Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Measuring Impact of U.S. DOE Geothermal Technologies Office Funding: Considerations for Development of a Geothermal Resource Reporting Metric

Katherine R. Young[1], Anna M. Wall[1], Patrick F. Dobson[2], Mitchell Bennett[1], and Brittany Segneri[3]

[1]National Renewable Energy Laboratory (NREL), 15013 Denver West Parkway, Golden, CO 80401
[2]Lawrence Berkeley National Laboratory (LBNL), 1 Cyclotron Road, Berkeley, CA 94720
[3]New West Technologies, LLC, 901 D Street, SW, Suite 910, Washington, D.C. 20024

katherine.young@nrel.gov

Keywords: geothermal, reporting metric, reporting code, reporting methodology, resource assessment, resource potential, exploration, geothermal grade, resource knowledge, CRIRSCO, PRMS, UNFC, investment

ABSTRACT

This paper reviews existing methodologies and reporting codes used to describe extracted energy resources such as coal and oil and describes a comparable proposed methodology to describe geothermal resources. The goal is to provide the U.S. Department of Energy's (DOE) Geothermal Technologies Office (GTO) with a consistent and comprehensible means of assessing the impacts of its funding programs. This framework will allow for GTO to assess the effectiveness of research, development, and deployment (RD&D) funding, prioritize funding requests, and demonstrate the value of RD&D programs to the U.S. Congress. Standards and reporting codes used in other countries and energy sectors provide guidance to inform development of a geothermal methodology, but industry feedback and our analysis suggest that the existing models have drawbacks that should be addressed. In order to formulate a comprehensive metric for use by GTO, we analyzed existing resource assessments and reporting methodologies for the geothermal, mining, and oil and gas industries, and we sought input from industry, investors, academia, national labs, and other government agencies. Using this background research as a guide, we describe a methodology for assessing and reporting on GTO funding according to resource knowledge and resource grade (or quality). This methodology would allow GTO to target funding or measure impact by progression of projects or geological potential for development.

1. INTRODUCTION

The U.S. Department of Energy's (DOE) Geothermal Technologies Office (GTO) uses various metrics to track and measure impacts of its funding meant to catalyze innovation and private investment. One metric that has been suggested for use in the GTO's Hydrothermal Program is a measure of how their portfolio of funded projects impacts the amount of geothermal resources deemed "available" for development. As an example, using the 2008 U.S. Geological Survey (USGS) geothermal resource assessment terminology, GTO might look at how funding innovative exploration technology field projects could be used to move some of the "Undiscovered" resources into the "Identified" category–a category that suggests more knowledge about the area, and potentially, more confidence and less risk to potential developers. A standard evaluation methodology could aid both in proposal evaluations and in monitoring project progress and milestones. These metrics could be employed by the GTO to evaluate the impact of its RD&D funding on furthering the identification, exploration and development of geothermal resources in the U.S. In addition, the metrics should be comprehensible for industry and non-industry alike so that budget decision makers (e.g. U.S. Congress) can understand the estimated impacts of funding decisions.

Though we use the 2008 USGS terminology in our example above, the USGS methodology does not provide enough detail to be able to fully characterize geothermal resources – particularly its reported "Undiscovered" resource – at the project level. The U.S. geothermal industry has not adopted a systematic methodology for resource reporting at the project level. Australia and Canada have recently adopted geothermal resource reporting standards, and other natural resource industries (such as mining, oil, and gas) have standards and terminologies that are used to guide resource assessments. We use these existing standards and guidelines to inform the development of a framework that best fits the needs of the GTO in reporting impacts of RD&D. Initial efforts are focused on reporting for hydrothermal systems, but this methodology could potentially be used for other types of projects (e.g., direct use, enhanced geothermal systems).

1.1 Role of Reporting Standards

One of the fundamental roles of reporting standards is to increase the comparability and reliability of data reported between the owner and the user/buyer. Efficient market theory, largely developed by Eugene Fama (1970, 1991), builds on the idea that inefficient markets are represented by mispricing between the market value and the intrinsic, true value of the item. As a result, reporting standards increase transparency by reducing information asymmetry. In practice, the efforts of the U.S. Securities and Exchange Commission "consistently have been based on the idea that the only way to achieve fair, liquid and efficient capital markets worldwide is by providing investors with information that is comparable, transparent and reliable." (SEC 2000) We have received mixed reviews from industry on the usefulness of reporting standards. Industry personnel have noted that codes compare projects and portfolios in a common way, provide a framework to prompt meaningful questions, and aid in making informed decisions. However, a code cannot prevent poor decisions.

Nevertheless, the existence of a standard by itself is not effective without industry-wide compliance. As Mueller summarizes in his discussion paper, "[i]n a voluntary disclosure regime, users of financial statements never know the quality of what is reported, let alone what remains undisclosed" (pg. 111, Mueller 2001). Thus, market mandates to follow resource reporting standards are critical to achieving transparent and credible data. SEC mandates the use of its Industry Guides to provide this transparency and comparability amongst U.S. mining and petroleum companies (White 2013).

It is this transparency and credible data that GTO is interested in. Government reporting standards, however, are primarily for the purposes of measuring the value and impact of the funding received, not the investment return or profit. Government entities like DOE are accountable for the use of resources rather than shareholder interests. Reporting metrics could help stakeholders understand how resources were used and to what benefit.

1.2 Scope of this Study

In order to formulate a comprehensive metric, we reviewed and analyzed existing resource assessments and reporting methodologies for the geothermal, mining, and oil and gas industries. Using this analysis and input from industry, investors, academia, national labs, and other government agencies as a guide, we describe the current status of the methodology that is being developed for reporting on geothermal resources. The result is a methodology that includes two parts – resource knowledge and resource grade (or quality). The former measures the progression of projects, and the latter can help GTO identify the geological potential (and challenges) for development. These data could potentially target RD&D funding to overcome these challenges and measure the impact.

This study is intended to inform and move toward standardization of the terminology we use within the geothermal industry, but does not attempt to create a country-wide reporting standard for hydrothermal resources. Concepts presented here have received preliminary feedback from industry stakeholders and will be further vetted and reviewed by the geothermal community. We plan to publish a more comprehensive assessment in 2015 in a technical report.

This paper is organized into four parts. First, we analyze concepts, structure, and terminology of natural resource codes developed by financial markets and industry groups internationally, and propose a structure for classifying projects based on knowledge of the available resource (project progress). Second, we discuss the concept of resource grade – first reviewing how resource grades have been developed for other resources (e.g., solar, minerals), and then proposing a structure for reporting geothermal resource grades at the project level. Third, we discuss standardizing the reporting of resource size. Finally, we discuss how these parts can be used together for reporting in different ways, as is needed for GTO's project portfolios.

2. RESOURCE REPORTING CODES: CONCEPTS, STRUCTURE, AND TERMINOLOGY

We started our analysis by reviewing recent literature on the classification of geothermal (and other resource) systems. We found that these classification systems could be grouped into four categories:

1. *Geologic Setting* – the classification of geothermal (or oil and gas) systems into groups (sometimes called "Play Types" or "Occurrence Models") based on their geological characteristics. Geothermal examples include: Brophy Occurrence Models (Brophy 2007), Moeck-Beardsmore Play Types (Moeck and Beardsmore 2014; Moeck 2014), and Faulds Structural Controls (Faulds et al. 2011).
2. *Project Progress* – the classification of projects based on progress. Examples include the U.S. Geothermal Energy Association's Terms and Definitions (2010), the Australian and Canadian Geothermal Reporting Codes (AGEG 2010, CanGEA 2010), and the United Nations Framework Classification (UNFC) System (UNECE 2013).
3. *Resource Grade* – the classification of geothermal (or other resource) based on its inherent physical properties. Geothermal examples include classifications by temperature (e.g., Sanyal 2005). Examples of other resource grades include those for mining (e.g., ASTM 1998; Mitchell 2014) or for petroleum (e.g., EIA 2012).
4. *Resource Size* – the classification of systems based on their size. As an example, the USGS 2008 Geothermal Resource Assessment (Williams, et al. 2008b) reported U.S. geothermal resources in terms of mean MWe using what the authors cite as the "volume method." Others have used different methods for calculating resource size (e.g., MIT 2006).

