previously, permitting is a developmental barrier that has extended impacts on the success of a project. It is for this reason that in this assumption, the

¹⁰ Source: (Deloitte Development LLC, 2008), values are rounded and assumes normal distribution.

explicit calculation of time by development stage is used. Assuming a normal distribution curve of the Deloitte data, the P50 value is estimated as an aggregate in Table 4.1.

4.2.3 Interest During Construction

As was introduced above, the calculation of levelized cost should reflect the impacts of development costs over time. The investment in and development of projects requires capital financing in the form of debt. For accounting purposes the project is able to carry interest payments on that capital debt as a project asset in the form of capitalized interest. Since the development process can be comparatively longer for geothermal, understanding the components of the development timeline are vital. To understand the capitalization of interest during the development process an “interest during construction” component must be included. As part of the initial research, this concept was introduced in multiple publications (OECD, Nuclear Energy Agency, 2010) (Sener, 2009), and according to the Nikolai, Bazley, and

Jones, in *Intermediate Accounting*, utility projects are generally allowed to capitalize interest during construction, since those costs will be included in the rate pricing (Nikolai, Bazley, & Jones, 2010). They also state that capitalized interest can be used for both debt and equity, and begins when expenditures have been made (Nikolai, Bazley, & Jones, 2010). Sener also incorporates capitalized interest in his calculations of levelized cost of geothermal power (Sener, 2009). A simplified version of his interest during construction (IDC) formula is given below.

Equation 6: Interest During Construction

$$IDC = \sum_{n=1}^{T_{Dev}} [d * P * I_n (1 + f_d)^{T_{Dev}-n} + (1 - d) * I_n (1 + f_e)^{T_{Dev}-n}] - \sum_{n=1}^{T_{Dev}} [d * P * I_n + (1 - d) * I_n * P] + P(C_{Exp})(1 + f_{Exp})^{(T_{Exp}+T_{Dev})} - P(C_{Exp})$$

(Sener, 2009)

d : Debt Ratio	T_{Dev} : Total Development Time
P : Installed Capacity	C_{Exp} : Exploration Cost
I_n : Investment Cost	f_{Exp} : Rate of Investment (Exploration only)
f_d : Rate of Debt	T_{Exp} : Exploration Time
f_e : Rate of Equity	n : Period

In this equation the accrued interest for both debt and equity are calculated, given the cost per kW and the installed capacity. By including this in the calculation of levelized cost it will be possible to assess the sensitivity of interest and debt to equity ratios in the cost of geothermal power. To clarify, stating the formula above is simplified from that of the one used in Sener (2009), is to say that it is to be calculated for each period, and summed annually.

To help reflect the distribution of debt versus equity in the development of geothermal projects, the use of interest during construction is intended to highlight specific sensitivities of LCOE in financing. A debt to equity ratio of 70/30 is used with an interest rate of 7% (but as high as 10%), according to Dan Fleischmann (Ormat Technologies), and reported by Cross and Freeman (2009). Referencing the interest rate, it was reported in Speer (2012, p. 7), and is the default setting used in the National Renewable Energy Laboratory’s CREST model, when modeling geothermal projects (Gilford & Grace, 2011). The modeling here within will use these values in its baseline

calculations and are included in the capital costs for period n.

4.2.4 Resource Decline Rate

Geothermal power is reliant on the natural processes of hydrothermal conduction to produce power. There are continual operational processes that take place, such as make-up wells, which allow plants to maintain their installed capacity, however, there is always an expected rate of decline as the reservoir gradually cools. The on-going cost of make-up wells is assumed to be part of the operations and maintenance costs for a plant over time. For the purposes here the model will use \$15/MWh (or \$0.015/kwh), as provided in Geothermal Tomorrow 2008 (Geothermal Technologies Program, 2009). Given this rate of decline, Dr. Subir K. Sanyal has published a number of articles referencing specific calculation in assessing output of geothermal power. As Sanyal is an expert in the field of reservoir engineering, his approach is quite specific. As it relates to the proposed research and its policy implications, it is believed that the extent of Sanyal's work is beyond the needs of this modeling. However, the need to incorporate a rate of decline is quite valuable. Sener also uses this concept in his modeling, and from these results it can be observed that the output declines, but not at a constant rate. In actuality, with the inclusion of make- up wells, the rate of decline decreases over time as well. Based on Sener's calculations the range of annual decline, with make-up wells, decreases from 5% to 2% over 30 years (Sener, 2009). The initial 5% rate of decline is determined by Sanyal's research and publication (Sanyal S. K., 2005a) (Sanyal S. K., 2005b) (Sanyal & Morrow, 2010). It is from these calculations, that a simplified decline factor is applied to the output in calculating levelized cost. Given a 5% rate of decline (lr) a long-term decline rate can be applied which ranges from 5% to 2.1% over 30 years. Please see the formula below:

Equation 7: Resource Decline

$$\text{Decline Factor} = 1 - (l_r - 0.001^t)$$

Since other sources of energy are dependent on fuel supplies (i.e. coal, natural gas, nuclear, biomass) there is no need for a standard decline factor in traditional levelized cost formulas. Also, as a factor of long-term resource risk, the level of production should stabilize over time. This will then reduce the annual thermal drawdown on the reservoir. Relative to resource risk being a developmental barrier, the decline rate calculation becomes an increasing benefit to geothermal production the longer the plant is in service. Because the annual sum of production is also discounted – to account for revenues over time within the LCOE - it is noted here that the 5 % decline rate is not sufficient to directly offset the discount rate over time (as shown in Fig. 10). This results in a calculated decline in production, but only in relation to the time value of money. Fuel costs, as it relates to traditional energy technologies can be excluded from a modified formula, as the cost of fuel will always be “0” for geothermal plants.

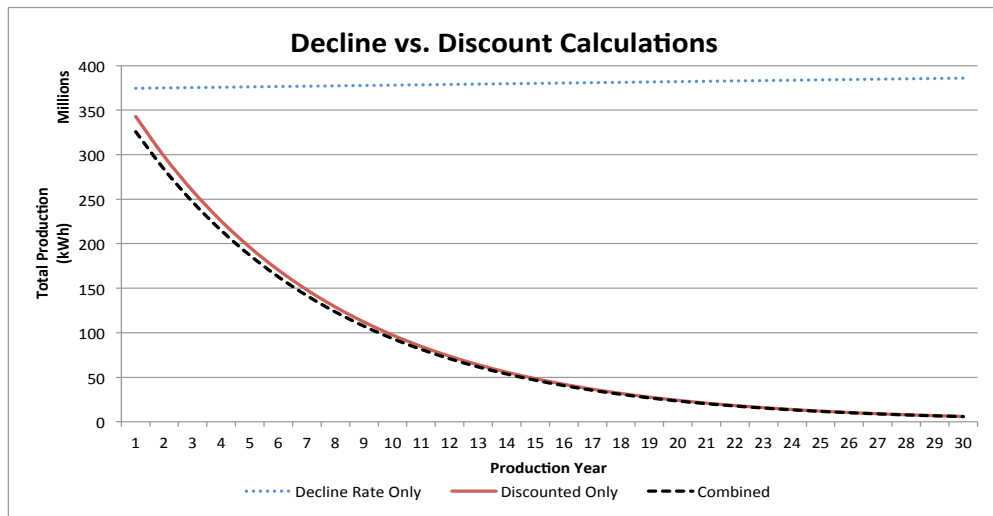


Figure 4.1: Discounting vs. Resource Decline

4.2.5 Probability of Success

Project development of any kind requires that the investors and stakeholders accept an appropriate amount of risk based on their respective positions. Each stage of development in a geothermal project bring with it a different set of risks and the probability of success changes as each stage is processed leading to the final production of energy. Referring again to the GETEM modeling at DOE, there is a process of accounting for project down-selects, which allows their modeling to scale down the life-cycle costs to achieve a successful power plant (Mines, 2013). This assumes that at each stage of development, there will be more projects started than will continue to the next stage. In 2008, Deloitte included the results of their probability calculations (Deloitte Development LLC, 2008). In order to reflect the actual state of project development for geothermal projects these probabilities are incorporated into the model at each stage of development. For example, a project has an approximately 9% probability of project success at the initial development stage, thus it is reasonable to expect that of the aggregate costs for that state of development that the developer will actually invest 11x more at that stage in order to meet a successful end. These values are estimated from the table provided by Deloitte (2008), and have been used in multiple market reports since (Islandsbanki, 2011) (Geothermal Technologies Program, 2009). The table below provides a replication of the table from Deloitte (2008).

The intended use of these probabilities is to help reflect the true costs of success at each development stage. Each probability is included in the annual calculation of costs to represent the total invested costs at that stage of development.

This is where the model is designed to account attributes instead of those related to specific projects. It is also a valuable calculation for policymakers when considering the effects of policy mechanisms during early stages of geothermal development. This

will be included in a later discussion of policy options and results.

The actual use of this data is best represented in Figure 3 (Chapter 2). Since the values given by Deloitte are more specific than is need for the GeoLEC design, it is important to correctly categorize the different values and determine an aggregate number that can be associated to each stage given by the GEA. For this purpose the categories are determined as “Identification”, “Exploration”, “Drilling”, and “Production”; and have respective values of 9.5%, 31%, 90%, and 99%. Note that the probability of success increase dramatically once the project has confirmed a resource and begins drilling production and injection wells.

Table 4.2: Investment Multiplier by Down-Select Phase

			Invest \$
Identification (9.5%)	Desktop	9%	\$ 11.11
	Recon	10%	\$ 10.00
Exploration (31%)	Geophysics	20%	\$ 5.00
	Exploration	42%	\$ 2.38
Drilling (90%)	Delineation	80%	\$ 1.25
	Feasibility	82%	\$ 1.22
	Initial Prod.	95%	\$ 1.05
	Fin. Close	96%	\$ 1.04
	Production	98%	\$ 1.02
Production (99%)	Injection	99%	\$ 1.01
	Construction	99%	\$ 1.01

* Figures estimated from table published by Deloitte (2008).

Table G also provides a reflective calculation on the value of \$1 as it relates to the probability of success for a project. If there is only a 20% probability of the project succeeding (e.g. Geophysics), then each dollar spent on a successful project represents approximately \$5 of total investment at that stage of development.

4.2.6 General Assumptions:

The final assumptions to be applied are specific to this research application. Typically levelized cost is a measure used to compare the unit cost of different energy technologies. With that in mind it is ideal for cross technology studies. In this application, however, there will be no assessment or calculation of other energy technologies. The modified formula should and is only applied to geothermal power. This must be understood prior to proceeding in the research, as it differs from more traditional applications of levelized cost, and has a significant effect on the use of this model.

A secondary point that should be made for the application of this model and research, is that it also does not compare to other studies of levelized cost. The intent is not to compare the product of the GeoLEC formula to that of studies, like the Projected Costs of Electricity Generation, but to assess the sensitivity of specific variables and analyze policy applications in a comparative setting. Although the reference research has used similar methods, the objective is very much different in this study when comparing the findings and results. This must also be made clear in the context of this study.

Discount Rate:

The calculation of levelized cost of energy is dependent on the discount rate selected. Short et al. (1995) determine that the discount rate for the utility industry should be equal to the weighted average cost of capital (WACC). They continue by calculating estimated rates by sector, and suggest that the WACC for industry equal 10% and utilities should equal 4.9% (Short et al.) Further analysis provided by the Western Governor's Association (2006) also utilizes this method of selecting a discount rate, and in its analysis used 10% for geothermal energy projects. Even the IEA/NEA/OECD reports on the Cost of Producing Energy, arbitrarily use 5% and 10% in its analysis of LCOE.

Where the proportion of debt versus equity is multiplied and summed against each respective interest rate the WACC can be calculated. Here the interest rate for debt is 7% and equity is 15%. Both Short et al. and the Western Governor's Association (2006) report use a debt to equity ratio of 70/30, which is also supported in Cross and Freeman (2009). See calculation below:

$$(7\%*70%)*(1-35\%)+(15\%*30\%) = 7.69\%$$

Debt + Equity = Weighted Cost of Capital

Although the calculation above is only 7.69%, and would be ideal to use as the discount rate if the power plant was owned and operated by a utility direct. In the U.S. however, this is not the case as geothermal projects are considered as independent power providers (IPP) and are engaged with the utilities through PPA contracts. As this is the nature of the U.S. market it is more appropriate to define the discount rate as the cost of equity, which in this case is 15%, and represents the true cost of developing a geothermal power plant over time as a revenue requirement. Keep in mind that the sensitivity of each variable in the model is being tested, thus a fixed discount rate is intended to aid in isolating the best variable for further policy analysis. It is also important to note that with a comparatively higher discount rate the levelized cost, as calculated in the GeoLEC, is expected to be higher than if a rate of 7.69% or 10% were used.

Once the discount rate is selected, the model must decide if that rate will be real or nominal. At 15%, the rate represents a nominal value. According to Short et al. (1995) a nominal discount rate is ideal for near-term analyses, and includes an inflation rate in the overall calculation. The real discount rate, on the other hand, supports longer-term projections and does not account for inflation. Depending on which of these rates is used

the rest of the model must reflect a respective currency: Constant \$ for a real rate and Current \$ for a nominal rate. To calculate one from the other, Short et al. have provided a conversion formula.

Equation 8: Nominal & Real Discount Rate¹¹

$$(1+dn) = (1+dr)*(1+e)$$

For example, a 15% nominal discount rate, with 2% inflation would be equal to a 12.75% real discount rate. The nominal currency rate is used for tax calculations, as referenced in Short et al. (1995). As such this study will use the 15% nominal rate.

Taxes:

As many policy mechanisms are designed to scale down or remove tax liability as an incentive for successful projects, it is important to consider the role of taxes in modeling project output. Thus any financial model, or policy tool, should also reflect this relationship as a baseline and under counterfactual scenarios. It is even more valuable, as policy mechanisms can be used to incentivize commodity markets, and encourage growth. This is widely seen with renewable energy technologies in the form of tax credits or accelerated depreciation methods (e.g. the Federal Production Tax Credit, the Business Investment Tax Credit, or MACRS).

The modeling of levelized cost is dependent on the definition of the assumptions used. Short et al. (1995) distinguish the role of taxes in the calculation of total life-cycle costs (TLCC). They note that taxes are for all intents and purposes indistinguishable from

¹¹ d_n = Nominal Discount Rate, d_r = Real Discount Rate, e = Rate of Inflation

any other O&M costs associated to plant operations, and should thus be included in the economic analysis (Short, Packey, & Holt, 1995). Furthermore, the inclusion of taxes in analytical modeling must also treat financial value in nominal terms.

As a key component to the calculation of levelized cost, the TLCC can be determined through alternative methods, depending on how taxes are treated. Government and not-for-profit entities should use a “no-tax” method, while a utility company should calculate its revenue requirement, and include tax payments, as part of the regulatory pricing methodology. Since taxes will be treated as an annual expense in the development and operation of a geothermal power plant, the total life-cycle cost is determined by calculating the pre-tax revenue requirement. Taxes are measured at the federal level to show the interaction of cash flows the project performance over time. With this comes the question of the treatment of state taxes, which for the purposes of this model are excluded. The reasons being that the individual variation of rates by geographic region and the macro-level approach to policy options as applied on a market-wide basis. As recognized previously, the current state of fiscal incentives are dominated by federal policies, and thus are used here to shape the design used in modeling.

Equation 9: Pre-Tax Total Life-Cycle Cost¹²

$$Pre - Tax TLCC = \frac{I - [T * PVDEP] + PVOM[1 - T]}{(1 - T)}$$

(Short, Packey, & Holt, 1995)

By using this formula to calculate the total life cycle cost of a geothermal plant it is possible to include the corporate income tax as part of the plant’s operating liability.

