Geothermal Resource Reporting Metric (GRRM) Developed for the U.S. Department of Energy's Geothermal Technologies Office

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Keywords

Reporting metric, reporting code, resource assessment, geothermal grade, polar area chart

ABSTRACT

This paper reviews a methodology being developed for reporting geothermal resources and project progress. The goal is to provide the U.S. Department of Energy's (DOE) Geothermal Technologies Office (GTO) with a consistent and comprehensible means of evaluating the impacts of its funding programs. This framework will allow the 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 and the public. Standards and reporting codes used in other countries and energy sectors provide guidance to develop the relevant 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 the GTO, we analyzed existing resource assessments and reporting methodologies for the geothermal, mining, and oil and gas industries, and sought input from industry, investors, academia, national labs, and other government agencies. Using this background research as a guide, we describe a methodology for evaluating and reporting on GTO funding according to resource grade (geological, technical and socio-economic) and project progress. This methodology would allow GTO to target funding, measure impact by monitoring the progression of projects, or assess geological potential of targeted areas for development.

I. 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. As an example, one GTO goal is to "accelerate development of 30 GWe of undiscovered hydrothermal resources" (based on the USGS geothermal assessment of Williams et al., 2008b). For goals to be useful, however, it is important to be able to develop and measure baseline values, as well as incremental improvements, both at the individual project and aggregated portfolio levels. This need is the driving force behind the development of the Geothermal Resource Reporting Methodology (GRRM).

Although the Geothermal Energy Association (GEA) has developed Geothermal Reporting Terms and Definitions (GEA, 2010) for reporting on *project* development, the U.S. geothermal industry has not adopted a systematic Protocol for *resource* reporting. Several countries, including Australia and Canada, have adopted geothermal resource reporting standards, and other natural resource industries (such as mining, oil, and gas) have worldwide standards and terminologies that are used to guide resource assessments. The United Nations Economic Council for Europe has recently partnered with the International Geothermal Association (UNECE and IGA, 2014) to develop a Geothermal Specifications document for the United Nations Framework Classification system (UNECE, 2013). All of these guides have provided valuable background information, insight, and influence in the development of the GRRM.

The GRRM provides a process for objectively appraising project progress and resource grade in in individual geothermal areas. This methodology aims to create:

- A method for assessing individual projects;
- A set of assessment tools (the GRRM Protocol, Young et al., 2015b) applicable to all stages of geothermal development; and
- A Protocol for evidence-based, objective assessment of a project's progress and grade.

This GRRM does *not* attempt to create:

- A standard, or a pass/fail mark—it only provides the means to identify characteristics of geothermal resources and associated projects;
- A reporting requirement for anything beyond the needs of GTO—namely for baseline assessment, goal setting, application evaluation, project close-out summaries, and portfolio reporting;
- A process or plan for geothermal exploration or development at any location;
- A replacement for geothermal expertise in assessing project potential; or
- A set of new national or local regulatory reporting requirements.

II. Background

The idea of the development of this reporting methodology surfaced around 2010 after GTO received funding from the American Recovery and Reinvestment Act (ARRA) (ARRA, 2009). Several ARRA projects were under way and GTO needed a way to report the individual and cumulative impact of its funded research. Development of a reporting methodology, however, would take years, and would need support and buy-in from industry to be successful.

In 2013, GTO began more formal discussions with industry, hosting a resource reporting knowledge exchange and discussion in Sacramento, CA, in conjunction with the Geothermal Resources Council (GRC) Resource Assessment and Optimization Workshop (June 2013), and discussions with the Boards of Directors of Geothermal Energy Association (GEA) and GRC at their joint meeting in Reno, NV (June 2013). Sufficient interest and support was provided to prompt funding of this effort by GTO in 2014.

In 2014, the National Renewable Energy Laboratory (NREL) partnered with Lawrence Berkeley National Laboratory (LBNL) and New West Technologies to begin developing this reporting methodology. These early versions of the GRRM were circulated to selected industry members (in the U.S. and internationally) and the GEA to solicit feedback on the direction of the methodology's development. Later drafts were presented during workshops at GEA (August 2014) and GRC events (September 2014).