For this study, we do not propose any new terminology or classification methodologies based on *geologic setting*. This paper focuses on the development of a classification system for only two of these: *project progress* (in this paper we focus on a subset, Resource Knowledge) and *resource grade*. To measure DOE's progress in geothermal RD&D, we propose a reporting structure that captures both of these concepts. While the former addresses the concept of measuring the movement of projects forward, the latter addresses a second GTO need: the ability to identify challenges to geothermal development and quantify the influence of these challenges on the U.S. geothermal potential. These data could then be used to target RD&D funding to overcome these challenges, and measure the impact of the funding in overcoming the barriers.

Future efforts in this initiative will also focus on a standard methodology for reporting *resource size*. In the interim, this study suggests how the three systems of *resource knowledge*, *resource grade*, and *resource size* can be used together to develop RD&D goals for GTO.

2.1 Project Progress: Geological Knowledge

As a first step in selecting appropriate terminology for indicating geological knowledge, we start with a comparison of extractive resource reporting standards that indicate project progress. A list of some of these standards is provided in Table 1. While methods to consistently compare and report petroleum and mineral resources exist in the U.S. today, no such method yet covers U.S. (or international) geothermal resources.

Geothermal resource potential has commonality with both solid- and liquid-extracted resources, but important differences exist. One essential distinction is that a geothermal resource consists of the extraction of thermal energy from the earth, which is "mined" through the circulation of a working fluid through the hot rock mass. Thus, it cannot be assessed as a simple volumetric extraction of hot fluids from this rock: as fluids are recycled through the rock mass to extract more thermal energy, the heat is gradually replenished through regional heat flow.

:

Table 1: Summary of Selected Reporting Standards for Extracted Energy Resources

Reporting Standard Title	Author	Location	Financial Reporting Standard? *
Minerals (Coals, Industrial Minerals, Gemstones)			
International Reporting Template[1]	Committee for Mineral Reserves International Reporting Standards (CRIRSCO)	Select countries: Australia, Canada, Chile, Europe, Russia, South Africa, United States	All except U.S.
SME Guide for Reporting Exploration Results, Mineral Resources, and Mineral Reserves[2] (2007, 2014-draft)	Society for Mining, Metallurgy and Exploration (SME)	United States	No – U.S. Securities and Exchange Commission (SEC) Industry Guide 7
Uranium			
Uranium - Resources, Production and Demand "Red Book"[3]	International Atomic Energy Association – OECD Nuclear Energy Agency (NEA)	International	No
Oil and Gas			
Petroleum Resource Management System (PRMS)[4]	Society of Petroleum Engineers (SPE) American Association of Petroleum Geologists (AAPG) World Petroleum Council (WPC) Society of Petroleum Evaluation Engineers (SPEE) Society of Exploration Geophysicists (SEG)	International	No (optional) SEC Industry Guide 2
Classification of Oil and Gas Fuel Reserves and Resources[5]	Russian National Resource Ministry	Russian Federation	Yes
Geothermal			
Australian Code for Reporting Geothermal Resources and Reserves[6]	Australian Geothermal Energy Group (AGEG) Australian Geothermal Energy Association (AGEA)	Australia	No
Canadian Geothermal Code[7]	Canadian Geothermal Energy Association (CanGEA)	Canada	No
Indonesian Geothermal Reserves Classification[8]	Indonesian Taskforce for Accelerating Investments in the Geothermal Sector	Indonesia	No
Geo-Elec Methodology of Resource Assessment [9]	Intelligent Energy Europe (IEE)	Europe	No
Geothermal Reporting Terms and Definition for Reporting Resource Development Progress and Results[10]	Geothermal Energy Association (GEA)	United States	No
Multiple Resources			
United Nations Framework Classification (UNFC) System	United Nations	International	No

[1] CRIRSCO 2013. [2] SME 2007. [3] OECD-, NEA and IAEA 2012. [4] SPE et al. 2011. [5] Novatek 2014. [6] AGEA-AGEG 2010. [7] CanGEA 2010. [8] Brophy 2012. [9] van Wees et al. 2013. [10] GEA 2010.

* Standard is required by governments or exchanges for financial reporting of resource holdings. Applies to the markets/exchanges in the listed location(s)

2.1.1. Discussion of Geothermal Reporting Standards

The two current reporting standards for geothermal resource development (in Australia and Canada) build upon the foundation of the CRIRSCO International Reporting Template, including terminology, with minimal adjustments. In contrast, the IEE voluntary reporting standard is more akin to a standardized methodology for calculating geothermal resource potential – a combination of a standardized heat-in-place calculation and the calculation of the project's levelized cost of energy (LCOE) (van Wees et al. 2013).

The Geothermal Energy Association's description of project development phases is a multi-criteria approach to categorizing projects in the U.S. focused solely on the progress of the development (GEA 2010). In other words, the outcome of this standard is a "Phase" categorization only - not the expected size of the resource, the quality of the research itself, or the uncertainty in the estimates. This voluntary standard indirectly incorporates economic viability by requiring financial viability (such as the existence of a PPA) to reach advanced phases.

2.1.2. Resource Reporting Integration within International Frameworks

It is useful to our discussion to describe, in general, the UNFC System developed by the United Nations, as this helps to constrain our discussion of project progress to resource knowledge. The UNFC System (UNECE 2013) listed in Table 1 was created as a way to map other reporting standards into a consistent framework for comparison of extracted natural resources. As shown in Figure 1, "bridging documents" have been written to map each resource standard (e.g., PRMS, CRIRSCO) into the UNFC System. There is growing interest in including geothermal in the UNFC system (Falcone et al. 2013, Falcone 2015).

Although the General Specifications state "application of UNFC-2009 requires reference to a Bridging Document for the relevant commodity- specific specifications" (UNECE 2013), a new protocol is being developed for renewables by creating technology-specific specifications, which would feed into renewable specifications, which in turn feed into the general specifications and then into the UNFC-2009 itself.

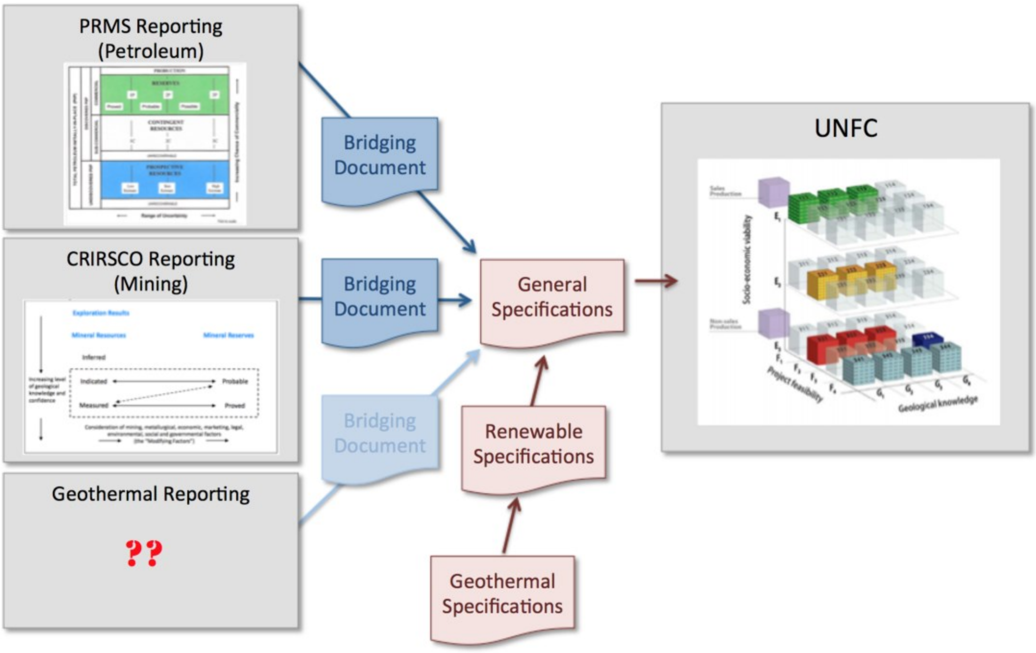

Figure 1: Diagram depicting the directionality of information between the UNFC System for extracted resources and individual resource reporting standards. It also shows the new protocol for incorporating renewables by developing specification documents rather than bridging documents.