¹² I = Initial Investment, PVOM = Present Value of O&M Costs, T = Income Tax Rate, PVDEP = Present Value of Depreciation

Taxes are also used as a means to determine a partial return on federal policy mechanisms. For example, as policy supports industry growth, the larger market also carries a growing responsibility for federal tax revenues. The inclusion of taxes, as a component of levelized cost, is considered separate from the assumptions discussed above. It is intended to best reflect the nature of development and operation of geothermal power plants in the U.S. market as a whole.

4.3 GeoLEC Formula:

By utilizing the basic formula for Short et al's levelized cost detailed above, it is possible to begin integrating assumptions. The integration of these assumptions and the supporting derivations produce the following formula:

Equation 10: GeoLEC Formula

$$GeoLEC = \sum_{n=0}^N \frac{\frac{[P * C_n - (T * DEP_n) + M_n(1 - T)] / (1 - T)}{(1 + r)^n * \partial}}{\frac{E_{n-1} * [1 - (l_r - 0.001^n)]}{(1 + r)^n}}$$

n: End Period (yr.)	Mn: O&M Cost (\$/kW)	CF: Availability Factor
T: Tax Rate (%)	d: Debt Ratio (%)	DR: Decline Factor
P: Installed Capacity (kW)	fe: Interest on Equity (%)	lr: Decline Rate (%)
Cn: Total Cost (\$/kW)	fd: Interest on Debt (%)	r: Discount Rate (%)
In: Investment Cost (\$/kW)	En: Annual Output (kWh)	Tdev: Development Timeline (yr.)

- Assumption 1: $\sum_{n=0}^N \gg \sum_{n=-T_{dev}}^N$
- Assumption 2: $T_{dev} = \sum(t_n)$
- Assumption 3: Capitalized interest¹³
- Assumption 4: $Decline\ Factor = 1 - (l_r - 0.001^t)$
- Assumption 5: Probability of Success ($\partial > 0$)¹⁴

¹³ IDC is included in the C_n for annual capital costs.

The GeoLEC formula shows that there are a number of variables that play a part in the calculation of levelized cost. Using research results from industry and market reports, each variable is established from the review of the literature. As noted in an earlier section Deloitte and the U.S. Department of Energy have recently published the installed costs and development durations for each stage of geothermal development. These figures are provided in Table H, and give a high and low range for each stage, and by integrating them into the model the research is able to account for the first and second assumptions of the GeoLEC formula. By structuring a model, based on the GeoLEC, to produce the output for a range of inputs it is then possible to assess each variable based on output sensitivity.

4.4 Quantitative Baseline Modeling:

The modeling of the GeoLEC, for purposes of further analysis, is done using a Discounted Cash Flow (DCF) method. In this method, the levelized costs are discounted annually, and structured to allow for variability in costs, time, rates, etc. Table 4.2 represents a sample of the modeling structure. Output from this model is represented by the sum of TLCC divided by the sum of production, given that each column is discounted annually.

4.4.1 Baseline Calculations:

Design of this model is to establish baseline figures that can be assessed and analyzed in understanding the dynamics of policy on levelized cost. In order to record

¹⁴ Probability of success must be greater than zero, because mathematically a value of “0” results in a zero TLCC. This assumes that a project stage with zero probability of success will not be pursued.

these baseline figures the model is configured to a specific series of parameters. The following is intended to establish those parameters and to record the baseline output of the model for further analysis.

Each input variable is represented by a series of inputs that define time and/or function. The variables used in the model will be explicitly linked to the input values.

- I_n : Investment cost is identified as the cost of development for the project. The input variables, which are used for I_n are the \$/kW installed for each phase of development. The GEA reports four phases and Deloitte gives the installed cost data. For baseline calculations a range average is used for input purposes, and is given in (\$2007).
- P : The installed capacity of the power plant provides the estimated size of output, annually, and the cost associated by development phase. Deloitte (2008) reported its cost figures for a 50MW plant.
- d_n : To calculate the interest during construction, the debt to equity ratio is needed. This input provides the percentage of debt used for each stage of development. It should be noted that debt financing is only realistic during phases III and IV (Salmon, Meurice, Wobus, Stern, & Duaiame, 2011).
- f_e/f_d : In addition to the ratio of debt for each phase the interest rate for both debt and equity are required. Salmon et al. (2011) provide data showing that the equity rates during phase IV are 12% for geothermal projects. Debt interest rates are also provided in the same report. Phase III/IV both require debt interests of 8% (Salmon, Meurice, Wobus, Stern, & Duaiame, 2011).
- CF : The total availability of a geothermal plant is comparatively higher than those of competing renewable technologies. A capacity factor is a calculation of the percentage time a plant will be in full operation. McIlveen (2011) finds that geothermal capacity factors are near 95% for both binary and flash technologies. Similarly, Kagel et al. (2007) note that geothermal capacity factors range from 87% to 97%. Included in this calculation are the capacity factor, plant efficiency, and resource factor.
- DR : Resource decline rates are discussed more thoroughly in the section above, and are available to account for resource risks over time. Sanyal (2010) and Sener (2009) each use a calculation of the need for make-up wells to determine the rate at which a resource will decline annually. In each case the rate used is 5% (Sanyal & Morrow, 2010) (Sener, 2009).
- OM : Operations and maintenance costs are associated to the continued operation of the plant. Payroll expenses and the cost of maintaining capacity are included in this value, which is defined by \$/kWh. Example estimates of O&M costs are determined to be \$0.015/kWh (Geothermal Technologies Program, 2009).
- E_n : This input characterizes the annualized output for each year. The calculation is given by multiplying the installed capacity by annual hours and the capacity factor.

- T: Each phase of development can be associated with a specific duration parameter. The input values for “T” are provided by Deloitte (2008), and represent a high/low range for each phase.
- r: The discount rate will remain constant throughout the analysis at 15% and will be treated in nominal terms.
- Plant Only Costs: In addition to the Phase IV costs, this model requires that the plant only costs also be provided. To calculate depreciation over time only the direct capital costs can be used.

In the table below (Figure 4.3), each input variables is provided as both range and median values for sensitivity analysis. For now it is important to understand the values in the far right column are direct input variables for the GeoLEC model.

Table 4.3: GeoLEC Modeling Input Data

Input Variable	Low (-10%)	Median	High (+10%)	Sensit
Phase I - Time	0.3375	0.375	0.4125	0.375
Phase II - Time	1.125	1.25	1.375	1.25
Phase III - Time	1.35	1.5	1.65	1.5
Phase IV - Time	1.35	1.5	1.65	1.5
Phase III D-Ratio (%)	43%	48%	53%	48%
Phase III D-Rate (%)	7%	8%	9%	8%
Phase IV D-Ratio (%)	63%	70%	77%	70%
Phase IV D-Rate (%)	7%	8%	9%	8%
Phase IV E-Rate (%)	11%	12%	13%	12%
Capacity Factor (%)*	81%	90%	99%	95%
Resource Factor (%)*	72%	80%	88%	100%
Parasitic Load Factor (%)*	78%	87%	96%	90%
Decline Rate (%)	5%	5%	6%	5%
O&M Costs (\$2007)	\$ 0.014	\$ 0.015	\$ 0.017	\$ 0.015
Phase I w Risk (\$2007)	\$ 132.63	\$ 147.37	\$ 162.11	\$ 147.37
Phase II w Risk (\$2007)	\$ 435.48	\$ 483.87	\$ 532.26	\$ 483.87
Phase III w Risk (\$2007)	\$ 850.00	\$ 944.44	\$ 1,038.89	\$ 944.44
Phase IV w Risk(\$2007)	\$ 1,454.55	\$ 1,616.16	\$ 1,777.78	\$ 1,616.16
Plant Costs w Risk (\$2007)	\$ 2,352.60	\$ 2,614.00	\$ 2,875.40	\$ 2,614.00
Phase I - Costs (\$2007)	\$ 12.60	\$ 14.00	\$ 15.40	
Phase II - Costs (\$2007)	\$ 135.00	\$ 150.00	\$ 165.00	
Phase III - Costs (\$2007)	\$ 765.00	\$ 850.00	\$ 935.00	
Phase IV - Costs (\$2007)	\$ 1,440.00	\$ 1,600.00	\$ 1,760.00	
Plant Only Costs (\$2007)	\$ 2,352.60	\$ 2,614.00	\$ 2,875.40	
Total Availability Factor (%)*	56%	63%	69%	81%
Installed Capacity (kW)		50000		50000
Discount Rate (%)		15%		15%

Modeling is configured using MS Excel to generate the output values for levelized cost, given the input variables in Table 4.3. When these inputs are applied, it is possible to adjust the output to reflect different estimates on the discount rate. With the 15% discount rate the baseline result for TLCC is \$283,646,634 with a levelized cost (GeoLEC) of \$0.179 per kWh.

Table 4.4: Baseline Modeling Output

GeoLEC Model: RESULTS		TLCC
(\$/kWh)	0.1791	\$ 283,646,633.68

4.5 Sensitivity Analysis:

The formulation of the GeoLEC formula alone offers limited insight in to the application of policy incentives specific to geothermal power. It does identify and incorporate unique attributes of geothermal power into the projected output. Further meaning must be derived from the formula, and the relative impact of each variable, to properly structure policy. Therefore, the research uses a method of sensitivity analysis called “one-at-a-time”, or OAT. This process is understood as the altering of a single variable to note the percentage change in the overall output. Due to the dependent and independent network of variables given in the GeoLEC, the objective is to identify those variables that require the least amount of change relative to the greatest measured change in output. In both the 2005 and 2010 editions of Projected Costs of Electricity Generation, the analysis uses a process of sensitivity analysis, and although there are a number of energy technologies included in the report findings, geothermal power is not (OECD, Nuclear Energy Agency, 2010) (OECD, Nuclear Energy Agency, 2005). In the 2005 edition, the authors note that the sensitivity analysis allows for the identification of

impacts of various parameters, which are subject to individual energy sources (OECD, Nuclear Energy Agency, 2005). Dr. Sanyal also uses sensitivity analysis extensively in his publications and research. In fact on the subject of geothermal costs he has published multiple articles, which rely on a method of sensitivity analysis (Sanyal S. K., 2005a) (Sanyal S. K., 2005b) (Sanyal & Morrow, 2010).

The application of sensitivity analysis is conducted using a software package that works in conjunction with Microsoft Excel, named Sensit. An appendix will be devoted to describing the Sensit software and application. The following identifies some of the key points to be utilized in the software, with a sample run of the GeoLEC formula.

- Sensit uses the triangular approach to determine a base, low, and high value for each variable being tested.
- Multiple output methods are available: spider diagram, single variable tornado diagram, and 2-variable tornado diagram.
- The spider diagram uses a definable percentage step.
- Tornado diagrams are assessed on an appropriate range for each variable, versus a standard percentage.

Using the sample output, attached, a preview of the use and interpretation of the research can be made. For example, each of the variables is ordered by degree of sensitivity. The top three results are: drilling time, capacity factor, and production time; but it can clearly be seen that drilling time has a greater impact on the GeoLEC output than the others. By assessing the sensitivity of each variable used, the research can narrow the methods of policy application to focus on those attributes of levelized cost that are most susceptible to change. In the following section regarding policy analysis, a sample policy application is discussed to provide a continuation of this procedural framework.

4.5.1 Single Variable Sensitivity Analysis

Having the additional capabilities of a software suite allows for the testing of variables and outcomes to be conducted more efficiently and in a timelier manner. The use of a software suite does not, however, relieve the researcher from properly developing an approach or methodology for the data and analysis. In this case the added benefit that comes from using the Sensit software is that the data can be ordered and the testing of iterations is more efficient. Thus the input parameters must be set in order to properly define the program capabilities. With reference to a triangular approach, there is a need for a baseline value. For this the GeoLEC model uses the general parameters with an outcome of \$0.179/kWh LEC. Each of these variables is detailed extensively in the preceding paragraphs, and therefore no further discussion is necessary. In addition to the baseline, each variable requires a “low” and “high” value to complete the triangular method. There are two possible approaches here: use industry ranges or set a standard step percentage. The reasoning for choosing the latter returns to the intent of the research, which is not an improved method of calculating levelized cost, although it is the hope here that this method will prove useful to continued research. Instead the intent is to use the functional LEC sensitivity to geothermal specific variables. Therefore, the use of a 10% adjustment above and below the baseline input variable places each variable in the same context within the model. To finish this thought, a 10% adjustment can then be compared to the percentage increase or decline in LEC, which offers a quantitative means of assessing the effectiveness of each input parameter. Chapter 5 will continue upon this course by interpreting the best method of manipulating each variable in accordance with suggested policy mechanisms.

Identical to the baseline values, the sensitivity model requires independent input parameters. This allows the model to return, or reset, prior to testing the next input

iteration. The product of this modeling is represented below in Table J. Each variable provides the input values used and the output range in \$/kWh. The variables are sorted to reflect the lowest output, and not the greatest range between high and low outputs. This selective assessment is used to reflect the research objective in trying to maximize the effects in lowering the LEC for geothermal.

Table 4.5: Sensitivity Output - Single Variable Test

Input Variable	Corresponding Input Value			Output Value		
	Low Output	Base Case	High Output	Low	Base	High
Phase III - Time	1.35	1.50	1.65	\$ 0.170	\$ 0.179	\$ 0.183
Phase III w Risk (\$2007)	\$ 850.00	\$ 944.44	\$ 1,038.89	\$ 0.171	\$ 0.179	\$ 0.187
Phase IV w Risk(\$2007)	\$ 1,454.55	\$1,616.16	\$ 1,777.78	\$ 0.172	\$ 0.179	\$ 0.186
Phase II - Time	1.125	1.25	1.375	\$ 0.172	\$ 0.179	\$ 0.181
Phase IV - Time	1.35	1.5	1.65	\$ 0.174	\$ 0.179	\$ 0.185
Phase III D-Rate (%)	7%	8%	9%	\$ 0.176	\$ 0.179	\$ 0.182
Phase II w Risk (\$2007)	\$ 435.48	\$ 483.87	\$ 532.26	\$ 0.176	\$ 0.179	\$ 0.182
Plant Costs w Risk (\$2007)	\$ 2,875.40	\$2,614.00	\$2,352.60	\$ 0.177	\$ 0.179	\$ 0.181
O&M Costs (\$2007)	\$ 0.014	\$ 0.015	\$ 0.017	\$ 0.178	\$ 0.179	\$ 0.181
Phase I w Risk (\$2007)	13263%	14737%	16211%	\$ 0.178	\$ 0.179	\$ 0.180
Decline Rate (%)	5%	5%	6%	\$ 0.178	\$ 0.179	\$ 0.180
Phase I - Time	34%	38%	41%	\$ 0.179	\$ 0.179	\$ 0.180
Phase IV D-Rate (%)	0.072	0.08	0.088	\$ 0.179	\$ 0.179	\$ 0.179
Phase IV D-Ratio (%)	63%	70%	77%	\$ 0.179	\$ 0.179	\$ 0.179
Phase IV E-Rate (%)	11%	12%	13%	\$ 0.179	\$ 0.179	\$ 0.179
Phase III D-Ratio (%)	43%	48%	53%	\$ 0.179	\$ 0.179	\$ 0.179
Capacity Factor (%)*	81%	90%	99%	\$ 0.179	\$ 0.179	\$ 0.179
Resource Factor (%)*	72%	80%	88%	\$ 0.179	\$ 0.179	\$ 0.179
Parasitic Load Factor (%)*	\$ 0.78	\$ 0.87	\$ 0.96	\$ 0.179	\$ 0.179	\$ 0.179

Notice that in Table 4.5 the most significant input variable, given a 10% reduction, is the time associated to Phase III development. This portion of the development timeline is heavily dependent on the development of sub-surface resources. It is prior to the construction of the power plant and comparatively has even lower costs per kW than Phase IV. It is here however that the model assumptions are playing the role in which they were intended. For instance, because the Phase III costs are incurred earlier in the development timeline than Phase IV, there is the additional discounted value thereby increasing the cost with respect to time. Assumption 5 should also be considered

here since the probability of success is only 90% for Phase III, making the overall costs 1.1x greater in the end to account for the likelihood of a 10% failure rate. Both Phase III Time and Costs are impacted by these assumptions as each is integrated into the final output value.