Inspired by the UNFC System, we use three similar categories to define project progress (displayed on a 3D project grid, Figure 2), and an associated grade (displayed on polar area diagrams).

Project progress and grades for the technical and socio-economic categories have not been developed as a part of this GTO resource reporting effort to date (December 2014). Their development, however, will be useful for measuring impact for other RD&D project goals, and are planned for development in 2015. Using this structure, we could describe projects in terms of barriers that DOE may be trying to address and quantify the impacts of RD&D in overcoming these barriers.

For example, permitting has often been cited as a barrier to geothermal development. Permitting aspects are reflected in the socio-economic category. Hypothetically, one could report:

1. Socio-Economic Progress – how far along is the project in social, economic, and legal aspects? (i.e., "Uncertain" → "Secured," as shown in **Error! Reference source not found.**), and

2. Socio-Economic Grade – what are the characteristics of the project that make it easy or difficult to develop? (i.e., is the resource located in a national park? If so, it is not likely to ever progress along the project's Socio-Economic Progress Axis).

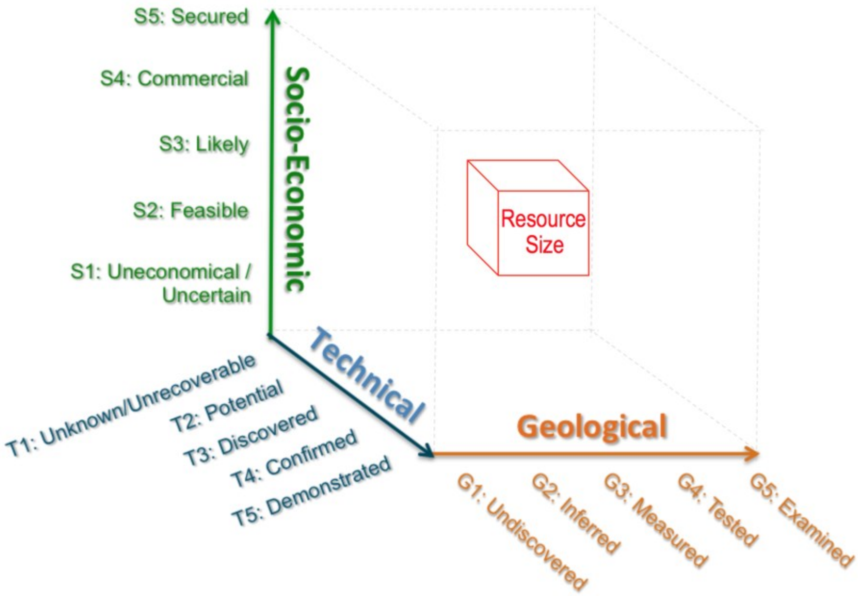

Figure 2: Graphical depiction of the 3D project progress grid. A project would be represented by a cube within the framework. The project cube would move within the larger framework, either forward or backwards (e.g. if a developer loses a PPA, the project may move backwards along the Socio-Economic axis) along the three axes. The project's estimated size could be represented in the project cube.

2.2 Comparison of Terminology

Development of GTO metrics requires consideration of the current definitions, including appropriate refinement, and the common usage of these terms. The next step in our analysis, therefore, was to try to align current geothermal terminology from the several systems. In **Table 2**, we provide a comparison of terms and definitions used by other reporting systems. To align these terms, we used specific activities conducted during geothermal development. We use dark grey boxes to indicate these *activity threshold* levels, but note that these terms from other systems do not align precisely across table columns. This lack of alignment is caused by broad definitions that include varying levels of progress along the three different axes; they are not isolated to geological progress. We use red shading in **Table 2** to indicate that the terminology goes beyond geologic definitions and includes some technical and socio-economic factors as well.

We used the remaining terms to propose terminology for the geological progress axis. Our proposed terms are shown on the left (Undiscovered, Inferred, Measured, Tested, Examined). The green shaded boxes indicate existing terminology in relative agreement with proposed terminology. These proposed terms are arranged (from bottom to top) in order of increasing *resource knowledge* (Proposed Terms, Table 2), and would describe moving along the geological axis from left to right.

These levels and associated criteria are not prescriptive "recipes" for conducting geothermal exploration, nor are they meant to suggest any required techniques or activities. Not all projects will go through each phase. For example, some developers may choose to skip drilling of slim holes or core holes at a given location. The area, therefore, would never be classified as "Measured." The levels are meant to provide a framework for communicating information about project locations in a consistent manner. GTO can use these reporting terms to better understand the status of the projects in its portfolio – both before and after the RD&D has been implemented – and can evaluate the impact of multiple projects.

We are in the process of developing draft criteria and a full glossary of terms for each of these phases and plan to revisit terminology and criteria through significant forthcoming reviews with geothermal stakeholders.

2.2 Resource Quality – Geothermal Grade

Quality grades provide a means to communicate the potential economic value of an energy resource. We have accepted means for grading quality of industrial minerals, ores, and gemstones; conventional energy feedstocks, such as coal, gas, and oil; and renewables, such as solar and wind. Criteria for assessing the quality of geothermal resources have not been codified into accepted reporting standards, though they do exist informally (Sanyal 2005).

Very few of the standards we reviewed report the quality of the resource, although this information is important to understanding the potential for development. For example, a larger low-temperature geothermal system and a small, high-enthalpy system could potentially have the same estimate of useable energy with the same confidence intervals, but these systems would have different (though possibly both economically viable) potential for commercial development.

Table 2: Comparison of terms for various reporting systems and proposed terms for the GTO reporting system. (Dark grey boxes indicate *activity threshold* levels, green boxes indicate existing terminology common to that proposed; red boxes indicate that the existing terminology goes beyond geologic definitions and includes some techno-economic implications as well.)

	Proposed Terms	McKelvey (1972)	USGS Circular 831 (1980)			USGS Circular 790 & 2008 Assessment		PRMS (SPE et al. 2011)	Australian Geothermal Code (AGEA and AGEG 2010)	Indonesian Geothermal Reserves Classification (Brophy 2012)
Identified	**Examined**	**“Proved”** *(no formal definition)*	**Confirmed**	**Demonstrated**	**“Measured”** - Quantity is computed from dimensions revealed in outcrops, trenches, workings, or drill holes; grade and/or quality are computed from the results of detailed sampling. The sites are spaced so closely and the geologic character is so well defined that size, shape, depth, and mineral content of the resource are well established.	**“Identified”** Unspecified concentrations of geothermal energy known and characterized by drilling and/or by geochemical, geophysical, and geologic evidence.	🟥 **“Producing”** - The reservoir is currently generating electric power.	🟥 **“Proved Reserve”** – High confidence in the commercial producibility of the reservoir as supported by actual production or formation tests.	🟥 **“Proven Reserve”** – A drilled and tested volume of rock within which well deliverability has been demonstrated and commercial production for the assumed lifetime of the project can be forecast with a high degree of confidence.	🟥 **“Proven Reserves”** – Evidenced by more than one successful exploratory well. Estimates of potential energy use a reservoir simulation combined with the volumetric method.
							“Confirmed” – The reservoir has been evaluated with a successful commercial flow test of a production well.			
	Multiple wells									
	Tested	**“Probable”** *(no formal definition)*			**“Indicated”** – Quality and/or grade are computed from information similar to that used for measured resources, but sites are farther apart or otherwise less adequately spaced. Degree of assurance is high enough to assume continuity between points of observation.		*No direct correspondence – jump from no well tests to commercial production wells.*	**"Discovered"** – One or more accumulations that has demonstrated a ‘significant quantity of potentially moveable hydrocarbons.’	🟩 **““Measured”** – Demonstrated to exist through direct measurements that indicate at least reservoir temperature, reservoir volume, and well deliverability, so that Recoverable Thermal Energy can be estimated with a high level of confidence..	**“Probable Reserves”** – Evidenced by a successful exploration well. Reservoir area and thickness are obtained from wells and from the results of a detailed investigation of integrated geosciences. Estimates of potential energy through volumetric methods.
	Drill first full-size diameter well									
	Measured						**“Potential”** – There are reliable estimates of temperature and volume for the reservoir but no successful well tests to date.	**"Prospect"** - A project associated with a potential accumulation that is sufficiently well defined to represent a viable drilling target.		**“Possible Reserves”** – Size and thickness of reservoir, rock, and fluid physical parameters are estimated based on geoscience data that is described in detail through an integrated tentative model. The formula estimates the potential energy used through volumetric methods.
	Drill slim hole, core hole									
	Inferred	**“Possible”** – *Deposits whose existence is known for at least one exposure*			**“Inferred”** – Estimates based on assumed continuity for which there is geologic evidence; may or may not be supported by samples or measurements.		*No direct correspondence – jump from “broad theory” to “reliable estimates.”*	**"Play"** – A project that requires more data acquisition and/or evaluation in order to define specific leads or prospects.	🟩 **“Inferred”** - Resource for which Recoverable Thermal Energy can be estimated only with a low level of confidence.	**“Hypothetical Resource”**- Indicated by active geothermal manifestations and basic data as the results of regional geological, geochemistry, and geophysics surveys. Estimation of potential energy is formulated by using the volumetric method.
	Field testing and sampling									
Undiscovered	**Undiscovered**	**“Undiscovered”** *(no formal definition)*	**Undiscovered**		“**Hypothetical**” – Undiscovered materials that may reasonably be expected to exist under analogous geologic conditions	🟩 **“Undiscovered”** – Concentrations of geothermal energy surmised to exist on the basis of broad geologic knowledge and theory.		**“Undiscovered”** – That quantity of petroleum estimated, as of a given date, to be contained within accumulations yet to be discovered.	*No direct correspondence.*	**“Speculative Resource”** – Characterized by active geothermal manifestations. Estimation of potential energy is carried by the comparison method.
					“**Speculative**” – Undiscovered materials that may occur in known types of deposits in geologic settings where no previous discoveries have been made or in as-yet-unknown types of deposits that remain to be recognized.					

Revisiting the USGS example, the study reports that approximately 80% of the 240 identified areas have reservoir temperatures less than 150° C (Figure , Williams et al. 2009). This type of information is critical in creating an accurate snapshot of resource potential.

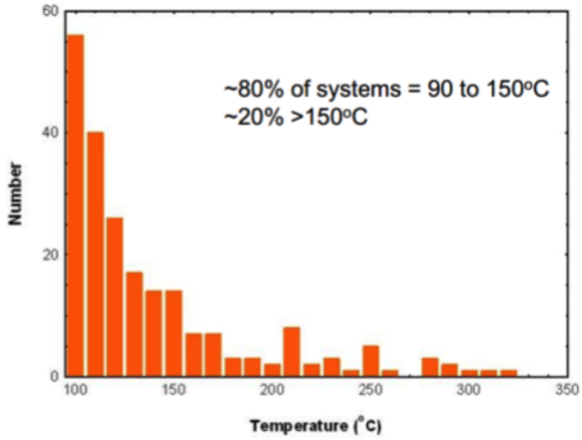

Figure 3: Estimated reservoir temperature distribution of 240 USGS identified geothermal resource areas (Williams et al. 2009).

2.2.1 Resource Quality Classifications

Qualitative metrics of resource quality frequently describe the resource in terms of a quantitatively defined class (Table 3).

- For **wind**, the ordinal classes are based quantitative calculation of wind density, capacity factor, and other factors.
- **Solar** resources are graded by insolation, radiation, and capacity factor.
- **Uranium** uses ordinal terminology to grade ore according to percentage content of uranium.
- **Coal** industry reports quality using both grade and rank. “Grade” refers primarily to the physical and chemical quality of the ore and is reported in terms of the percent carbon content. “Rank” describes the physical and chemical maturation of the ore, from lignite (lowest carbon, least mature) to anthracite (highest carbon, most mature). There is also a measure of sulfur content.
- **Oil** does not have a formal system for quantifying quality; but the industry does describe crude oil quality using grade terminology. Sulfur content ranges from sweet to sour, and density ranges from light to heavy.

Table 3: Comparison of Quality Standard Components for Selected Energy and Extractive Resources.

Resource	Quality System(s)	Unit of Comparison	Factors Used to Determine Quality	Components
Wind [1]	Wind Power Class	Unit-less value (1 to 7)	W/m^2	• Wind speed and air density (adjusted for elevation, pressure, and temperature) • Qualitatively evaluated/adjusted for effects/evidence of topographic features
Solar [2]	Insolation	kW/m^2	none	• Hourly radiance images from weather satellites • Daily snow cover data • Averages of atmospheric water vapor, trace gases, and the amount of aerosols in the atmosphere
	Radiation	kW/m^2	none	• Solar radiance
Uranium Ore [3]	Grade	Terminology (low to extra high grade)	lbs eU_3O_8 / ton and/or percent	• Volume of ore (area and thickness) • Specific density of ore
Coal [4]	**Grade**: degree of impurities and calorific value	Terminology (standard to ultra-high)	Percent weight carbon	• Useful heat value • Ash + moisture content (from measured moisture, ash yield, mineral matter, total sulfur content), and/or • Gross calorific value (from of heat of combustion)

Resource	Quality System(s)	Unit of Comparison	Factors Used to Determine Quality	Components
	Rank: degree of maturation (metamorphism or coalification)	Terminology (lignite to anthracite)	Multi-factor: • % fixed carbon • % volatile matter • BTU/lb or MJ/kg	• Carbon content (adjusted to remove moisture and mineral matter content) • % volatile matter (adjusted to remove moisture and mineral matter content) • Gross calorific value (adjusted to remove mineral matter)
Crude Oil [5]		Terminology (heavy to light)	API gravity	• Oil density
		Terminology (sour to sweet)	% content sulfur	• Sulfur content

[1]Elliot et al. 1986. [2]NREL 2013. [3] Campbell et al. 2008; Jet West Geophysical, n.d. [4] ASTM 1998; Mitchell 2014. [5] EIA 2012.

2.2.2 Composing a Geothermal Quality Grade: Geological Attributes

We propose here geological grades based on four attributes: temperature, volume, permeability, and fluid availability. Temperature and volume of the reservoir are relatively standard characteristics for measuring quality. Permeability of the reservoir formations is also important because it affects the accessibility and potential recovery of available energy (Williams 2007). The fluid availability and recharge rate of a reservoir can impact its useful lifetime and the effort required to transport heat from the reservoir.

Additional attributes for the Technical and Socio-Economic categories are planned for development in 2015. For example, technical attributes may include things such as drilling and fluid chemistry. The chemistry of these reservoir fluids is important: low pH fluids can cause corrosion, high salinity fluids can cause mineral precipitation, i.e. “scaling,” and mitigation measures for either may affect profitability. The quality of any one of these attributes may significantly influence the economic barriers associated with development and operation. Low grades are not always a negative, though. For example, those interested in using hydrothermal fluids for mineral recovery would view the chemistry ranking differently than those who prefer more benign and dilute geothermal fluids.