Phase IV is the third most significant single input variable and follows closely behind Phase III Costs. Phase II Time can be a heavy impact variable, and reflects the potential impacts of permitting on the overall project cost. Phase IV Time is closely related to the higher unadjusted costs of Phase IV development, and after accounting for the time discount there is almost a 2% reduction in LEC that can be attributed to a 10% reduction in Phase III Debt Ratio. Although this is not the full list of input variables, it does reflect those that are most prominent in testing the sensitivity of the GeoLEC model. Figure 11, below, provides a visual representation of the single-factor sensitivity.

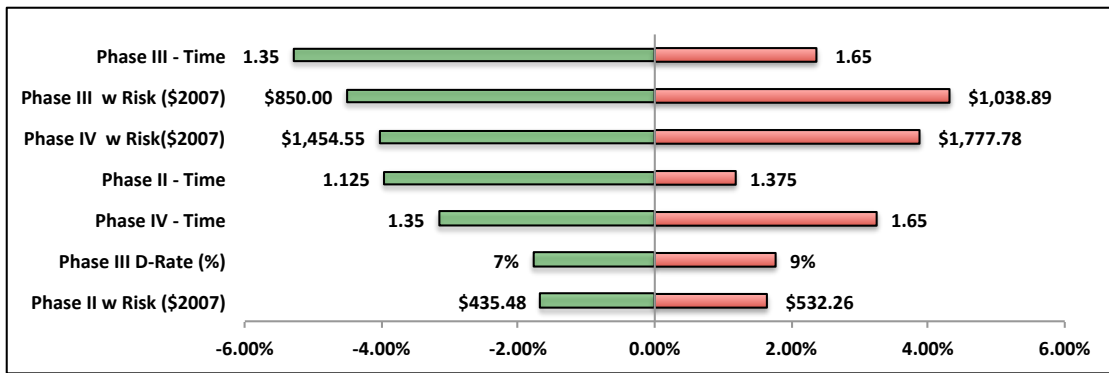


Figure 4.2: Single-Variable Sensitivity

Another point to note regarding Table 4.5 is that many of the single variables tested do not have an effect on the GeoLEC at 10% variation. This is not to say that there is no change but to the number of decimals selected there is none. Effectively this suggests that the last six variables in the table are the least actionable for policy

considerations. Among these six are each of the factors used to calculate the TAF (Total Availability Factor). A possible reason for this is the group effect of the variables together as opposed to individually, but additional consideration should account for the effect of discounting the factor reduction over time. The result shows a limited effect of individual factors of plant capacity.

4.6 Summary:

The results of modeling a geothermal specific form of levelized cost has benefits in identifying the underlying barriers and components that are most relevant to developing a particular energy technology. In this chapter, it begins by defining the method for which the modeling will be used. In that method, the EIA, IEA, OECD, Department of Energy, and BNEF¹⁵ have articulated the value of levelized cost analysis from their respective studies and research. The goal here is, however, not to replicate the methods and processes used in other research but to use a conceptual methodology to identify and quantify the results of the barrier analysis in earlier chapters. The result is a model that accounts; through its specific assumptions, for the unique characteristics that are valuable in developing geothermal energy.

Through these modeling efforts a baseline output series has been developed to test for sensitivity and, in the following chapter, applied policy analysis. These results are intended to narrow the potential sources for applying policy mechanisms and creating a more efficient method for constructing and implementing policy for the purposes of supporting individual energy technologies. The outcome of this chapter is to highlight the need for measured policy responses that allow barrier mitigation targeted to Phase

¹⁵ Bloomberg New Energy Finance

II/III/IV – Time and Phase III/IV – Costs. Due to the nature of the model used, this also supports the needs of the geothermal community in addressing issues of risk, cost, permitting, and time.

Chapter 5

POLICY ANALYSIS

In previous chapters it was discussed, and shown, that geothermal power has many unique characteristics and challenges alike. As a technology it is akin to both the fossil fuel/mining industries and the renewable energy sector. Is it possible to have the best of both worlds? This may be argued on a variety of stances, but it is only through a very informed understanding of the technology and markets that geothermal power projects can be assessed under the limitations and constraints of modern policy initiatives. The reward of naturally pairing the most effective policy tools with the unique characteristics of geothermal projects is the aim of this chapter.

To best identify the process for which this chapter will achieve its task, it is important to understand the values found in a series of preselected policy options that are either referenced in the literature review, found in chapter two, or are among the current stable of policy mechanisms used by a contemporary geothermal industry in the United States. The overarching goal of this chapter is to identify the components, which have resulted from lock-step analysis in preceding chapters and that identify the most unique and efficient factors used to measure and test geothermal cost as levelized. Resource risk, initial costs, permitting, and financing all play pivotal roles in creating, and thus mitigating, market barriers to developing geothermal power in the U.S. Realizing these barriers through the assumptions of quantitative modeling the GeoLEC model resulted in further granulation of the factors affecting the industry's success. Phase III costs and time, risks, permitting and overall costs need to be the focal points for further policy research, as determined in Chapter 4.

Continuing this research study, further analysis will define a variety of policy options, and then quantify their use in the GeoLEC model. Once the model has been modified to reflect each of the policy variables, a baseline reading is taken to establish the effects of said policy on the GeoLEC. Policy options and current policy mechanisms will be tested in the same manner. In some cases a policy option will have multiple settings to reflect different levels of application. It is intended that through this process each policy option will be honed to reflect it's most efficient state. Once all of the policy mechanisms have been tested the results are to be presented and assessed.

The policy options to be modeled, as noted, are collected from the literature review, as is the case with Feed in Tariffs (FITs), Cost-Sharing and Insurance Schemes. Others, such as Master Limited Partnerships, have existed for some time, but may be amended during the 113th Congress to be more tailored to renewable energy projects, including geothermal power. Modeling for policy related to permitting will require established time and cost factors related to a more streamlined approach. To follow these discussions, existing/past policy mechanisms are reviewed in the same manner, and will include a brief assessment of their roles in the development timeline for geothermal.

5.1 Policy Analysis Model and Criteria:

Policy analysis will be greatly informed by the analysis and results of both the barrier and sensitivity analysis. Most notably, it uses the formula derived in the review of levelized costs, titled the GeoLEC. It is through this formula that the research identifies the impacts, and in some cases ranges, of both dependent and independent variables in the GeoLEC. Given the review of policy applications in the previous section, each will be assessed on how it can be applied to the GeoLEC. Once this has been done, the objective is to take each of the policy alternatives and integrate them into the GeoLEC individually.

This can be thought of as a type of sensitivity analysis where in all variables are kept equal and only those subject to the respective policy are changed. In the discussion of geothermal policies, there is no precedence already made for this method. The resulting measures are ranked against contemporary policy incentives. The following briefly describes the process for applying the research process.

When this value is substituted into the GeoLEC modeling, the results give a comparable valuation of the levelized cost related specifically to the application of the geothermal risk guarantee. For simplicity the 10% nominal discount rate is used. The application of this research is intended to expand and identify policy options that are better for geothermal development and more effective for the implementer. This process of testing will focus on both existing policy applications, as well as alternative policy formulated by governments and the private sector. The implications found in the analysis allow for a method of universally ranking the different policy applications, while reflecting multiple test parameters to account for economies of scale. It is also for this reason that levelized cost was the chosen measure because it is well suited for assessing rank (Short, Packey, & Holt, 1995). It is, furthermore, this method of ranking that will allow policy makers to make initial valuations of policy paths by determining levelized cost.

5.2 Applied Policy Alternatives:

Master Limited Partnerships

While having been used as a tax shelter since 1981, master limited partnerships (MLP) were not explicitly defined or limited until passage of the Tax Reform Act of 1986 and Revenue Act of 1987. It was this act that also set forth clear qualifications standards for income from such entities. Internal Revenue Code § 7704 stipulates that

qualifying income is defined, under subsection (e) as “income and gains derived from the exploration, development, mining or production, processing, refining, transportation (including pipelines transporting gas, oil, or products thereof), or the marketing of any mineral or natural resource (including fertilizer, geothermal energy, and timber).” This, therefore, qualifies geothermal energy projects as eligible to be structured as a master limited partnership, as long as more than 90% of income was from a qualified source, such as geothermal steam. Under the current structure of MLPs, the structure of geothermal entities creates a barrier to full utilization by the industry. The cause lies in the formulation of project organization, with the steam resource not acting as the commodified unit. Instead the industry relies on the sale of electricity as the basis of revenue generation. Under the proposed Master Limited Partnership Parity Act of 2012 (Coons, 2012), renewable energy technologies would be included as qualified entities based on the sale of power instead of the sale of the resources generating that power. This modification to MLPs would considerably change the dynamics of project finance by lowering the initial and long terms costs associated with corporate taxation.

Unlike traditional corporate entities, MLPs are exempt from federal corporation taxes, with shareholders responsible for individual taxation relative to the buying and selling of their shares. This structure avoids double-taxation (Bullock, Weinstein, & Johnson, 2012), and allows the shareholders to retain greater revenues, while limiting the amount of total taxes paid on revenues.

The partnership structure of an MLP is devised of both general partners and limited partners. General partners ideally hold less than 2% of the ownership stake, but are responsible for the management of the MLP operations (National Association of Publicly Traded Partnerships, 2012). Limited partners are the holders of publicly traded stock in the MLP. Their role is to provide capital, with no direct role in operations or

management. Limited partners receive a quarterly cash distribution, which have been increasing at 4-10% annually (Bullock, Weinstein, & Johnson, 2012).

Historically, MLPs have not been a successful financing tool for the geothermal industry, and has seen very limited use. The reason, according to (Gawell, 2012) resides with the nature of geothermal steam resources and configuration of resource ownership. In the case of MLPs, the steam is the commodity to be sold, not the power generated for the steam resource. The geothermal industry is configured in such a way that the entity developing a steam resource and producing power are often the same. This means that there is no actual transfer and sale of resource between entities. In a more contemporary sense, the Master Limited Partnership Parity Act was introduced in front of the U.S. Congress in 2012 (Coons, 2012). This Act would expand the parameter of qualified resources to include other renewables, like solar and wind. It will also transfer the definition of qualified resources to the production of energy (kwh) derived from renewable resources, thus expanding the option as related to geothermal projects. For the calculation of the GeoLEC, the model uses a corporate approach to tax calculation. It is here, based on the content from Short et al. (1995), an alternative calculation for Total Life-cycle Costs (TLCC) is used to reflect a non-corporate entity, and remove the inclusion of corporate taxes from the project cash flows. This TLCC is determined by calculating the total investment cost, plus the present value of O&M costs over the life of the plant. Making this adjustment removes the payment of corporate taxes, thus reducing revenue requirements. As a result the GeoLEC is rewritten as:

Equation 11: GeoLEC - No Taxes

$$GeoLEC = \sum_{n=0}^N \frac{\frac{[P * C_n + M_n]}{(1+r)^n}}{\frac{E_{n-1} * [1 - (l_r - 0.001^n)]}{(1+r)^n}} * \partial$$

It is worth noting that the assumptions placed in the GeoLEC equation still hold. Interest During Construction, Discounted Capital Costs, Resource Decline, Probabilities of Success, and Availability all remain. This modification removes the present value of depreciation and the calculation of corporate taxes.

Table 5.1: Master Limited Partnerships

GeoLEC Model: MLP RESULTS	TLCC	Mitigation
(\$/kWh) 0.1356	\$ 227,809,569.38	24.3%

In application the use of a Master Limited Partnership doesn't fully remove the taxation as represented in this model. To be more specific, the project entity is responsible for the corporate tax and its shareholders are responsible for income taxes subject to project revenues in a C-corporation format. As a MLP, the project is exempt from the corporate tax; however, the capital gains tax is transferred to the individual investors as a tax on cash distributions. The benefit here is derived in the form of double taxation, which is not placed on the investors. Ultimately, the investor will pay this tax, either as a C-corporation (~15%) or as a MLP (~35%). The latter provides greater revenues while removing the secondary taxation. The result provides the project with elevated revenues and the investor with a lower tax liability. In this model the MLP was selected on a project basis, which improves the overall financial dynamics of the project, while the investors absorb the tax liability and greater revenues. It should be noted that depreciation is transferable, while tax credits (e.g. PTC and ITC) are not.

Feed-in-tariffs:

Popular in Europe, the feed-in-tariff (FIT) application is beginning to be applied at the sub-federal level. These tariffs can be developed depending on power plant size

and time frame within which the investors can rely on the investment safety. Usually the FIT systems are independent of the time of feed-in. Although not always the case, Hungary has applied a FIT higher at periods of peak demand (usually around mid-day). With this in mind, Rybach (2010) suggests that solar and geothermal technologies would benefit most from such schemes. Given a price premium under this model, the cost of applied energy would reduce, with a goal of grid parity. This is achieved by creating standardized pricing and a more streamlined approach, allowing greater ease to market entry (Taylor, 2010).

Because the calculation of FIT rates is based on the localized costs of geothermal project development, there is an obvious variation from country to country, region to region, and even state to state. For instance, Indonesia has different rates based on the variations of its geothermal resources among its islands. The average rate is estimated at \$0.135/kWh (Taylor, Stopforth, & Kuang, 2012). Japan adjusts its FIT by project capacity, with those projects sized below 15MW priced at \$0.44/kWh and larger projects being eligible for \$0.29/kWh, equivalent in US dollars. The Japanese FIT is available for 15 years, while Indonesia has no term limits or escalation of rates over time (Nakamura, Woodward, & Sjardin, 2013). This later point reflects the impact of inflation on FIT pricing over time. Germany, for example, has priced its FIT at \$0.1039/kWh, according to Rickerson et al. (2012) with a digression rate of 1% annually, meaning that the price decreases over time to support the ability of the technology to become fully commercialized without continued subsidies. In each of these cases the FIT is in lieu of a Power Purchase Agreement (PPA), while creating a comparable source of stable revenues. The most notable point to realize in discussing global FIT pricing is the reality that each FIT is priced based on a localized development cost. Thus, it is not appropriate to suggest that the price for Japan or Germany is directly applicable to the United States

market. For this an alternate approach is needed. It is also stated in Rickerson et al. (2012) that the utilization of a FIT versus a PPA also reduces development time required to secure a sales contract for power output.

Alternative analysis from the National Renewable Energy Laboratory on FIT design shows that there are multiple models available to choose from. A FIT could be designed based on the cost of energy production, either using levelized cost or the value of generation, plus a premium (Couture, Cory, Kreycik, & Williams, 2010), or the FIT can take the form of a fixed or auctioned price, the latter being set by the market. In the case of each of these options the authors of the NREL report also acknowledge a difference in constant versus sliding price strategies. A sliding strategy varies according to the price on the spot market (Couture, Cory, Kreycik, & Williams, 2010). Furthermore, there should be adjustment in price based on the technology, location, size, and quality.