Quality values like these can assist in evaluating geothermal resources. Confidence in the quality values can be increased with understanding of (1) the activity (e.g. use of an exploration technique) used to determine the measure and (2) how effectively the technique was implemented. For example, Projects A and B may both be reported as large, high-temperature systems, but Project A used geothermometry to derive its conclusions, and Project B has a single temperature measurement from one well. It might be assumed that Project A has less accurate data. The accuracy of geothermometry temperature estimates can depend on basic corrections and sample checks, such as corrections for mixing or boiling and a check of the cation and anion balance. However, if the downhole temperature measurement for Project B was taken immediately after drilling, rather than after the temperature in the well equilibrated, then that data, too, may be inaccurate. Reporting a measured downhole temperature without this knowledge of the effectiveness of the execution may provide a false sense of accuracy. Therefore, we consider both the activity and the execution of the technique to be integral to understanding estimates of resource quality. We also consider that exploration techniques appropriate for one type of geothermal system may not be appropriate for other systems (e.g., IGA 2014), so we avoid a prescriptive approach for exploration development.

This paper attempts to set out a logical framework to consider and combine these attributes systematically. Our ongoing work will (1) identify the most critical attributes to report, (2) evaluate the accuracy of exploration techniques for obtaining values for these attributes, and (3) create protocols for evaluating the diligence of the execution of the techniques.

2.2.3 Framework for Attribute Grades

To evaluate each attribute (e.g., temperature, permeability) systematically as described, we developed three indices—*character*, *activity*, and *execution*. Just as each attribute is assessed independently from others for the purpose of the framework, these indices are also independently evaluated for each attribute. Though not yet developed at the time of the completion of this paper (December 2014), plans for future work include the development of specific criteria for the value (e.g., A-E) of each index (character, activity, and execution), so that there would be no ambiguity in the assigning of values for each attribute grade. As an example, we use preliminary, unvetted details for the temperature attribute (e.g., Sanyal 2005; Williams et al. 2011) to illustrate this framework, as shown in Table 4.

Table 4: Proposed component indices standardizing the assessment of geothermal resource temperature.

(a)

Character Index (Estimated Temperature)		
A	>300°C	High-temperature two-phase liquid-dominated OR high enthalpy vapor-dominated
B	230-<300°C	Two-phase liquid-dominated systems: - high temperature, high enthalpy - moderate- temperature, moderate enthalpy
C	150-<230°C	Moderate to low temperature, moderate to low enthalpy liquid-only systems
D	90-<150°C	Low temperature systems
E	<90°C	Very low temperature systems

(b)

Activity Index	
A	Measured temperatures: downhole temperature probe readings (well(s) drilled into reservoir)
B	Extrapolated temperatures: TGH/well(s) not drilled into reservoir
C	Geothermometry (reservoir brines)
D	Geothermometry (immature or mixed fluids, inconsistent results between geothermometers)
E	Regional heat flow data

(c)

Execution Index (Example: Subsurface Temperature Probe Readings)	
A	• Probe allowed to equilibrate • Cuttings and/or geophysics confirms measurement within the reservoir (i.e., downhole alteration mineralogy consistent with reading)
B	• Probe allowed to equilibrate • Cuttings and/or geophysics have *not* confirmed measurement within the reservoir (i.e., downhole alteration mineralogy not consistent with readings)
C	• Probe *not* allowed to equilibrate • Cuttings and/or geophysics have *not* confirmed measurement within the reservoir
D	• Results taken from previous third-party studies of the area (either literature or contractors) with little or limited information on survey methods, replication, or error
E	• Assumed from studies of analogous geothermal settings or extrapolated from studies of nearby areas

The first index, the *character index*, is used to describe the attribute itself. For example, a resource with a high temperature may be given a temperature character index of A, while a resource with a low temperature would be assigned a temperature character index of E, as shown in Table 4(a). However, without any indication of how the attribute's character was actually determined, the accuracy of any character index is unknown.

In proposing an *activity index* (e.g., Table 4(b)), we developed a qualitative grade of activities (in this case, exploration techniques) appropriate for each attribute from any combination of accepted geochemical, geophysical, and/or remote sensing techniques. Each of these techniques is given a grade on the basis of its appropriateness for estimating the given attribute. For example, temperature measurements from thermal gradient holes provide a different set of assumptions and limitations than silica geothermometers but are likely to provide a closer measure of deep temperatures than would uncorrected silica geothermometry measurements using fluids where silica has precipitated prior to sample collection. Thus, thermal gradient hole measurements would be assigned a higher activity index grade than the silica geothermometer to represent the higher degree of confidence in the accuracy of the temperature estimate. We expect that exploration programs will use more than one activity for estimating an attribute's character, and therefore, we anticipate that the criteria developed will accommodate such combinations.

The *execution index* compares the diligence with which any given activity was executed. For example, results of sulfate-water oxygen isotope geothermometry could show little variation in resulting temperature with few outliers, suggesting high confidence in the results, but these results could be impacted by shifts in the oxygen isotope compositions of the water and/or the sulfate caused by processes such as boiling, dilution, and bacterial activity (e.g., McKenzie and Truesdell 1977), which would render these results to be less reliable. In this case, a moderate value of the execution index could be assigned to represent this mixed confidence in the geothermometry conclusions. A second example of an execution index for temperature probe readings is shown in Table 4(c)

One way to visualize resource grades is via a polar area chart (or rose diagram) (Figure 4), where each quadrant represents one of the four attribute grades and is subdivided to show the values for the character, activity, and execution indices. The diagram allows one to quickly assess the strengths and weaknesses of an area by scanning the darkly shaded wedges. In the illustrative example shown in Figure 4, the temperature and volume resource grades of the reservoir are high, the permeability is about average, and the fluid availability is low. By reviewing the lightly shaded areas, one can get a glimpse of the certainty of these values and understand where more work may be needed to better understand the geothermal system. In the context of GTO's need for metrics, the rose diagrams can be used to understand RD&D impacts at a particular location, showing how the information for a given area has changed in response to the results of funded projects.

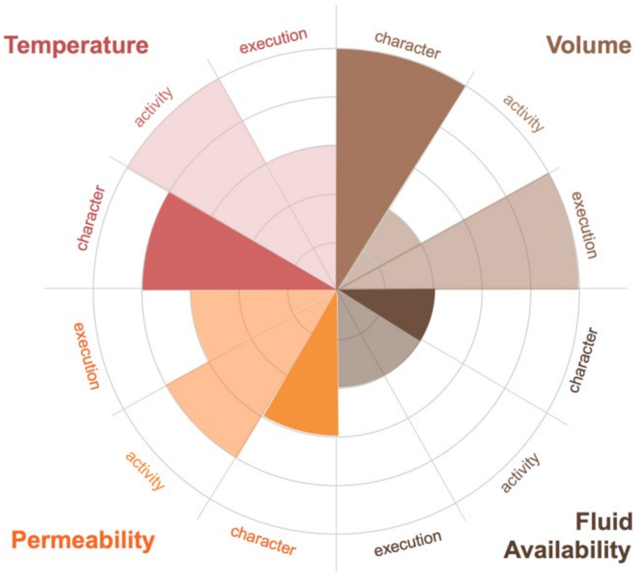

Figure 4: Example visualization using a polar area chart of the four geological attribute grades for an illustrative location. Each quadrant represents a different resource attribute and is subdivided to show the character, activity, and execution index values. The darkly shaded wedges indicate the grade of the four geological attributes, while the lightly shaded wedges indicate certainty (activity and execution).

2.2.4 Comparing Resource Grades

The proposed grading system gives each attribute a rating on a scale of A-E, with A being highest. However, some business models or plant designs may target grades lower than A for some or all of the attributes. Examples are given below:

- Some developers may be targeting average temperature resources (Temperature Grade = C) and poor fluid chemistry (Fluid Chemistry Grade = D-E) to take advantage of secondary mineral recovery potential from the geothermal brine.
- Near-field resources (resources located near operating plants) may have high temperatures but low permeability and/or fluid and may be candidates for the application of enhanced geothermal system (EGS) techniques.
- A very high-temperature resource does not necessarily need to have a large volume to be economical for some business models; in fact, a small- or average-size, high-temperature resource could be a viable target.

As these examples indicate, each developer must evaluate which grades are appropriate for their target business model. Resources with all attribute grades equaling A rarely exist.

Figure 4 displays the grade and certainty in a specific location. Figure 5 compares resource grades in multiple locations. In this graphic, the volume attribute is represented by the size of the circle; the temperature attribute is represented by the color of the circle; the permeability attribute is indicated on the x axis; and the fluid availability attribute is indicated on the y axis. In the center of the circle, one could indicate the estimated MWe.

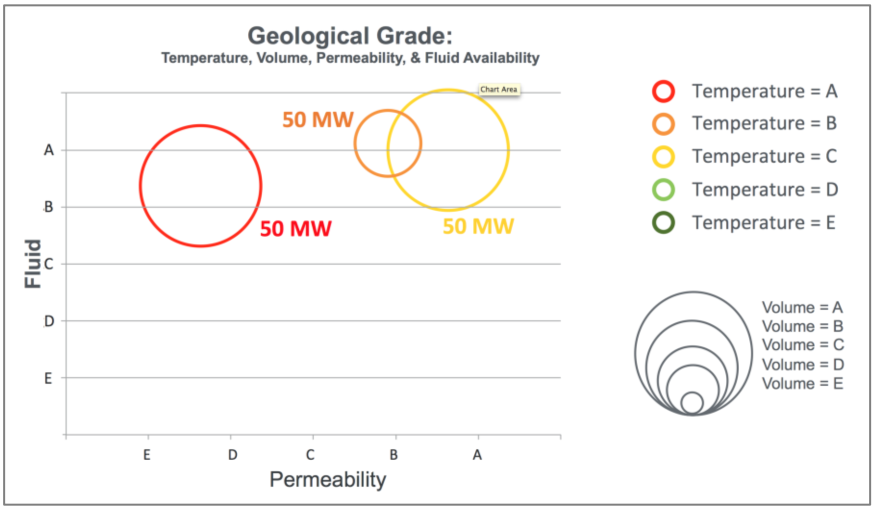

Figure 5: Illustrative figure for displaying the geological grades for multiple project areas. Each geothermal project is indicated on the graph using a circle. The temperature attribute is indicated by color; volume attribute is indicated by the size of the circle; permeability and fluid availability attributes are indicated by the circle's position on the x and y axes.

2.3 Resource Size

For reporting both resource grade and project progress, estimates must be made of resource quantity (e.g., number of BTU or MWe), which will allow reporting at both the project level and the cumulative portfolio level. It is important, therefore, to establish a methodology for estimating this value for each resource area. For example, the USGS, in its 2008 U.S. geothermal assessment of the United States, reported a mean of 9 GWe of identified geothermal power generation potential, and quantitatively reported uncertainty using 5th and 95th percentile values developed through Monte Carlo simulations (Williams et al. 2008b).

In the USGS example, their reporting of resource size was broken into two complimentary assessments: a *level of knowledge* (a.k.a. project progress) and a *level of certainty*. As increased knowledge of the geothermal system is gained (e.g., with additional exploration activities up to and including the drilling of production wells), the margin of error is likely to decrease, increasing statistical confidence. This type of structure was used by the USGS in its most recent 2008 assessment of U.S. geothermal resources (Williams 2008b), as shown in Table 5, in which "undiscovered" resources are "unspecified concentrations of geothermal energy surmised to exist on the basis of broad geologic knowledge and theory" (Muffler and Guffanti 1979). In contrast, Muffler and Guffanti (1979) define "identified" resources to be "specific concentrations of geothermal energy known and characterized by drilling or by geochemical, geophysical, and geologic evidence" (p. 58). Based on comments from multiple industry professionals, drilling is viewed by the geothermal industry as the only reliable means of confirming resource discovery (personal communication, July– September 2014). This matrix reporting approach has the potential to improve the consistency and transparency of reported resource estimates.

Table 5: Example of reporting matrix quantifying resource knowledge and certainty:
2008 USGS Geothermal Resource Assessment of the United States (Williams et al. 2008b).

		Level of Certainty		
		P_5	**P_{50}**	**P_{95}**
Level of Knowledge (Geological Knowledge)	**Identified**	16.5 GW_e	8.4 GW_e	3.7 GW_e
	Undiscovered	73.3 GW_e	23.7 GW_e	7.9 GW_e

Figure 6 shows our proposed expansion of resource knowledge (as described above) and provides a visual representation of the standard error of a resource size estimate. This error should be inversely related to the level of information. Early estimates of potential capacity are only estimates; for the purposes of resource reporting, it may be more useful to consider qualitative *low*, *medium*, and *high* estimates for undiscovered resources rather than more quantitative P_5 and P_{95} estimates. Further work in this study will aim to standardize how resource size is reported to GTO when applying for funding applications and in close-out reporting in order to reduce subjectivity in reporting.

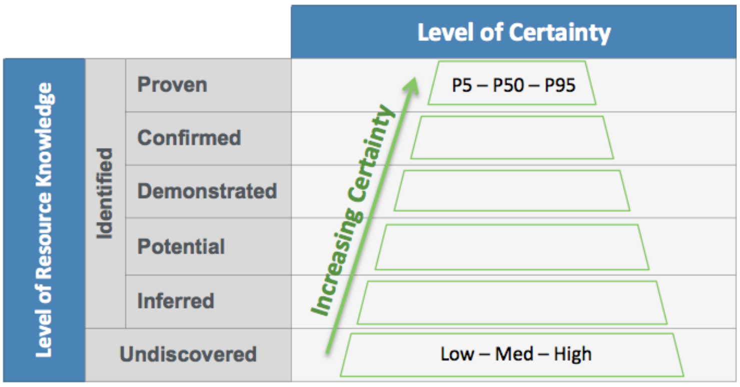

Figure 6: Diagram representing the expected relationship between level of resource knowledge and level of certainty. As information about a geothermal resource increases, certainty in the resource estimate increases and standard error decreases. At early stages of exploration, when little data are available, certainty may more accurately be reflected using qualitative terms, such as low, medium and high estimates. As more data are gathered, these estimates may be quantitatively estimated using P_5, P_{50} and P_{95} resource size estimates.

2.3.1 Developing Resource Estimates

The quantity of recoverable heat for a geothermal resource is typically calculated in early stages of project development using one of two methods: the USGS heat-in-place volume method (Williams et al. 2008a), or a method developed by Massachusetts Institute of Technology (MIT 2006). The two methods use different assumptions on the extraction of heat for power generation. In both methods, the volume of recoverable heat in the reservoir is calculated as the quantity of thermal energy that can be extracted from a uniformly porous and permeable rock given a thermal recovery factor. The USGS calculation assumes the entire reservoir could potentially be extracted and cooled to the reference temperature, and the hurdle is the resource's recovery factor and the plant's utilization efficiency (Williams et al. 2008). MIT assumes that 1) because power plants are specified for only a narrow temperature range, the reservoir will lose economic value and will be abandoned if it falls out of the useful temperature range, and 2) the use of a plant's thermal efficiency better estimates the reinjection temperature of waste heat (MIT 2006).

As more information is gathered at a geothermal location, conceptual and numerical reservoir models are typically constructed, integrating multi-dimensional reservoir characteristics. Information obtained through increased field observations permits calibration of the reservoir model using well flow test data, which helps to improve the accuracy of these models. Significant long-term testing is required to properly calibrate these models. As an example, a volume method could be used to estimate an undiscovered or inferred resource during the early phases of exploration, but a numerical reservoir model constrained by extensive well test results would be required after resource discovery and confirmation through drilling. Confidence intervals, then, would likely be more deterministic (low, medium, high) during the early phases, and would become probabilistic (P_{10}, P_{50}, P_{90}) as reservoir models are developed that could provide statistical distributions of possible outcomes.