As a FIT is designed to replace the need for a PPA, according to Rickerson et. al., the full payment of a FIT using values from Japan and Indonesia is likely to mitigate all costs. However, this is short sighted since without a FIT the producer would use a PPA to stabilize the project finance component of the project. If a theoretical FIT is based on the calculated GeoLEC values used as a baseline, and then incorporates a margin for the weighted average cost of capital (WACC)¹⁶, the premium (Gipe, 2010) (Caperton et. al., 2011) is given at 7.69%. This follows the design suggested in the literature and that of the City of Gainesville, FL, the first applied FIT in the US (Couture, Cory, Kreycik, & Williams, 2010). With the calculation of a FIT, based on the GeoLEC model, a 7.69% premium places the price at \$0.192/kWh. This premium could also be set based on

¹⁶ $WACC = (7\% * 70\%) * (1 - 35\%) + (15\% * 30\%) = 7.69\%$. The WACC is used as a reasonable rate of return.

technology specific power service to differentiate baseload versus peaking supply, as well as a tool for isolating policy support by source.

Rickerson (2012) uses an annual 2% price escalation. Therefore the true benefit of a FIT on a project’s cash flow is most readily determined by calculating the difference between a FIT design and a PPA price, which providing a 1.5 debt service coverage ratio (DSCR) for the repayment of project debt over 20 years would require a higher price. This approach is in line with comments from Gipe (2010), who suggests that the most effective form of FIT provides a stable pricing platform relative to the cost of actual generation. The value of such a pricing subsidy begins at \$0.025/kWh and increases to \$0.042/kWh over 20 years.

The increased subsidy over time is the result of a higher escalation rate for the FIT price compared to the average PPA price, even though they both use 2%. The duration of 20 years (Couture et al., 2010) is used in the model and the results below are based on the same method of cash flow analysis as applied in calculating the PTC. It should also be noted that although the beginning PPA price of \$0.168/kWh is below the GeoLEC, with the 2% rate of escalation it would meet the 1.5 DSCR requirements for the project debt over time.

Table 5.2: Feed-in-Tariffs

GeoLEC Model: FIT Results	TLCC	Mitigation
(\$/kWh) \$ 0.149	\$ 216,569,532	16.57%

Geologic Risk Coverage:

Several countries have existing methods mitigating the risk associated to geologic discovery. According to Ryback, France utilizes a “Short-term Risk Guarantee” to provide security for the project manager. In this case costs are reimbursed for all or part

of the investments made in the event of total or partial failure of the drilling operations. “Long-term Risk Guarantee” follows that the developer be covered during a 25 years exploitation phase against the risk of having the geothermal resource decrease or disappear, and against damages that may occur to their installations (Rybach, 2010).

The Swiss have also implemented policies to manage geologic risk. In 1987 the risk guarantee fund was applied to development drillings with depths >400m (The Federal Authorities of the Swiss Confederation, 2011). The coverage provided 50% of drilling and testing costs (including reinjection). The risk guarantee covered the accrued costs in case of insufficient thermal power. No coverage was provided for permitting, insurances, or unforeseen capital costs. Successful development required no contributions have been paid (Rybach, 2010). More recently, Rybach finds that the Swiss case applies a maximum guarantee is 50% of the subsurface costs, with a program cost ceiling of \$163.5 million (US) (The Federal Authorities of the Swiss Confederation, 2011).

In a similar attempt to subsidize the costs of developing geothermal resources the United Nations has created the UN GeoFund. Determining success of project performance in geologic exploration risks is based on factors of temperature, permeability, flow rates, drilling depth, and cost (Combs, 2006). In return the fund creates security in taking on development risk by insuring up to 70% of exploration costs against failure (Bloomquist, Petty, & Wagner, 2007) (GEOFAR, 2009a).

In the case of geologic risk coverage, the policy is to be put in place so as to minimize the potential of catastrophic risk for developing a geothermal resource. In both the Swiss and UN examples the funds are capped. For modeling purposes the effects of these caps are not readily felt since a sample project is to be assumed as an awardee of said coverage. Therefore, the project is afforded a guarantee of 50% to 75% percent of the cost of exploration, but only on the probability of failure. To model this in the

GeoLEC model the costs for Phase III will be levied against the 42% probability of success (Deloitte Development LLC, 2008) that is estimated for exploration. As a result the cost of \$944.44/kW installed with risk probabilities in the model will be reduced to \$547.78 as actual costs at risk. Of this, the risk coverage would subsidize failure costs of \$273.89 and \$410.83 per kW installed for 50% and 75% coverage, respectfully. Since the time value of money is a key factor in calculating costs it is fair to assume that payments from such a coverage fund would not be immediate. As a result the payment will not be available in the cash flows of the project until Phase IV development. Of course this is a point of speculation, but in reality the policy design should account for a more specific payment schedule. Here, it is a matter of encouraging theoretical design.

Table 5.3: 50% Geologic Risk Coverage

GeoLEC Model: Risk Coverage (50%) Results	TLCC	Mitigation
(\$/kWh) \$ 0.174	\$ 272,953,867	2.64%

Table 5.4: 75% Geologic Risk Coverage

GeoLEC Model: Risk Coverage (75%) Results	TLCC	Mitigation
(\$/kWh) \$ 0.172	\$ 267,607,679	3.96%

Cost Sharing:

Dr. R. Gordon Bloomquist suggests that federal policy should also include cost-sharing applications, like the User Coupled Confirmation Drilling Program applied in 1980 (Bloomquist, 1985). Bloomquist details the program, making a clear distinction between direct-use and electric generation. The program, in both cases, would place the cost primarily on the developer for successes and the government for failures, reflecting 90% and 20% financial responsibility respectively. Although success followed, the

application, historically, was restricted to direct-use technologies, preventing the power sector from participating. In more recent work Bloomquist notes that exploration and development grants, exploration cost-sharing, risk-mitigation insurance, loan guarantees, and PTC are leading policies that are needed to aid geothermal development (Bloomquist, 2010). Deloitte (2008) recommends cost sharing to mitigate the costs and risk associated with exploration and development, while Doris et al. recommend that drilling assistance be provided during exploration (Doris, Kreycik, & Young, 2009). In both cases the intent is to draw down the financial risks of exploration and drilling. A program of this nature would protect developers when dry wells are discovered directing a portion of the costs to the federal level. Cases of successful wells would then allocate fees to further fund the program, thus allowing it to be self-sustaining. The emphasis, according to Deloitte, is to produce added value for the industry. An additional component of the Deloitte position is to include a funding requirement, which includes the submission of exploration data for a national database for geothermal resources. In their reporting this combination of procedures would deter future exploratory risks for geothermal (Deloitte Development LLC, 2008). Ideally, Rybach adds, Governments would finance exploratory and pre-feasibility phases of geothermal development, allowing investors to enter without the risk of resource failure (Rybach, 2010).

The application of a cost sharing mechanism is relatively straightforward. As the sponsor is subsidizing a portion of the costs up front, the actual cost of the related Phase of development is then reduced. More importantly the cost reduction is only applied to those wells in which resulted in a failure. Therefore, like the geologic risk coverage, cost sharing is only applied to a portion of the total cost. In this case the model uses a 50/50 cost-sharing ratio.

Table 5.5: 50% Cost Share - Exploratory Drilling

GeoLEC Model: Cost Sharing (50%) Results		TLCC	Mitigation
(\$/kWh)	\$ 0.169	\$ 260,035,523	5.83%

NEPA - Categorical Exclusion:

The National Environmental Policy Act of 1969 (1970) established protocols to enhance the protection of the environment in the United States, and promote a harmony between man and his (or her) environment moving forth. In compliance with this legislation project developers are required to conduct an environmental assessment (EA), an environmental impact statement (EIS), or both. The extent to which is dependent on the expected environmental impact of the project. All energy projects are subject here, if development is proposed within US territories.

Given the nature of geothermal exploration, similarities with oil and gas development is subject to the same legislation. However, with respect to NEPA, oil and gas projects can file for a categorical exclusion (CE or CX) on exploration activities, where as geothermal projects cannot (Deloitte Development LLC, 2008). According to the Bureau of Land Management (2008), a categorical exclusion is “a category of actions (identified in agency guidance) that do not individually or cumulatively have a significant effect on the human environmental, and for which neither an environmental assessment nor an EIS is required (40 CFR 1508.4)”. This means that prior to advancing a project to exploration, the geothermal industry must comply with either an EA or EIS, for which there is the possibility of finding no resource. The oil and gas sector, however, is able to minimize the conditional requirements for NEPA, through a CX, until an identifiable resource has been found and is ready to be exploited. The result of the disparity, adds an

estimated 6-24 months (Hance, 2005) and \$1.30-4.00/kW¹⁷ to the development process, but more so requires that the additional regulatory measures are provided for all projects, not only those that will become successful. In the preceding chapter, the probability of success is discussed at different development phases. A project preparing for exploration has approximately a 40% chance of success, where as the transition from feasibility to production is estimated near 90-95% (Deloitte Development LLC, 2008).

In allowing the categorical exclusion for geothermal exploration, the development of these projects would benefit from reductions in time and cost. Although an EA or EIS would need to be ultimately prepared in all successful projects there would be a significant streamlining of the process for both federal regulation and the developer.

Since this policy option is a modification of an existing regulatory policy, it is important to conceptualize how a change of this nature would interact with the GeoLEC framework and model. As mentioned previously, there is a shift in both time and cost related to actions taken under different probabilities of success. The processes would remain, but would offer a more streamlined approach. In order to do this, the current model interacts with the probabilities at the cost level while also reflecting time. Using the calculations from Hance (2005), the cost per kW and time for Phase II development are reduced and the costs of Phase III will be increased by \$4/kW. The model already adjusts for the factoring of risk probabilities, allowing the development phase shift to include cost and probability. The key here is the cost reduction in an earlier phase actually amplifies the effect of discounting and project down-selection.

¹⁷ These values were calculated on a range of \$65,000-\$200,000 provided by Hance (2005) against the plant sized modelled of 50,000kW.

Table 5.6: NEPA Categorical Exclusion¹⁸

GeoLEC Model: Categorical Exclusion	TLCC	Mitigation
(\$/kWh) \$ 0.157	\$ 254,768,710	12.53%

RD&D Funding – Drilling/Exploration Technologies

Supporting research, design, and development (RD&D) is frequently the role of federal agencies. The US Department of Energy channels the development of geothermal technologies through initiatives from the Geothermal Technologies Office. As a result the office targets the development of Enhanced Geothermal Systems, Low Temperature/Co-produced, and Innovative Exploration Technologies designed to advance industry growth and market penetration to follow the current development pipeline. This means that these efforts are focused on the geothermal technologies that have yet to be commercialized by the industry.

The federal funding system is able to project RD&D funding well into the future by making the effort now to create the next best-practice in geothermal development. It is difficult to focus on precise developments, but more appropriate calculations should target the proportional reduction of costs and time outlays related to various stages of development.

¹⁸ This assumes a shift of permitting costs (\$4/kW) from Phase II to Phase III, plus a 6-month delay of incursion.

Table 5.7: Federal RD&D Support

GeoLEC Model: Phase III R&D (30% Cost)	TLCC	Mitigation
(\$/kWh) \$ 0.156	\$ 248,408,550	12.94%
GeoLEC Model: Phase III R&D (10% Cost)	TLCC	Mitigation
(\$/kWh) \$ 0.171	\$ 271,900,606	4.31%
GeoLEC Model: Phase IV R&D (30% Cost)	TLCC	Mitigation
(\$/kWh) \$ 0.158	\$ 243,958,567	11.62%
GeoLEC Model: Phase IV R&D (10% Cost)	TLCC	Mitigation
(\$/kWh) \$ 0.172	\$ 270,417,278	3.87%
GeoLEC Model: Phase III R&D (30% Time)	TLCC	Mitigation
(\$/kWh) \$ 0.160	\$ 263,027,478	10.64%
GeoLEC Model: Phase III R&D (10% Time)	TLCC	Mitigation
(\$/kWh) \$ 0.170	\$ 271,702,217	5.02%
GeoLEC Model: Phase II R&D (30% Time)	TLCC	Mitigation
(\$/kWh) \$ 0.166	\$ 267,729,640	7.21%
GeoLEC Model: Phase II R&D (10% Time)	TLCC	Mitigation
(\$/kWh) \$ 0.172	\$ 273,334,753	3.81%
GeoLEC Model: Phase IV R&D (30% Time)	TLCC	Mitigation
(\$/kWh) \$ 0.164	\$ 273,001,517	8.54%
GeoLEC Model: Phase IV R&D (10% Time)	TLCC	Mitigation
(\$/kWh) \$ 0.174	\$ 279,938,978	3.06%

If current investments are able to reduce the technical requirements of development it is possible to project within the GeoLEC model where RD&D funding should be targeted. To model this approach, the underlying question is asked; what would happen if the time or costs were reduced by 10% and 30% during each respective phase of development. The results are individual, not cumulative.

5.3 Contemporary Policy:

In reviewing policy incentives, each is arguably complex enough to warrant individual books. For the purposes here within, those complexities are not believed to be

a vital component to the discussion, but will be included as it is felt necessary. There are some observations that prove useful when the incentives are correlated with the two selected barriers.

An important consideration for this analysis is the respective position of each of the policy incentives in relation to the stages of development for a geothermal project. How do policy incentives interact with early-stage development? This is introduced for though because of the respective nature of both “resource risk” and “initial cost” as development barriers. In previous comments there has been a strong linkage between “resource risk” and early-stage development, and is even part of the basis for which “resource risk” was grouped and cataloged. Similarly, the discussions in the readings related to “initial cost” presented a barrier to market entry, thus implying that existing market actors would be better suited to address this specific barrier. Again, there is also the direct correlation between risk and cost that offers a strong indication that each of the barriers is not mutually exclusive.

An alternative observation is much more fundamental, but relies on the underlying functionality of the method of policy incentive design. There appears to be a significant dependence of incentives on a measurable commodity. Because this case is dealing with the development of energy, the commodity in question is the kilowatt-hour (kWh). All but one of the policy incentives discussed above are directly dependent on the production of the kWh, which is at the last stage of development.

Federal Production Tax Credit (PTC):

Federal production tax credit (PTC), available to geothermal energy in 2004 for only a portion of the wind credit and for the full credit in 2005 (Doris, Kreycik, & Young, 2009). This has allowed a tax credit to be issued to geothermal electric projects at a rate

of US\$ 0.015/kWh for the first 10 years of each project. This price is further adjusted for inflation and currently is equal to \$0.023/kWh (GPO, 2013). Time constraints are applied and projects placed in service or “under construction” prior to December 31, 2013 will qualify (112th US Congress, 2012). Salmon et al. (2011) suggest that under the original formulation – without the “under construction” clause – the PTC is less applicable to geothermal projects, since project development timeframes are typically 4-7 years.