For estimating the range of values in these resource models (whether measured or assumed defaults), Monte Carlo analysis a typical analytical method to determine the likely distribution of these parameters, and are widely used in both geothermal and other resources (SPE et al. 2011; Williams et al., 2008a). Sufficient information to complete these scenarios is critical to defining clear statistical confidence intervals, and thus also the "levels of certainty" proposed by this framework.

Future work on this study includes development of a protocol for estimating resource potential at different phases of project development.

3. USING RESOURCE KNOWLEDGE AND GRADES FOR PORTFOLIO REPORTING

The resource knowledge terminology introduced in Section 2 can be used in a number of ways as a metric for GTO. For example:

- The program can report the number of projects (or MW) it is funding at each level (from Table 3, e.g., undiscovered, inferred, potential).
- The program can target barriers with its RD&D funding and report movement of its funded projects (in number of projects or MW) across a given activity threshold (see Table 3).
- The program can use these metrics to evaluate applications, requesting that applicants explain how the proposed activity will impact a particular geothermal area, or a proposed technology improvement will help other projects to move across thresholds more quickly or with less cost or risk.
- The program can then use the above metrics as *one* measure of project and portfolio success – did the projects succeed in the proposed *measurable* outcome?

While the rose diagram (Figure 4) for individual resource areas can be used to report RD&D impacts for a particular area, the data need to be aggregated to report grades for GTO's portfolio of projects. For each goal or target, GTO can select a set of grades to report. For example, creating a table comparing temperature and volume, for all areas with permeability above C. This concept expands on Figure 1, which shows the temperature distribution of the USGS identified geothermal resource base. The projects in a portfolio could then be added together. The results might look something like Table 6, which reports a portfolio of (in this case, illustrative) projects. Each cell reports total MW and the number of projects (reported in parentheses). For example, there are five projects totaling 500 MW with a temperature and volume grades of "a". The data in the table can be summed vertically to look at resources based on volume grades or horizontally to look strictly at temperature grades. For example, the illustrative data show 3.6 GWe of high-volume-grade resources, spanning all temperature ranges; the data also show 1.2 GWe of high temperature resources (spanning all volume grades).

Table 6: Using resource grades for portfolio reporting.

Volume Grade Temp Grade	A	B	C	D	E	TOTAL
A	500 (5)	200 (2)	300 (3)	100 (1)	**10(1)**	**1,110 (12)**
B	1000 (25)	400 (10)	720 (30)	440 (20)	**200 (15)**	**2,760 (100)**
C	800 (40)	640 (32)	620 (57)	400 (80)	**220 (15)**	**2,680 (224)**
D	1,150 (114)	410 (130)	200 (115)	310 (164)	**90 (5)**	**2,160 (528)**
E	165 (55)	42 (30)	111 (90)	42 (66)	**0 (0)**	**360 (241)**
TOTAL	**3,615 (239)**	**1,692 (204)**	**1,951 (295)**	**1,282 (334)**	**610 (36)**	**9,160 (1108)**

The program can use the resource knowledge levels and the resource grades in reporting on projects across its entire GTO portfolio—both before and after RD&D funding. It could also be applied to a subset of projects—perhaps only to hidden or blind systems or only to enhanced geothermal systems (EGS) to look at various subsets of the portfolio.

6. CONCLUSIONS

This paper sets the foundation for a set of metrics that can provide a comparable basis for the identification, exploration, and development of geothermal resources. When completed, these metrics could be used by GTO's Hydrothermal Program to evaluate the impact of RD&D funding on the basis of potential or actual production, and also according to developmental barriers that the funding helped reduce. The metrics can be used to inform the program and those they report to: Congress and the public. However, these will not be the only metrics GTO uses in determining project impact and success. Additionally, in each round of funding, it will be important to evaluate the successes and failures and to develop lessons learned so that future funding opportunities can continue to improve their implementation effectiveness.

We have developed a system of reporting the progress of a geothermal project and the grade of a geothermal area. , It is useful to characterize additional aspects of project progress and research, using similar, symmetrical progress and grading systems for technical and socio-economic parameters.

Ideally, these proposed metrics of geothermal resource knowledge and quality will create comparable, measureable milestones for geothermal project evaluations, increasing transparency into the impact of GTO funding on strategic goals and aiding both the GTO and decision makers outside the geothermal industry.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Geothermal Technologies Office (GTO) under Contract No. DE-AC36-08-GO28308 with the National Renewable Energy Laboratory and No. DE-AC02-05CH11231 with Lawrence Berkeley National Laboratory. The authors wish to thank Colin Williams (USGS); Paul Brophy (EGS, Inc.); Graeme Beardsmore (Hot Dry Rocks); Ann Robertson-Tait (GeothermEx); Ben Matek (GEA); Mark Ziegenbein, Eric Hass, and Jay Nathwani (DOE); and numerous workshop participants for their insights and suggestions relating to this study. We also thank the NREL review team, including Kendra Palmer, Scott Gossett, Emily Newes, Jeff Logan, and David Mooney.

REFERENCES

American Society for Testing and Materials [ASTM]. (1998). *ASTM D388: Standard Classification of Coals by Rank*.

Australian Geothermal Energy Association [AGEA] and Australian Geothermal Energy Group [AGEG]. (2010). Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves, *The Geothermal Reporting Code*, Second Edition, 28 p.

Brophy, P. (2007). A Brief Classification of Geothermal Systems. *Geophysical Techniques in Geothermal Exploration Workshop*. GRC Annual Meeting. Sparks, Nevada.

Brophy, P. (2012). Accelerating Investments in the Geothermal Sector, Indonesia. Taskforce for Accelerating Investments in the Geothermal Sector, Indonesia (Bappenas).

Campbell, M.D., J.D. King, H.M. Wise, R.I. Rackley, B.N. Handley. (2008). *The Nature and Extent of Uranium Reserves and Resources and Their Environmental Development in the U.S. and Overseas*. http://emd.aapg.org/technical_areas/uranium.pdf.

Canadian Geothermal Energy Association [CanGEA]. (2010). *The Canadian Geothermal Code for Public Reporting, Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves*, 2010 Edition, 32 p.

CFA Institute. (2013). *Financial Reporting Disclosures: Investor Perspectives on Transparency, Trust, and Volume*. http://www.cfapubs.org/doi/pdf/10.2469/ccb.v2013.n12.1.

Committee for Mineral Reserves International Reporting Standards [CRIRSCO]. (2013). *International Reporting Template for the Public Reporting of Exploration Results, Mineral Resources, and Mineral Reserves*. http://www.crirsco.com/templates/crirsco_international_reporting_template_2013.pdf.

Elliott, D.L., C.G. Holladay, W.R. Barchet, H.P. Foote, W.F. Sandusky. (1986). *Wind Energy Resource Atlas. Appendix A*. Pacific Northwest Laboratory, Richland, WA. http://rredc.nrel.gov/wind/pubs/atlas/appendix_a.html.

Energy Information Administration [EIA], (2012). Crude Oils Have Different Quality Characteristics, *Today in Energy*, July 16, 2012. http://www.eia.gov/todayinenergy/detail.cfm?id=7110.

Falcone, G., A. Gnoni, B. Harrison, C. Alimonti. (2013). Classification and Reporting Requirements for Geothermal Resources, *European Geothermal Congress 2013*, Pisa, Italy.

Falcone, G. (2015) Proposal of a consistent framework to integrate geothermal potential classification with energy extraction. Geothermal Energy Science, v. 3, p. 7-11.

Fama, E. (1970) Efficient capital markets: a review of theory and empirical work. *Journal of Finance.* (25): 383-417.

Fama, E. (1991) Efficient capital markets: II. *Journal of Finance*. (46):1575-1617.

Faulds, J.E., N.H. Hinz, M.F. Coolbaugh, P.H. Cashman, C. Kratt, G. Dering, J. Edwards, B. Mayhew, H. McLachlan. (2011). “Assessment of Favorable Structural Settings of Geothermal Systems in the Great Basin, Western USA.” *Geothermal Resources Council Transactions*. v. 37, p. 777–783.

Fournier, R.O. (1992). “Water Geothermometers Applied to Geothermal Energy.” Chapter 2, in: *Applications of Geochemistry in Geothermal Reservoir Development-Series of Technical Guides on the Use of Geothermal Energy.* UNITAR/UNDP Center on Small Energy Resources, Rome, Italy, p. 37-69.

Gehringer, M., V. Loksha. (2012). *Geothermal Handbook: Planning and Financing Power Generation*. Energy Sector Management Assistance Program, The World Bank, Technical Report 002/12, 149 p.

Geothermal Energy Association [GEA], (2010). *Geothermal Reporting Terms and Definitions: A Guide to Reporting Resource Development Progress and Results to the Geothermal Energy Association*. http://geo-energy.org/pdf/NewGeothermalTermsandDefinitions_January2011.pdf

Giggenbach, W.F., R.L. Goguel. (1989). *Collection and Analysis of Geothermal and Volcanic Waters and Gas Discharges*. Report No. CD2401, Chemistry Division, Department of Scientific and Industrial Research, Petone, New Zealand, 81 p.

Henley, S. (Accessed May 27, 2014). *CRIRSCO and UNFC.* Committee for Mineral Reserves International Reporting Standards. http://www.eurogeologists.de/images/content/panels_of_experts/minerals_and_their_sustainable_use/CRIRSCO%20and%20UNFC%202013.pdf.

International Economic Energy Agency [IEEA]. (2008). *Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems. IAEA-TECDOC-1575 Rev. 1.* Vienna, Austria: International Economic Energy Agency.

International Geothermal Association [IGA]. (2014). *Best Practices Guide for Geothermal Exploration* (2nd edition), 194 p.

Jet West Geophysical Services. (n.d.). *Uranium Ore Logging*. http://jetwestgeophysical.com/files/samplelogs/U308GJcalsForK.pdf.

Karingithi, C.W. (2009) Chemical Geothermometers for Geothermal Exploration. United Nations University Geothermal Training Programme. http://www.os.is/gogn/unu-gtp-sc/UNU-GTP-SC-10-0603.pdf.

Mitchell, G.D. (2014). Coal Utilization in the Steel Industry, *Steelworks*. http://www.steel.org/en/Making%20Steel/How%20Its%20Made/Processes/Processes%20Info/Coal%20Utilization%20in%20the%20Steel%20Industry.aspx.

McKelvey, V.E. (1972). Mineral Resource Estimates and Public Policy. *American Scientist*, v. 60, no. 1, pp. 32-40.

McKenzie, W.F., A.H. Truesdell. (1977). The Oxygen Isotope Compositions of Dissolved Sulfate and Water From Hot Springs and Shallow Drillholes. *Geothermics*, v.5, pp. 51-61.

MIT-Led Interdisciplinary Panel [MIT]. (2006). *The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century*. Massachusetts Institute of Technology. ISBN: 0-615-13438-6

Moeck, I.S. (2014) Catalog of geothermal play types based on geologic controls. *Renewable and Sustainable Energy Reviews*, v. 37, pp. 867-882.

Moeck, I. and G. Beardsmore. (2014). A New 'Geothermal Play Type' Catalog: Streamlining Exploration Decision Making. *Proceedings, 39th Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, CA, SGP-TR-202, 8 p.

Mueller, G. (2001) The Role of Financial Disclosure: Discussion. *The Boston Federal Reserve*. https://www.bostonfed.org/economic/conf/conf44/cf44_8.pdf

Muffler, L.J.P., M. Guffanti. (1979). *Assessment of Geothermal Resources of the United States – 1978*. Introduction. In: L.J.P. Muffler, ed. Assessment of geothermal resources of the United States, U.S. Geological Survey Circular 790, 163 p.

National Renewable Energy Laboratory [NREL]. (2013). Solar Maps Development- How the Maps were Made, Dynamic Maps, GIS Data, & Analytics Tools. http://www.nrel.gov/gis/solar_map_development.html.

Novatek. (2014). Classification of Reserves, *OAO Novatek Press Center*. http://www.novatek.ru/en/press/reserves/.

OECD Nuclear Energy Agency and the International Atomic Energy Agency [OECD-NEA and IAEA]. (2012). *Uranium 2011: Resources, Production and Demand*. ("The Red Book"). Nuclear Fuel Cycle and Materials, Nuclear Fuel Cycle & Waste Technology. OECD, Paris, France. ISBN 978-92-64-17803-8 EURO 140, USD 196, GBP 126, Japanese YEN 18 200. http://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/uranium-production-cycle-redbook.html#RedBook.

The Resources and Reserves Committee of the Society for Mining, Metallurgy, and Exploration [SME]. (2007). *SME Guide for Reporting Exploration Results, Mineral Resources, and Mineral Reserves*. Littleton, Colorado. (2007, 2014-draft) http://www.crirsco.com/usa_sme_guide_2007.pdf.

Sanyal, S.K. (2005). Classification of Geothermal Systems - A Possible Scheme. *Proceedings, Thirtieth Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, CA, SGP-TR-176, 8 p.

Securities and Exchange Commission (2000). *International Accounting Standards* http://www.sec.gov/rules/concept/34-42430.htm

Society of Petroleum Engineers [SPE], American Association of Petroleum Geologists [AAPG], World Petroleum Council [WPC], Society of Petroleum Evaluation Engineers [SPEE], Society of Exploration Geophysicists [SEG]. (2011). *Guidelines for Application of the Petroleum Resources Management System*. http://www.spe.org/industry/docs/PRMS_Guidelines_Nov2011.pdf.

United Nations Economic Commission for Europe [UNECE]. (2013). *United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 Incorporating Specifications for its Application.* New York and Geneva: United Nations.

United Nations Economic Council for Europe [UNECE]. (March 24-25, 2014). Workshop on Developing a United Nations Framework Classification (UNFC) for Renewable Energy. Washington, D.C.

U.S. Bureau of Mines, and U.S. Geological Survey [USGS]. (1980). *Principles of a Resource/Reserve Classification for Minerals.* U.S. Geological Survey Circular 831, 5 p.

van Wees, J.D., T. Boxem, P. Calcagno, C. Dezayes, C. Lacasse, A. Manzella. (2013) *A Methodology for Resource Assessment and Application to Core Countries.* Geo-Elec Deliverable 2.1. http://www.geoelec.eu/wp-content/uploads/2011/09/D-2.1-GEOELEC-report-on-resource-assessment.pdf.

White, M.J. (2013). The Path Forward on Disclosure. *Securities Exchange Commission.* http://www.sec.gov/rules/concept/34-42430.htm

Williams, C.F. (2007). Updated Methods for Estimating Recovery Factors for Geothermal Resources. *Proceedings, 32nd Workshop on Geothermal Reservoir Engineering*, Stanford University, SGP-TR-183, 7 p.

Williams, C.F., M.J. Reed, R.H. Mariner. (2008a). *A Review of Methods Applied by the U.S. Geological Survey in the Assessment of Identified Geothermal Resources.* United States Geological Survey Open-File Report 2008-1296, 27 p.

Williams, C.F., M.J. Reed, R.H. Mariner, J. DeAngelo, S.P. Galanis, Jr. (2008b). *Assessment of Moderate- and High-Temperature Geothermal Resources of the United States*, U.S. Geological Survey Fact Sheet 2008-3082, 4 p.

Williams, C.F., M.J. Reed, J. DeAngelo, S.P. Galanis, Jr. (2009). Quantifying the Undiscovered Geothermal Resources of the United States. *Geothermal Resources Council Transactions*, v. 33, pp. 995-1002.

Williams, C.F., M.J. Reed, A.F. Anderson. (2011). Updating the Classification of Geothermal Resources. *Proceedings, 36th Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, CA, SGP-TR-191, 7 p.