Federal Production Tax Credits originated as part of The Energy Policy Act of 1992, and originally had a policy horizon of July 1999. In December 1999, March 2002, October 2004, August 2005, and December 2006 the production tax credit was extended or renewed, but with each renewal there was either a gap or the renewal period was shortened. Developers and the renewables industry, as a whole, have taken to this inconsistency with a great deal of uncertainty in government support. Deloitte (2008) estimates development timelines for geothermal exceeding 3.25 years, at best. This supports the Salmon et al. (2011) claim that boom to bust cycles may create less reliance for geothermal projects on the PTC. (see note on H.R. 8 in ITC description)

Results:

- Annual discounted net production * \$0.023/kWh

Table 5.8: Production Tax Credit – PTC

GeoLEC Model: PTC Results	TLCC	Mitigation
(\$/kWh) \$ 0.162	\$ 244,271,397	9.73%

Investment Tax Credit (ITC):

Federal forms of the Investment Tax Credit have been part of the tax code for quite some time. The more contemporary application of this policy mechanism was

enacted in late 2008, with the Energy Improvement and Extension Act of 2008. Further alterations to the ITC were passed in the American Recovery and Reinvestment Act of 2009, which applied increased allotment for investment tax credits, from 10% to 30% of qualified expenditures for project placed in service prior to December 31, 2013. Following which the ITC will return to 10% (Salmon, Meurice, Wobus, Stern, & Duaiame, 2011). More specifically the ITC allows investors to apply a tax credit against their respective tax liability appetite reducing the indirect expenditures associated to the project development over time. For geothermal systems there is no maximum credit, and eligible property includes both geothermal heat pumps and energy produced from geothermal deposits. The ITC is limited to equipment up to, but not including, the transmission stage.

As part of the H.R. 8 (112th US Congress, 2012) - legislation passed both the House and Senate at the end of the 112th Congress - the PTC and ITC both were amended to expand the definition of qualified projects to include those, which are under construction at the close of 2013. A project is qualified as under construction when it has begun work of a significant nature or has incurred 5% of total project costs (Internal Revenue Service, 2013). This is very similar in nature of the guidance given to the 1603 Cash Grant, but does further require projects to maintain a consistent state of construction once qualified, unlike projects under 1603. For wind power projects this also extended the tax credit for an additional year to end on January 1, 2014 (112th US Congress, 2012). Geothermal, solar, and biomass maintained the same horizon date as before. These legislative changes to Sections 45d and 48a of the tax code have the potential to extend qualified awards by 2+ years. This is taking into account that the typical timeline for Phase IV is 1.5-2 years (Deloitte Development LLC, 2008).

- Year 1 payment of 30% of construction costs.

Table 5.9: Investment Tax Credit – ITC

GeoLEC Model: ITC Results		TLCC	Mitigation
(\$/kWh)	\$ 0.172	\$ 266,785,593	4.17%

Section 1603 Cash Grants:

Extension of the 30% investment tax credit (ITC) to new geothermal energy projects also allowed developers to apply for a cash grant in lieu of the ITC (Holm, Blodgett, Jennejohn, & Gawell, 2010) or PTC. Because in some cases, project owners were unable to use tax credits, due to limited tax liability, and thus sell the credits at a discount and use the Treasury Cash Grant to pay off upfront costs. These grants are attractive by being: quick, complete payout; not limited by tax liability (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). Incentive levels for geothermal projects do vary by qualified plant costs (30%) or development equipment (10%) (Doris, Kreycik, & Young, 2009) (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). In addition, Salmon et al. discuss the relative deadlines that are applicable to cash grant deployment, with current policy remaining until January 1, 2017 at the 10% incentive. The 30% incentive will remain until January 1, 2013 mirroring both the PTC and ITC policies, and include a “safe harbor” statement to allow for projects to qualify if under significant construction. To easily define “under construction”, the Treasury Department recognizes a more than 5% cost expenditure as qualifying, but only if occurring in 2009-2011. Most importantly the cash grant incentives elevate the need for an equity investor to absorb the tax credits above through an appropriate tax appetite (Salmon, Meurice, Wobus, Stern, & Duaine, 2011). Since 2009 all commercially developed geothermal projects in the U.S. have opted

for the 1603 Cash Grant, for a total to-date subsidy of \$555.6 million (US Department of Treasury, 2013).

- Year 1 payment of 30%/10% of construction costs.

Table 5.10: Section 1603 Cash Grants

GeoLEC Model: 1603 Results		TLCC	Mitigation
(\$/kWh)	\$ 0.170	\$ 262,566,265	5.21%

Sections 1703/1705 Federal Loan Guarantees:

EPA Act of 2005 offers federal loan guarantees to renewable energy projects, including geothermal. These loan guarantees can be applied to a limit of 80% of total project costs and are focused on technologies and projects that offer mitigation of greenhouse gas emissions (Geothermal Technologies Program, 2011). The technologies can fall under two categories: innovative (1703) and commercial (1705). Securing of a loan guarantee is an assurance made by the U.S. Department of Energy to accept the risk of the loan for the lender. This ensures that in cases of default the loan payment is taken over by the Department of Energy. Budgeting of funds for loan guarantees is not a factor of the sum of loans, but a measure of the expected payment, more commonly known as the “credit subsidy cost” (Caperton, 2011).

Of the policy incentives that are under review, the Federal Loan Guarantees (FLG) is most capable of addressing the argument that has been made relating to the development timelines. The details of this are subject to the broadened scope of the development process and the fact that the FLGs can be applied to up to 80% of project costs. This could, therefore, be understood to also include early-stage development, and the barriers in question. There is, however, some concern over this as a viable method of addressing these barriers and could be suggested as only an indirect relationship. The

question remains, with regard to resource risk and initial cost, because the FLG mechanism potentially reduces its own effectiveness by instituting administration costs that suppress the benefits gained through the FLG in the first place.

Due to the nature of cost reduction and regulatory requirements, it appears that there is limited actual benefit that is derived from the 1703/1705 awards. In addition, only three geothermal developers have won the 1705 awards, and of that one such award was returned. This further substantiates the overall return. As such, this study will view these loan guarantee awards as merely a method of maintaining the current GeoLEC at \$0.175/kWh.

5.3.1 Summary of Contemporary Policy Incentives

Financial subsidies, in a contemporary sense include multiple approaches to enact cost reductions for development projects. Using tax credits allows developers to leverage their existing tax liabilities, or entice equity investment, to further project development. In lieu of a tax credit the cash grant program offered a more direct subsidy option for cash strapped developers, while the loan guarantees promoted federal loan security for projects with innovative interests. All these options aside, there are obstacles to each that made for less than efficient implementation. Briefly, they are discussed as follows.

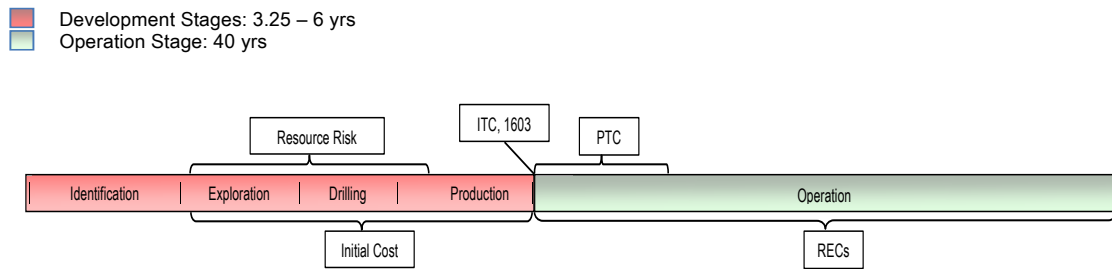


Figure 5.1: Policy Implementation Timeline with Barriers

- Tax credit and cash grant options are specifically awarded once the project is operational. This provides security for federal funds but places the development burden on the project. (See Fig. 12 above)
- Additionally, the tax credit options require that a developer have sufficient tax liability or find an equity investor whom can monetize the credits.
- Federal Loan Guarantees can be used for costs occurring throughout the development process, thus having potential to address initial costs and resource risk. The problem with implementation is that few geothermal projects have been approved and in some cases the administrative and regulatory requirements to exercise the loan guarantee may be cost prohibitive.
- Renewable Portfolio Standards do enable renewable energy credits (RECs) to help subsidize the overall cost of development and production of renewable energy projects, however, like ITCs and PTCs the timeline on accessing those credits is well beyond the feasibility stage. Although the RPSs drive the development of renewable energy technologies across the country, these policies do little to mitigate the initial cost and resource risk that is present in geothermal power.

Table 5.11: Policy Modeling Results

<u>Policy Options</u>	<u>GeoLEC</u>	<u>TLCC</u>	<u>Mitigation</u>
Master Limited Partnerships	\$ 0.133	\$ 223,322,345	25.9%
Feed in Tariffs	\$ 0.149	\$ 216,569,532	16.6%
Phase III R&D (30% Cost)	\$ 0.156	\$ 248,408,550	12.9%
Categorical Exclusion	\$ 0.157	\$ 254,768,710	12.5%
Phase IV R&D (30% Cost)	\$ 0.158	\$ 243,958,567	11.6%
Phase III R&D (30% Time)	\$ 0.160	\$ 263,027,478	10.6%
Production Tax Credit	\$ 0.162	\$ 244,270,770	9.7%
Phase IV R&D (30% Time)	\$ 0.164	\$ 273,001,517	8.5%
Phase II R&D (30% Time)	\$ 0.166	\$ 267,729,640	7.2%
Drilling Cost Share (50%)	\$ 0.169	\$ 260,035,006	5.8%
1603 Cash Grant	\$ 0.170	\$ 262,565,638	5.2%
Phase III R&D (10% Time)	\$ 0.170	\$ 271,702,217	5.0%
Phase III R&D (10% Cost)	\$ 0.171	\$ 271,900,606	4.3%
Investment Tax Credit	\$ 0.172	\$ 266,785,002	4.2%
Geologic Risk Coverage (75%)	\$ 0.172	\$ 267,607,052	4.0%
Phase IV R&D (10% Cost)	\$ 0.172	\$ 270,417,278	3.9%
Phase II R&D (10% Time)	\$ 0.172	\$ 273,334,753	3.8%
Phase IV R&D (10% Time)	\$ 0.174	\$ 279,938,978	3.1%
Geologic Risk Coverage (50%)	\$ 0.174	\$ 272,953,240	2.6%
1703/1705 DOE Loan Guarantee	\$ 0.179	\$ 283,646,006	0.0%
Aggregate Results:	\$ 0.165	\$ 260,797,144	7.9%

Although the points above are not complete as to the obstacles associated with current policy mechanisms in the U.S., it does present reason for developing policy mechanisms that are more directly relevant to the needs of the geothermal power community. This brings the study back to the developmental barriers identified in earlier chapters, and how it has been able to quantify those barriers in assessing levelized cost in the GeoLEC model. Once each of the afore mentioned policy options, or alternatives, has been introduced into the model the resulting values for levelized cost and total life-cycle costs can be compared for efficiency. The table below details the results for those comparative purposes.

There is a range of mitigated effects that result from this testing of the model. On

the upper end there is an overall reduction of the GeoLEC of 20%, while in two other cases the policy options tested resulted in no mitigated effect. On average the results of comparative testing produced a GeoLEC of \$0.098/kWh and an overall reduction of 8.1%. While 8% isn't sufficient enough to produce greater impacts on cash flows than when using the PTC, it is more suitable for geothermal than what is presently available given the ITC and 1603 Cash Grants. Taking a look at Fig. 13 below, the PTC result can be used to benchmark a targeted grouping of primary policy results and secondary policy results. In a comparative setting these options are intended to recognize mitigation performance against a counterfactual case (e.g. the PTC).

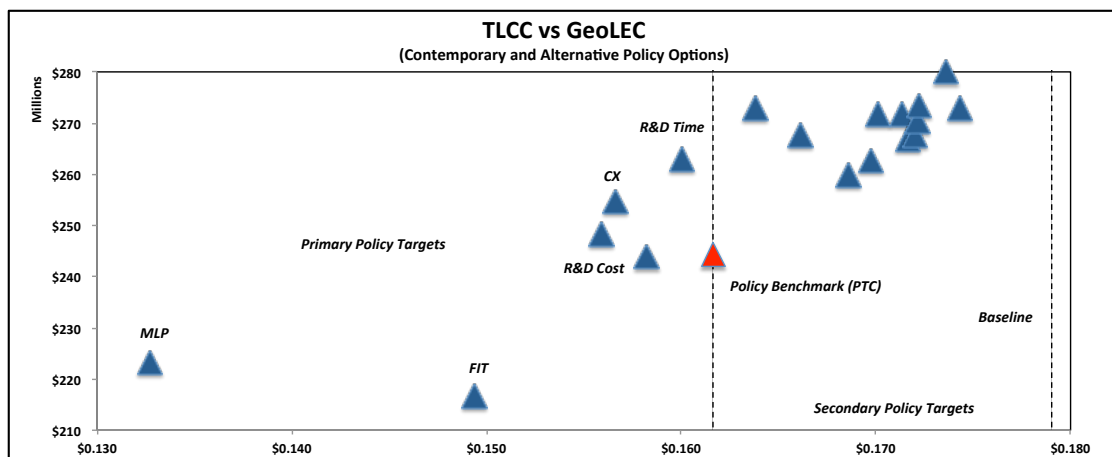


Figure 5.2: Policy Cost Comparison

The primary policy options are those that performed better than the PTC in the GeoLEC model. As the premise of this study is to target policy options that are more substantive and efficient than contemporary options, the PTC is used as the policy counterfactual. Those policies that offer results below this baseline of \$0.179/kWh, but above the PTC results, should also be considered, but offer less overall mitigation. The

aim of these comparisons is to look at the individual impacts of each policy as a stand-alone option; however, the combined effects of certain policies may have a more pronounced effect than any one policy alone. This will be a point for further/future study.

Primary policy options should be given the greatest consideration. From this analysis master limited partnerships, categorical exclusions, and feed-in-tariffs are each a comparative improvement in measuring levelized cost. Additional policy options, such as R&D funding for Phase III/IV Cost and Phase III time reduction targets of 30% are each ways in which development barriers can be addressed. These barrier mitigation goals, if reached, provide a reduction of 10.6% to 12.9% on the GeoLEC. Respectively, the percentage mitigation that results from each of the most effective (non-R&D) policy applications are: 25.9%, 16.6%, and 12.5% respectively. All of these options interact with the initial costs, time, or risks associated with geothermal development, but at different levels. Briefly, each will be discussed and assessed with respect to the study.

5.4 Master Limited Partnerships:

In the spring of 2013, the Master Limited Partnership Parody Act (S. 795 - 113th Congress, 2013) was reintroduced in the U.S. Senate, and a similar bill in the House of Representatives. The aim of these bills is to extend the definition of qualified resources to include renewable energy facilities. This effectively allows the electricity produced to share the qualifying attributes of natural resources, currently utilized by the oil and gas, timber, mining, and even geothermal.

The results of modeling policy options within the GeoLEC model show that substantial cost reductions (25.9%) are available under a MLP format. By removing the double taxation requirement on renewable energy projects as corporate entities, the tax liability is transferred to the shareholders and does not rest upon the project. As

mentioned in the preceding paragraph, geothermal energy is already qualified. However under the current qualifying terms (H.R. 3838 - 99th Congress, 1985) the MLP entity is only able to sell the steam as a resource, and not the energy produced from that steam. Unfortunately, due to project structuring the development of geothermal resources and the production of power are vertically integrated, making the MLP structure ineffective. By extending the terms to include renewable energy, including geothermal, the potential cost reduction by differing the partnership tax, and removing the corporate double taxation, is greater than 25%. Although not modeled, the MLP format is also one that, with additional legislative modifications, could be used in conjunction with existing policies like the PTC. The combination of these two policy options would have a substantial impact on reducing the measure of levelized cost for geothermal energy. By allowing tax credits (e.g. PTC, ITC) to be transferable to investors this policy combination could be achieved. Presently the transferability of tax credits is limited under Sections 48 and 45, or the ITC and PTC respectively. Whether individually or in conjunction with tax credits, the MLP tax structure is a potent policy option for geothermal developers in the U.S.

5.5 Feed in Tariffs:

There are many ways to design a feed-in-tariff for a secure pricing model within a greater energy market. Other countries have implemented, tested, and found success in a variety of methods, but what is clear is that as a policy, the feed-in-tariff must be adaptive over time. For modeling purposes, the approach used in this study targets the benefits possible for geothermal developers using feed-in-tariffs as discussed in Rickerson et al. (2012) and focuses on levelized cost in calculation (Couture et. al., 2010). Thus the benefits of a FIT policy should be considered as the additional pricing support beyond an

average PPA. These FIT benefits focus specifically on this point, resulting in a 24.3% overall reduction in the GeoLEC.

In initial model testing a higher GeoLEC baseline value was used. As a result the benefits derived from a levelized cost based FIT prices were comparatively high. By reviewing the dynamics of the model this concern was addressed by improving the way in which capacity factor is considered over time. Although this concern has been addressed, it does highlight potential sensitivities observable within the model by selecting certain ranges of input variables. By linking the FIT price to the levelized cost, there is a natural benefit in having a higher cost value. In this case it proved overly so since the average PPA price did not reflect this higher levelized cost calculation. For those developments incurring higher costs, the PPA pricing is expected to adjust accordingly.

5.6 Categorical Exclusion:

To model the results of adding a CX option to the permitting process there were several considerations that needed to be made. Conceptually, a streamlined permitting process will reduce the time required for project development. The issue that has not been addressed in the literature is determining how much. Additionally, permitting occurs in conjunction with other development tasks, which means that a reduction in permitting time may have no impact in overall development time if other tasks take as long. In a discounted cash flow model, as used in the GeoLEC calculations, it is easy to see that a reduction in time can have an immediate impact, based on the time value of money, thus reducing the overall cost. Because of these uncertainties, time was modeled at a minimum shift of 6 months from Phase II to Phase III. Costs associated with permitting also migrate between phases, which create a calculated result in also shifting risk as part

of the down-select function. The reduction in the GeoLEC is a larger function of time, cost, and risk being shifted later in the development process. This is a conceptual result, but from the modeling it does present a very curious outcome when the placement of each of these variables is considered relative to the development process. Risk and cost are two significant barriers to geothermal development that result from Chapter 3. These results indicate that merely shifting those barriers closer to the point of production can have a remarkable affect. In the case of a CX, the diversion of those factors reduces the GeoLEC by 12.5%, nearly 3% more than what is currently a result of the PTC alone.

Like the MLP option, the use of a CX has potential to be used in conjunction with other policy options like the PTC. Unlike the MLP, there is no additional restriction to the transfer of tax credits to investors with an appropriate level of tax liability. This would make the CX option potentially as potent as that of the MLP, but would not defer the corporate tax revenue at the federal level. A key benefit of a policy pairing of this nature is the inter-policy approach to joining regulatory policy and financial policy. This is a consideration that policy makers should find returns well on the policy investment.

5.7 R&D Barrier Mitigation:

Research and development goals are targeted towards the reduction of market entry constraints. Based on the results of the GeoLEC model, by using a generalized goal of reducing time and/or cost at different stages of development there are significant gains to be had. This is not universally significant because in each test case the reduction of time or cost at a 10% target has only limited effect against the results of the counterfactual baseline (PTC), but at 30% the reduction of time or cost can have a substantial benefit when focused on a specific part of the development timeline. As a theoretical case there is little that can be definitively discussed in terms of mitigation, but

understanding the importance of, or in this case the sensitivity, of Phase III and Phase IV barriers in time and cost allows those in the research and development field to have a substantial impact in long-term levelized cost reduction.

An example here is the DOE Geothermal Technologies Office, which had set program area goals, which target specific DOE targets for levelized cost. As a result all activities that are funded through annual appropriations are aimed at this overarching goal – to reduce the levelized cost of geothermal technologies to meet grid parity with current fossil fuel technologies by 2020 and 2030 at \$0.06/kWh (U.S. DOE, 2012). Specifically, there are current targets to reduce permitting by 1 year, O&M by 50%, and a 15%-30% reduction in the cost of resource identification. Each of these mitigation goals, reachable by 2020, contribute to the overall reductions needed to change the levelized cost by nearly 53% by the target horizon. The efforts at GTO are a combination of policy and research directives. As a policy component agencies such as the Department of Energy are subject to federal appropriation and budget constraints. This process requires that goals be long term in nature and need time to develop and ultimately become deployable for industry. The research component is integrated in the U.S. system of national laboratories, and focus broadly on supporting the federal government across a number of technology areas. In the geothermal space, there are active projects at all national laboratories focusing on the unique abilities of each lab. For instance, Sandia National Laboratory (SNL) is uniquely skilled in research focused on drilling and sub-surface dynamics, while the National Renewable Energy Laboratory (NREL) is tasked with systems analysis and soft cost studies. Combined this network of research centers and federal agencies is designed to support the geothermal R&D community.

5.8 Summary:

This chapter uses the research and methods developed in preceding chapters to produce modeling results to test our overall hypothesis. The question that this research is striving to answer is what policy options can be more tailored for geothermal development to target the barriers unique to geothermal energy? Using the production tax credit as a next best alternative, or counterfactual, the results in this chapter find that there are three policy options that can reduce the GeoLEC more than can be compared to the PTC. In order of impact, the most notable policy option is to allow geothermal energy to qualify for Master Limited Partnerships as an energy resource. This expands the current tax policy, which limits geothermal to the sale of steam and not energy, but would reduce the GeoLEC by 25%. Categorical exclusions would shift risk and cost back in the development process by streamlining the permitting process and allow projects to reduce the preparatory work required in certain cases of permitting. As a result the GeoLEC is reduced by 12.5%, only surpassed by the application of an MLP. Lastly, the use of feed in tariffs has a similar effect as implementing a CX by removing risk and cost from securing a PPA. At 16.6% reduction in GeoLEC this is a substantial diverter of financial risk for project development. R&D reductions targeting cost and time at specific stages of development are also notable, but must be significant enough to result in an improvement over the PTC. Each of these options is compared to the implementation of the production tax credit, which allows for \$0.023/kWh in tax credits for the first 10 years.

Showing that other policy options are possible to reduce costs for geothermal energy is the underlying goal of this study. More so, this chapter proves that although current policy options have an impact, the use of a targeted analysis of barriers and financial modeling can produce even more substantial results. The next step is to shift the way in which policymakers and stakeholders think about geothermal policy options.

Chapter 6

CONCLUSIONS & FUTURE STUDY

This chapter begins with a review of the research as presented. The key areas of focus are the analytical and theoretical frameworks, as represented as the working structures of the preceding research. Because the analytical framework is cyclical in design, it carries the intent from conclusion back to its origin, thus completing the cycle.

6.1 Research Review

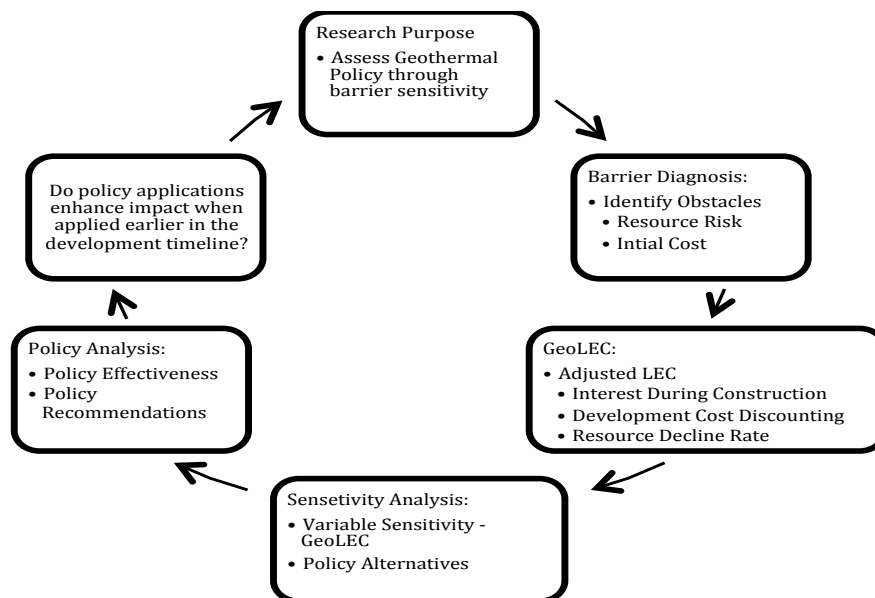


Figure 1: Analytical Framework

Chapters 1 and 2 draw out this intent by prescribing a process of study as detailed in Figure 1 (re-stated above). The reader will have found through this process that it is designed to carry through multiple stages in a cycle of progression. The two literature

reviews – Chapters 2 & 3 - provide background on the state of the technology and market for geothermal power in the United States. After better understanding these factors and defining barriers to market development, the quantitative model and results adds definition by quantifying the needs of the industry, which presently restrict the sector as a competitive force in the US energy market. Resource risk, capital costs, and permitting are the primary points of focus, with time also considered as an integrated barrier to development stemming from early development to permitting challenges.

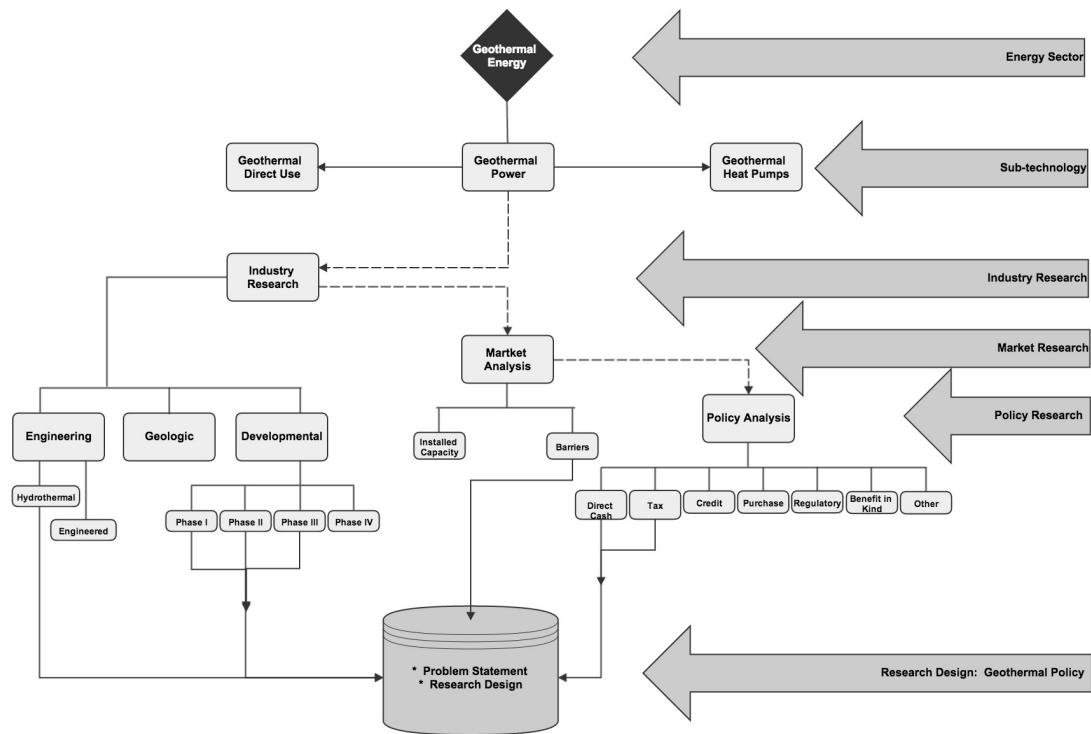
The use of levelized cost modeling, in the form of the GeoLEC model, allows for the research to test, adjust, and quantify the existing network of dependent and independent variables, which individually impact the overall life cycle cost and levelized cost of developing geothermal power. As a result, Chapter 5 provided a baseline output for policy integration. The model accounted for these specific variables in the form of assumptions, and was built on the premise of the work provided by Short et al. (1995). Recognition of the role assumptions, in general, play, the model assesses the discounting of development cost, the itemized development stages, the capitalized interest, resource decline, and stage-based development risk in the form of probability of success. The result of this modeling is a GeoLEC output of \$0.179/ kWh and a TLCC of \$283,646,634, based on a 50MW test case. This is a substantial cost for producing power. However, given the average geothermal capacity factor is highest among comparative technologies, the potential output is substantial. With the consideration of discounted time and an expected resource decline over time the costs are not unexpected. As the baseline value there are no individual incentives, but as accelerated depreciation is universally applied, it is considered as part of the after-tax model.

The baseline output value steps the research up for sensitivity testing, which identified key variables for initiating change in the GeoLEC and TLCC for geothermal

power. To initiate change, the research identifies Phase III time, Phase III/IV costs, and Phase II time as key factors contributing to the baseline GeoLEC. As the risk profile is more substantial in the earlier phases (I-III) this puts a greater emphasis on those phases within the model, as seen from the sensitivity analysis. At this point the framework moved into the policy analysis phase and uses the literature review in Chapter 2 to quantify policy options that help support positive interactions with these early stage variables. Master limited partnerships, feed in tariffs, categorical exclusions, cost shares, federal RD&D, and risk insurance are all targeted to offer support in both the cost and time of developing a 50 MW project. The results of each of these model iterations highlight the potential in master limited partnerships, feed in tariffs, RD&D, and categorical exclusions, with the estimated reduction in GeoLEC of 25.9%, 16.6%, 12.9%, 12.5%, 11.6% and 10.6%, respectively. All of these are more of an improvement than the current counter-factual policy option being considered, the production tax credit, with a GeoLEC sensitivity reduction of 9.7%. This supports the research question of designing a policy incentive, which targets the unique nature of geothermal power projects.

As the analytical framework defines the process in which the research results are provided, it is structured on a more theoretical foundation. Like the analytical framework, the theoretical basis for this research was also created on a procedural approach. The theoretical framework ventures from defining geothermal technologies, and transitions to a market research method for policy analysis as defined in the analytical framework. Technology, industry, market, and policy components are combined to make the GeoLEC modeling mechanism, and sensitivity analysis is used to assess the importance of applied policy. This process is known, as the preceding chapters

lay it out. In this, the concluding chapter, the results are briefly reviewed to discuss implementation and further study. Figure 2 is re-introduced below.



Theoretical Framework – Figure 2.1 (p. 17)

6.2 Conclusions

The conclusions of the analytical study are provided in Chapter 5. To conclude the study in full the research questions are revisited from Chapter 1. These questions are restated below:

- **How are barriers to geothermal development reflected in the measurement of policy incentives?**
- **What policy options are best suited to address the unique developmental barriers expressed within the geothermal sector?**

In Chapter 5 current policy incentives are discussed with respect to the development cycle. Key barriers to development are capital cost and resource risk, which are

presented by McIlveen (2011) as front loaded, while policy incentives are back-end loaded. Figure 9 best represents this, but to address the first research question this study presents these results. First, the industry is focused on risk, cost, and time as prime barriers of development. These barriers take different forms but are all related to a project's state prior to the production of energy. The PTC is directly linked to the kilowatt-hour (kWh), and the ITC and 1603 cash grant are only available once the project has begun operation. Only the section 1705 loan guarantee program incentivizes an earlier stage of development through a reduced cost of capital, but also carries additional reporting requirements, which nullify much of the intended benefits of a lower cost of capital. The result of GeoLEC modeling shows that of these contemporary mechanisms the PTC is most substantive, but does not address the initial cost of capital or reduce the time and risk of geothermal development. Tax equity investors can provide additional investment financing, but if the market for this equity is diminished then the required rate of return is higher than expected. And since most developers do not carry high enough tax liability to off take the monetized benefits of tax credits themselves, this secondary issue for the PTC and ITC complicates the implementation process.

Second, this study not only researches and tests the definition of what constitutes a barrier to developing geothermal power, but it also questions where policy should be targeted to draw the greatest affect. The sensitivity analysis used in Chapter 4 recognizes where in the model the GeoLEC is most impactful. To this end how does the PTC, as the counter factual policy option, relate to the Phase III time, Phase III/IV costs, and Phase II/IV time? It could be argued that with respect to time, the administrative requirements of qualifying and acquiring a tax equity provider is in itself an additional time constraint, as noted above. This can help reduce the cost of capital by providing access to capital for development but at what cost? The average rate of equity modeled is 15%, but is one of

the least sensitive variables tested in the model. As a result the modest gains of reducing the cost of equity would have very little effect on the GeoLEC. This is equally true for the results of testing the ITC and 1603 Cash Grant.

The secondary research question addressed in this study targets where policy incentives should best be applied. Based on the results of this study key barriers are identified that represent resource risk, capital cost, and permitting. Using the method of sensitivity analysis keenly focuses on the relationship of time and cost in Phases II-IV of the development cycle. Can the time to develop be reduced by streamlining the permitting process? Theoretically an expansion of how categorical exclusions are defined would achieve this and also have the benefit of reducing costs by removing the extent of the cost multiplier as part of the down-select process in Phase II, when it is more costly. This in the end makes projects quicker to deploy and less costly compared to alternative technologies. Master limited partnerships can offer substantial cost reductions in the GeoLEC, as modeled, but do not directly target actual time and cost factors in the development process without hedging these barriers within portfolios. The benefit to MLPs is truly the reduced cost of producing geothermal power through tax reductions, making geothermal a more competitive power source within power markets and with power providers. Larger geothermal developers, with greater financial stability, will find the MLP path more supportive than those developers with small project portfolios and limited experience in the sector.

A third policy option is quite promising and has found great success in Europe as a driving force for renewable energy development. The feed-in-tariff provides the developer with a guaranteed revenue source at a known, and often stable, pricing structure, if cost-based. In financial terms this in itself reduces risk by lessening the probability of loan default. It also means that the lender/investor can more accurately

define their cost of lending over time and thus provide lower rates of interest. This in turn reduces the cost of capital for developers and the LCOE for a geothermal project. Rickerson et al. (2011) also suggest that time be a factor considered in the use of FITs because as the standard PPA is replaced by the FIT, the developer no longer is required to compete for utility requests for proposals (RFP) to secure an energy off-taker or compete in capacity markets. Since time is a substantial component to project development in geothermal projects, as detailed in the GeoLEC model, any reduction can be attributed to targeted reductions in LCOE. In relative terms, the relationship of a FIT or PPA to the levelized cost is the most substantial form of benefit of a policy of this nature.

Other policy options are provided in the GeoLEC modeling output in Chapter 5, but few provide the level of improvement that is currently experienced with the PTC. As a result, only the MLP, categorical exclusion, and feed-in-tariff are discussed as implementable strategies for targeted geothermal barriers. As target reductions in time and cost at specific stages of development R&D funding is discussed in less detail due to the general nature of implementation, but theoretically should not be disregarded as a more than suitable option for reducing the GeoLEC by targeting unique barriers to geothermal development.

6.3 Implementation Strategies

Specific considerations must be taken into account for each policy option discussed in the conclusion. This section will aim to identify existing barriers to implementation so as to better expand on each option as a viable alternative. Both future and contemporary options are discussed.

MLP

The implementation of Master Limited Partnerships as a policy strategy for geothermal power projects requires that two perspectives be considered. The first is the current definition of qualified resources within the MLP structure and the second is the expanded version, which would include most renewable energy sources (e.g. wind, solar, and biomass). Since there are multiple strategies, it is proper to have a course of implementation for each.

The details of MLPs were discussed in Chapter 2, but to reintroduce the topic there are several points that need to be addressed under current legislation. As it is written in the Tax Reform Act of 1986, the revenues generated from steam sales qualify geothermal projects. If 90% of an entities' revenue were derived from the sale of geothermal steam then it would qualify to operate as an MLP. The problem, as given by Karl Gawell (2012), is that no developer in the U.S. operates resources with the intent to effectually wholesale the steam to a power plant operator. Thus the revenues derived from the sale of geothermal power do not qualify. There is, however, an option, as the resource owner, developer, and/or operator are not required to be one and the same. If a secondary market were to be implemented for wholesale steam, then power plant operators would be able to purchase the steam as fuel to produce power. Thinking this scenario through, there are two obstacles that would need addressing. The first is the potential tax liability incurred by the off-taker (i.e. power plant) when purchasing the resource at wholesale. Even in a case where the wholesaler and retailer are the same because of the financial nature of the transaction the local jurisdiction would carry the authority for sales tax. This reduces the power plant operator's potential profit margin. Second, only the wholesale entity would qualify as an MLP. This means that should a power plant operator decide to manage both sides of the resource transaction, the

potential benefits from the sale of steam for an MLP would expectedly be lower than the revenue potential of the power plant, as the fuel is the market commodity. Thus the resulting benefit under this scenario would be much lower than that modeled in the GeoLEC analysis. Under both considerations the complexity of operating an MLP would also be challenging. Quantitatively this is beyond the scope of this research but would be an important consideration to be mindful of given the current regulation. It is also likely, but not definitive, that this is itself the reason why geothermal developers have not embraced the MLP structure in the past.

With contemporary challenges aside, the alternative application strategy for applying an MLP is to enact regulatory change. This is best suggested by adding additional qualifications of revenue creation. Under the currently proposed legislation (Master Limited Partnership Parity Act of 2013) in the U.S. Senate, energy produced from renewable resources would not be classified as a resource. It would be included as a by-product of the resource used to create the energy, thus a power plant operator would be able to use MLPs directly to defer taxes as corporate entities. The results of the GeoLEC model show that there would be substantial savings toward levelized cost and total life-cycle costs for geothermal projects. With this in mind, it also highlights the fact that by transferring the tax liability to the individual investor through project revenues, the investor retains the benefits of single taxation although paying a higher tax rate on those revenues. Put another way, the net value after taxes is greater for the investor through an MLP than if they were to invest in a traditional c-corporation. This benefits the project by lowering costs and the investor by raising net revenues.

The key discussion point now is the question of how is this to be implemented. Given that there are two cases for the use of MLPs – contemporary and proposed – it is ideal to address the former. In the contemporary structuring of MLPs, geothermal steam

is treated as a qualified resource, and requires that 90% or more of the entities revenues be generated from the sale of that steam. Since the market in the U.S. is not, at present, structured to allow for wholesaling of steam to produce power this would be the first means of implementing an MLP without delving into the dynamics of corporate structuring. Developers would be able to act as a parent organization and general partner to an MLP while also retaining a substantial amount of the limited partnership shares. On paper the MLP would directly sell the steam under the general partner's management to a power plant operator for the production of power. The question is whether or not there is an upcharge on the sale to account for overhead costs such as sales tax and O&M fees. As a result the economic viability of such an arrangement is simply balanced by the cost of such charges against the tax savings from the MLP. It should also be noted that the sale of electricity would likely generate a significantly higher level of revenue for investors than the wholesale of steam, which leads to an argument of diminished return potential for investors.

A second option for MLPs and geothermal power projects is currently being represented on both sides of the U.S. Congress. The Master Limited Partnership Parity Act of 2013 would further define energy produced from renewable resources as a qualifying source of revenue. It is not saying that the energy itself is qualifying but is in fact expanding the terms for which the 90% revenue rule can be applied. This would open the MLP structure to not only geothermal, but also wind, solar, biomass, and others. The result would be to remove the need for a wholesale market of steam and the potential costs associated with such a market to directly extend the transfer of tax liability from project to investor based on the dispersement of energy revenues. In order for this to occur there needs to be a bill passed into law that amends the current definition of qualified revenue to include the sale of electricity generated from renewable sources. As

noted earlier the expected success rate of either of these bills being enacted into law is less than 1%. Once the bill has been passed into law then the energy sector as a whole would still need to embrace this type of project structuring to make it a viable option as the more universal benefit of MLPs is to be able to hedge risks of a variety of technologies and diversify financing portfolios.

Feed in Tariff

As feed in tariffs have had limited exposure and minimal success in the U.S., attention is turned to an implementation strategy that focuses solely on geothermal as a technical resource. There are barriers to implementing a FIT policy and even jurisdictional challenges in geographic distinction and authority, the idea that a pre-defined revenue stream for geothermal can be developed to support industry growth, without creating windfalls, is worth investigating. As part of the continued discussion on implementation strategies for various policies, the discussion of FIT design is directed towards identification of barriers and strategies, and less on the processes needed to create legislative action. The reason for this approach is to focus on how, rather than the process.

NREL summarizes the current state of the FIT discussion and its research by recognizing that there remain a number of implementation barriers to designing an appropriate FIT in the U.S. Continuing the discussion of time-value analysis that relates to geothermal development and incentives, the FIT strategy, like the MLPs, recognizes that there is an inherent inability of pricing programs to address higher upfront costs required to develop renewable energy projects (NREL, 2013). This of course is exacerbated in the case of geothermal projects. FIT pricing is also likely to be transferred to the consumer and has the potential to raise electricity rates, which would pose a

secondary barrier beyond that of upfront costs. This barrier may be of less concern, however, if the implementation of FIT was restricted either geographically or by technology. To follow this thought, it is suggested by the author that in the case of a technology, like geothermal, with a smaller percentage of market penetration the effects of a structured pricing method would be less dramatic than if it were applied across renewable technologies. NREL (2013) also notes that the administrative requirements for implementing a FIT are costly and pricing must be adaptable to reflect actual market conditions. The last implementation/design barrier provided by NREL is that inclusion of transmission costs would incentivize less than optimal siting of power plants in order to create a pricing windfall for operators (NREL, 2013). Due to the existing siting constraints for geothermal projects – proximity to resources – this is less of a concern, and would further support a technology specific approach (NREL, 2013), as well as it would utilize a greater portion of the transmission capacity at any given time considering the comparatively higher capacity factor.

Beyond the barriers to implementation of a feed in tariff, there are also design considerations that must be made. Couture et. al. (2010) provides several key points for consideration in the implementation of a FIT program. These considerations are eligibility, utility role, duration, caps, forecasting, and grid access. To implement a FIT, the policy must identify who is eligible as a producer and off-taker of the power, and to define which technologies are qualified. As suggested in the preceding paragraph, a geothermal specific qualification strategy would allow for a very isolated means of supporting this technology, because of already existing geographic and capacity restrictions. As geothermal power projects are almost entirely designed at utility scale, the terms for qualifying who can produce power under the FIT is much more simplified than compared to a policy that would include scale ranges from residential solar to utility

scale wind farms. Thus a more defined technology base would ease the implementation of eligible sources through greater standardization of stakeholders.

The terms of a FIT policy should also be considered in terms of potential impact on market growth. If used as a driver to spur growth the FIT can be used on a limited term basis to provide a kick-start, which in the case of geothermal may be needed to break from the slow, steady growth experienced by the industry. Typical contract durations range from 5-25 years, and Couture et. al. (2010) notes that the longer-term contracts do offer more stable levelized payments and cost recovery. If the case of geothermal is examined here, this is less of a concern, since geothermal power after multiple years of service is naturally more stable to output variations than competing technologies.

To round out the points made by Couture et. al. (2010), a FIT policy should include consideration of caps, or more simply put policy targets. Should the policy have a horizon capacity in place to scale down support as market growth takes over? Should the policy focus on duration? In either case there is a need for accurate forecasting and adaptation. Strong policy design and implementation thus requires that a reasonable target align with that forecast, but also be configured to properly adopt changing conditions in the market. This is where the design of a FIT can compliment already existing policies at the state level that determine renewable portfolio standards. Based on the combination of carve-outs¹⁹ and overall RPS requirements the continual progress to meet those goals can be used to also determine the adequacy of pricing for the FIT.

¹⁹ An RPS carve-out is a functional set-a-side within the renewable portfolio standard that requires that a defined portion of the standard be met by a specific renewable technology. A present, only the state of New Mexico has a carve-out that includes, but is not limited to geothermal.

There is also a point of caution that should be noted. Because the development of geothermal projects is comparatively long in duration, the modification of FIT pricing would also need to account for the time lag needed to spur or ease development.

The implementation of a FIT, like that of the MLP, can be implemented in two distinct ways. The first, as discussed by Hempling et. al. (2010), states that state legislatures can engage in the use of FITs through the existing Public Utility Regulatory Policies Act (PURPA) legislation. In order to meet the requirements of this process the state must set pricing for the FIT no higher than the avoided cost of the utilities (Hempling et. al., 2010). This presents a problem, if the FIT is intended to attract renewable energy technologies, including geothermal, because the avoided cost will most often be lower than the actual cost of generation. This requirement is in accordance with regulations given by the Federal Energy Regulatory Commission (FERC). In addition to the PURPA guided pricing strategy, the state then can also provide supplementary incentives, in the form of RECs and/or grants, to further incentivize the production of energy from geothermal, or other renewables. Hempling et. al. (2010) also includes utility subsidies that would counter a pricing strategy, which exceeds the avoided cost. In the end, to authorize a FIT under PURPA for geothermal, the FIT is likely not the only policy tool to be utilized.

On this first point, there is an additional consideration that should be made. Under PURPA there is no size limit for qualified facilities, and as most FIT policies attempt to circumvent the FERC regulations by catering to smaller, residential suppliers, this is not an option for geothermal power plants. Given that there is no limit to power plant size this can be a benefit for geothermal over other technologies, such as solar.

Similarly, FERC is also able to make exemptions for power plants below a certain size, 20MW (Hempling et. al., 2010), which is a second option for states to develop a FIT

policy. The Federal Power Act of 1935 provides FERC the sole authority to govern the pricing of wholesale electricity in interstate commerce. Thus, any state wishing to incorporate a FIT policy must get approval from FERC that the contract pricing is “just and reasonable” and not “unduly discriminatory” (Hempling et. al., 2010).

There are two approaches for this approval process. The first is cost-based, and requires the state to submit the pricing contract for review and much be determined to not collect more than a reasonable return on equity²⁰. A primary issue in this approach is the project-by-project nature of the review (Hempling et. al., 2010), thus it is not practical for applying this method to renewable energy as a whole or by technology.

The second approach that can be applied through FERC is to seek approval based on market-based terms. This allows for a broader application of the terms and is not project specific. It is, however, contingent on a process of negotiations between buyer and seller, which is in similar context to the currently applied PPA process. This type of approval process must also be repeated every three (3) year, in accordance with FERC mandates.

By taking the discussion beyond the courses of action relevant to PURPA and FERC, there is action that could be taken by Congress on the matter of feed-in-tariffs. For this to be enacted, Congress would need to modify the terms of PURPA and the Federal Power Act to allow FITs (Hempling et. al., 2010). Even in the case of extending the exemptions currently included in each act, renewable energy technologies could be better allowed to support state energy needs.

²⁰ This is the basis for taking a conservative approach in determining the FIT pricing in the GeoLEC model and using the WACC.

In each of the three-implementation cases for FITs, there is opportunity and challenge. While exemptions do exist to ease the regulatory nature for states, there remain barriers to full implementation. As much of the discussion in the industry literature recognizes the interest is directed largely towards residential solar PV projects that are limited in scale. Geothermal power projects could benefit the most of the various technologies if the pricing structure for individual technologies was designed to interact more directly with the characteristics that are unique to geothermal. More is needed to implement a geothermal FIT, but when compared to the requirements set forth in a PPA, there is a process for accessing the comparative benefits of a FIT, as an effective policy tool.

Categorical Exclusion

The use of categorical exclusions is not foreign to the geothermal power sector. The Bureau of Land Management (BLM) issued an equal number of CX's for geothermal exploration on federal lands, as compared to oil & gas, prior to 1992. This changed, however, following a revision of agency manuals, which excluded geothermal exploration from 12 of 18 existing CXs. This left the geothermal industry at a disadvantage in comparative terms to oil and gas developers, leading to a decline in annual capacity additions through the 1990's and into the 2000's. Deloitte (2008) identifies an expansion of applicable CX's to geothermal as a means to reduce both time and cost in the exploratory stages of development. Under these known variables, the development of an implementation strategy is relatively straightforward with two strategy options, one legislative and the other regulatory.

Starting with the legislative option, Congress is capable of implementing CX's for geothermal exploration by way of introducing a bill into law. In 2012, the US House of

Representatives reviewed H.R. 2171, as introduced by Raul Labrador (R-ID) (Exploring for Geothermal Energy on Federal Lands Act of 2012). This bill failed to advance past committee and was subsequently re-introduced in 2013 as H.R. 1363, alternatively known as Exploring for Geothermal Energy on Federal Lands Act (2013). The reason for how and why this bill is important relates directly to the expanded use of categorical exclusions for geothermal exploration. Under the proposed terms of the bill, geothermal exploration activities that have limited environmental exposure, such as narrow borehole diameters, limited depth, and no new transportation infrastructure, would be excluded from additional NEPA regulation (Exploring for Geothermal Energy on Federal Lands Act of 2013). Each of these exclusions would bring geothermal projects more inline with oil and gas exploration activities on federal lands and would balance NEPA standards across sub-surface technologies. Signing a bill into law, such as HR 1363, would amend the EAct of 2005, which is also responsible for maintaining the reduced number of exclusions eligible to geothermal exploration.

In contrast to the legislative option, a more direct approach may be applicable. Within the BLM intra-agency guidance, such as the 1992 manual, an opportunity to re-direct actions applied to NEPA statutes. Since NEPA defines the requirements for environmental protection, and conducting environmental assessments (EA) and environment impact statements (EIS) each agency is charged with directed regulation on it's lands. Thus, the BLM is able to expand the number of exclusions for geothermal as it did for oil and gas exploration in 1992. To implement this strategy, the BLM would need to conduct a review of the historical guidance on categorical exclusions and make a determination on the applicability towards geothermal. As part of the Department of Energy's Geothermal Technologies Office, efforts to develop the Regulatory Roadmap, in conjunction with the National Renewable Energy Laboratory (NREL), are underway to

provide an historical review to determine patterns in the issuance of CX's for geothermal on BLM lands. Since at present there are 6 exclusions that can be applied to geothermal exploration, this review highlights the significance of the existing guidance, while recognizing more can be done. This analysis is forthcoming from the DOE and NREL.

The reason that a regulatory approach is valuable in this discussion is that the process of implementation; a review, decision, and guidance within BLM is potentially more time significant than the alternative, legislative option.

To add support to the need for implementing a process of permit and regulatory streamlining, NREL analysts (Wiedmeyer, Schwabe, and Williams) published the results of a study on the impact permitting on LCOE. This study identified the impact of change in time, cost, and a combination in terms of reductions and additions. Their results show that reduced time is more significant to reducing LCOE than changes in the cost of permitting, but more importantly, increases in either can have a substantial impact in the overall LCOE of a geothermal project. For this analysis, the authors use both the DOE GETEM model and NREL's CREST model for comparative purposes (Wiedmeyer et al., 2013). Although the intent of this study is to highlight over-run impacts, the fact that permitting can have significant effects on the baseline LCOE supports the results of the GeoLEC model presented in the previous chapter. Thus implementation of a streamlined permitting process, through the use of expanded exclusions (CX's), is most significant in the reduction of development time.

6.4 Closing Remarks

Through the course of this research study the underlying objective has been to identify, and then also quantify the role that barriers play in geothermal development. McIlveen, Doris et al., and Bloomquist provide the basis for how to think about the issue,

and offer their own insight on how the needs of the industry can best be met. The quantification of policy options is not only a step beyond, but also a new direction in researching geothermal specific theory. As the premise is straightforward in design, the results are presented in a way that brings the reader back to an original premise. By focusing on the needs of the industry, the results in fact rule out the more promising policy options by questioning how well each fits with in a uniquely structured technology sector. Therefore, when geothermal developers continue to face barriers to market entry, such as high capital costs, resource risk, and permitting the probability of project success will be deflated. Reduction in levelized cost is a strong incentive in choosing one technology over another, but even the best back-end policy design can only incentivize risk to a point. This is a restatement of need for front-loaded policy (McIlveen, 2011), because this is where the greatest obstacles occur in the development of geothermal power.

MLPs and FITs are policy options that create strong incentive to pull a project through the final stages of development, but are these policies the basis for which the developer chooses to move a project, or series of projects, from desktop to exploration? Well-capitalized companies in the geothermal space can certainly take these risks and recognize the potential reward of back-end policy drivers, but this only accounts for a fraction of the development community. For the rest, and for driving market growth, a more near-term perspective is needed. Unlike the introduction of MLPs and FITs, the expansion of categorical exclusions and RD&D research for early-stage geothermal technologies incentivize more directly the needs of the industry. Reducing the time to development of projects and the costs associated to project procurement and regulation also has the benefit of freeing resources for continued development and market expansion.

Of the policy options modeled, only the expanded use of categorical exclusions and RD&D meet both hypotheses of this study. The first by offering a policy alternative with comparable reductions in GeoLEC when compared to the PTC, and second, by targeting directly the early stage of development necessary for geothermal developers to overcome market barriers. The alternatives – MLPs and FITs – meet the first but like the PTC, fail to really address the front-loaded barriers found in geothermal. In following the research design it is concluded that financial incentive programs need to be re-addressed to meet the needs of the geothermal market in the U.S. Additionally, those financial incentives, which did target early stage development – cost share, etc. – addressed the timing but were uncompetitive when compared to the PTC. Without further modeling, this raises an issue of economic feasibility in policy design by asking how much would need to be invested in a policy to provide a substantive result? In closing, these questions will be expanded in discussing future studies.

6.5 Further Study

In advancing this research, there are several areas where further study can be focused. It has always been the intent of this design to introduce questions and spur continued discourse in the area of geothermal policy and finance. Here are several topics that can and should be expanded in future study, each accompanied by a brief discussion of importance.

LCOE and MLPs: There are multiple assumptions put in place to engage MLPs in the model. The first suggests that a benefit of the MLP structure is the delegation of tax liability from the project to the investor. This assumption is made with the understanding that even in traditional corporate models the investor tax liability is not a factor within a calculated LCOE. The only point that has changed here is the extent to

which individual investors are carrying the liability. It is not a question of the correctness of making this assumption in the model but the recognition that a geothermal MLP is yet to be applied. Further analysis and research is required on how the industry and markets will apply such a model to their respective benefits. It is also unknown how securitized portfolios of technologies will regard the required rate of return when containing geothermal within their structures. Both of these points are beyond the scope of this research and should a more in-depth evaluation of MLPs be applied, a more stringent approach would be needed across the policy options.

Tariff design: It is well noted in the preceding chapters that a feed in tariff is effective only by its unique design, which can be based on cost or market pricing. Rickerson et al. (2009) acknowledges this by offering a number of viable methods for structuring a FIT policy in the United States. The problem, when looking at the current stable of approaches, is that each country requires a different dynamic in which the FIT will support renewable technologies. It is with this in mind that further analysis be applied to FIT design specifically in the US market and the current mix of energy. It is agreed here with Rickerson et al. (2009) that a key benefit of the FIT is the circumvention of standard PPA practices. It is also relevant to acknowledge that US energy markets may in fact be more properly driven with pricing incentives instead of cost reduction incentives. For this perspective to be given greater credence, a more extensive analysis is recommended.

Modeling Design - CX: With respect to categorical exclusions, it is only in theory they can be applied within any type of LCOE model. As the time and cost savings are unique by project, the best-case method of shifting both barriers is logical. However, there is no quantifiable support for how much each variable can and will be significant under a non-theoretical basis. Here a complimentary area of study is to assess change as

it applied to oil and gas development during the initial stages of policy application. The pricing of such data is not thought to be comparable to the geothermal case, but if the rate and level of change can be established for time and cost, similar sensitivities may be applicable to geothermal. It is here that a more substantive case can be made for the economic value of streamlined permitting and is an area of regulatory research that has been limitedly applied.

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Appendix A: PRIMARY INDUSTRY SURVEY

Industry Perceptions of Barriers to Geothermal Power Development

Name (Optional): _____

Date: _____

Industry Role (Please Circle):

Geology/Science

Engineering

Business Development

Public Policy

Other: _____

Please select the **three (3) barriers*** you feel are presently the most limiting to the development of geothermal power in the United States:

- Environmental Problems
- Financing
- Geographical
- Government Support
- Incentives
- Industry Size
- Initial Cost
- Permitting

- Public Opinion
- Resource Data
- Resource Risk
- Technological Competitiveness
- Time
- Transmission
- Workforce Development
- Other: _____

* Please find descriptions of each barrier category on the back of this survey.

If other, please provide a brief description of your response:

*Survey Administrator: Christopher Richard
PhD Candidate – University of Delaware
Center for Energy and Environmental Policy*

Barrier Definitions:

- Environmental Problems: Any issues that require mitigation or resolution that involve impacts on the natural environment.
- Financing: This covers a broader area than other barriers, but is all inclusive of barriers related to the financing duration, rates, and access for geothermal projects. Each of these factors has an inverse effect on the overall cost that is associated to finance.
- Geographical: Geographic limitations on siting, discovery, and sustainability of hydrothermal resources.
- Government Support: Stable and consistent policy and legislation is needed for long-term project completion.
- Incentives (Subsidies): Application of policy incentives favors other renewable energy sources when compared to geothermal (Curtis, 2010).
- Industry Size: Comparative level of installed capacity and number of developers, with regard to other energy technologies in the U.S.
- Initial Cost: The initial costs relate to actual and perceived development costs, as well as drilling.
- Permitting: An all-encompassing legislative barrier involving the access, use, requirements, and definition of land, but is focused primarily on federal lands.
- Public Opinion: Perception and opinions held by the public and the need to have a better-established understanding of geothermal power.
- Resource Data: Collecting and availability of current geologic and development data for geothermal resources to aid in future development efforts.
- Resource Risk: Any direct risk or need for risk mitigation that is associated to geothermal development.
- Technological Competitiveness: Ensuring access to drilling equipment within development timeline and establishing more advanced methods of exploration and production to reduce costs and development timelines.
- Time: This accounts for any implication of duration for project development and includes lead-time and development timeline.
- Transmission: Factoring the associative costs of remoteness and resource discovery and development, with accessible means of transmission and distribution of power.
- Workforce Development: Requiring the adequate level of workforce support to drive anticipated development of geothermal power into the future.

Appendix D: SECONDARY INUSTRY SURVEY

Industry Perceptions of Barriers to Geothermal Power Development

Survey Description: This research is a voluntary survey of industry professionals on perceived developmental barriers to geothermal power. The survey is a supplement to doctoral research at the University of Delaware's Center for Energy and Environmental Policy. Survey responses are anonymous, and each respondent is free to answer the survey in full, in part, or may discontinue their responses at anytime.

The Geothermal Resources Council is not a survey sponsor, and the research here within is solely that of the author. * Required

Industry Role (Please Select): *

- Geology/Science Business Development Other: _____
 Engineering Public Policy

Please select any barriers you feel are presently the limiting to the development of geothermal power in the United States:

* Listed alphabetically

- Environmental Problems: Any issues that require mitigation or resolution that involve impacts on the natural environment.
- Financing: Barriers related to the financing duration, rates, and access for geothermal projects.
- Geographical: Geographic limitations on siting, discovery, and sustainability of hydrothermal resources.
- Government Support: Stable and consistent policy and legislation is needed for long-term project completion.
- Incentives (Subsidies): Application of policy incentives favors other renewable energy sources when compared to geothermal.
- Industry Size: Comparative level of installed capacity and number of developers, with regard to other energy technologies in the U.S.
- Initial Cost: The initial costs relate to actual and perceived costs prior to production.
- Permitting: An all-encompassing legislative barrier involving the access, use, requirements, and definition of land, but is focused primarily on federal lands.
- Public Opinion: Perception and opinions held by the public and the need to have a better-established understanding of geothermal power.

- Resource Data: Collecting and availability of current geologic and development data for geothermal resources to aid in future development efforts.

- Resource Risk: Any direct risk or need for risk mitigation that is associated to geothermal development.
- Technological Competitiveness: Ensuring access to drilling equipment and labor resources, and establishing more advanced methods of exploration and production.
- Time: This accounts for any implication of duration for project development and includes lead-time and development timeline.
- Transmission: Factoring the associative costs of remoteness and resource discovery and development, with accessible means of transmission and distribution of power.
- Workforce Development: Requiring the adequate level of workforce support to drive anticipated development of geothermal power into the future.
- Other: _____

Please provide any additional comments that you feel are relevant to this survey or topic.

Contact Information:

Survey Administrator: Christopher Richard/PhD Candidate
University of Delaware's Center for Energy and Environmental Policy
Email: crichard@udel.edu

<https://docs.google.com/spreadsheet/viewform?formkey=dG9UT3RteWgtUEVyQ1E4RjFXZEdQbEE6MQ#gid=0>

Appendix E: INDUSTRY SURVEY DATA

Table E.1: Industry Data

Date	Survey Number	Industry Role	Development Barriers															
			Environmental Problems	Financing	Geographical	Government Support	Incentives	Industry Size	Initial Cost	Other	Permitting	Public Opinion	Resource Data	Resource Risk	Technological Competitiveness	Time	Transmission	Workforce Development
10/2/12	1	Other	X	X									X					
10/2/12	2	Engineering	X									X	X					
10/2/12	3	Geology								X		X			X			
10/2/12	4	Business Dev.	X		X	X				X		X		X				
10/2/12	5	Other	X		X	X												
10/2/12	6	Engineering	X							X		X						
10/2/12	7	Geology								X		X			X			
10/2/12	8	Geology							X		X	X						
10/2/12	9	Other	X		X								X					
10/2/12	10	Engineering	X					X						X				
10/2/12	11	Public Policy	X							X		X						
10/2/12	12	Other						X		X		X						
10/2/12	13	Other	X							X						X		
10/2/12	14	Engineering	X	X						X								
10/2/12	15	Business Dev.	X	X							X	X						
10/2/12	16	Geology	X							X						X		
10/4/12	17	Geology				X		X				X						
12/13/12	18	Geology	X									X		X				
10/25/12	19	Engineering	X	X		X	X				X	X		X				
10/25/12	20	Other	X	X	X	X	X			X		X		X	X	X		
10/25/12	21	Geology	X				X					X						
10/25/12	22	Other	X		X	X		X		X					X			
10/25/12	23	Engineering						X										
10/25/12	24	Engineering	X	X		X	X	X	X	X	X	X		X	X			
10/26/12	25	Geology	X	X		X	X		X		X							
10/26/12	26	Geology	X	X	X	X	X		X		X		X	X		X		
10/27/12	27	Geology	X			X	X		X	X		X						
10/31/12	28	Geology				X		X				X						
28			10	16	3	10	11	2	11	0	13	6	4	18	2	7	7	0
Compiled: 12/23/12			36%	57%	11%	36%	39%	7%	39%	0%	46%	21%	14%	64%	7%	25%	25%	0%