After further refinement, a draft of the methodology was presented to and discussed at an international working group of the International Geothermal Association (IGA) in Bonn, Germany (December 2014) and in Washington, D.C. (March 2015), as well as during the 2015 World Geothermal Congress in Melbourne, Australia (Young et al., 2015a), during presentation and a targeted workshop at the GTO Peer Review (May 2015), and through targeted discussions during the GEA Summit (June 2015). Continuous refinement has occurred along the way, and has led to the development of a Protocol, which will consist of six documents, including:

- **Background Document** *(released July 2015)*
- **Geological** Assessment Tool *(released July 2015)*
- **Technical** Assessment Tool *(planned for development in 2016)*
- **Socio-Economic** Assessment Tool *(planned for development in 2016)*
- **Resource Size** Assessment Tool *(released July 2015)*
- **Case Studies:** Application of the GRRM Protocol *(planned for development in 2016)*

Three of these documents are planned for release in July 2015 for the initial trial period, slated to begin in 2016 (contingent on continued funding). During this period, the Protocol will be tested on DOE's previous and current portfolio of RD&D projects, and refined, as necessary, to overcome any issues identified during the implementation of the Protocol. We welcome any feedback and suggestions from all stakeholders.

III. Principles of the Methodology

The GRRM is based on the concept that a geothermal system can be described both in terms of the quality of the geothermal resource as it relates to the potential to extract heat ("Resource Grade"), and the progress of research and development efforts over the lifetime of the project ("Project Progress").

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

By assessing the development activities of the project, users can report on incremental *project progress*. Like the resource grade, project progress will continually be updated throughout the project lifetime.

Resource grade and project progress are reported for three assessment categories: geological, technical, and socio-economic. Each category has specific criteria and guidelines for assessing both resource grade and project progress, as outlined in each of the following assessment tools (and associated colors); see tables and charts below:

- **Geological** Assessment Tool (representative colors: reds, oranges, browns)
- **Technical** Assessment Tool (representative colors: blues, purples)
- **Socio-Economic** Assessment Tool (representative colors: greens, yellows).

Additionally, users will need to estimate the project size (often reported in MW_e or MW_t). To provide consistency in calculating resource potential for comparisons, the Protocol also includes a separate *Resource Size Assessment Tool*.

These tools are written for industry professionals assigned to report resource grade and project progress to GTO. The Protocol is meant to aid and provide consistency in the reporting process, and does not replace intelligent expertise in geothermal exploration, in project development, or in preparing and selecting data to report.

IV. Resource Grade

Traditionally, a description of the grade of a natural resource includes a combination of multiple factors. For example, the grade of a mined ore is described as the ore's mineral concentration that can be technically recovered, and the grade of oil is described in terms of a combination of heavy to light and sweet to sour. We apply these concepts of grade to geothermal resources by identifying "attributes" specific to each of the three assessment categories (geological, technical, and socio-economic).

Resource Grade Attributes

The attributes used by the Protocol to describe a geothermal resource include the constraints on the quality of the geothermal resource, as well as the technical and socio-economic characteristics that determine whether the heat in the system can be produced.

Each attribute is ranked on a scale of "A" through "E," with "A" being the highest. An attribute grade of "A" is not necessarily the "best" value for a specific project goal. Some business models or plant designs may target grades lower than A for some or all of the attributes. Examples are given below:

- Some developers may be interested in 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 (Temperature Grade = A), but low permeability (Permeability Grade = C) and may be candidates for the application of Enhanced Geothermal System (EGS) techniques.
- For some business models, a very high-temperature resource does not necessarily need to have a large volume to be economical; 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 his/her target business model. Resources with all attributes with grade A rarely exist.

Geological Grade Attributes

Attributes controlled by the structural, geophysical, and hydrological constraints are important in describing the *Geological Grade*. The usefulness of a geothermal resource can be defined by the available work of the geothermal fluid – the thermodynamic exergy.

The exergy that can be extracted from the heat of a geothermal reservoir is related to the flow rate of fluid and the difference between the enthalpy of the fluid in the reservoir and at the surface (DiPippo, 2004). The following attributes represent the geologic constraints on the quality of the geothermal heat resource:

- **Temperature**: The in-situ reservoir temperature indicates the amount of energy carried by the geothermal fluid, and is thus a commonly used proxy for the available enthalpy of the fluid.

- **Volume**: The size of the reservoir (thickness and area/extent) is necessary for determining the quantity of heat available.
- **Permeability**: The permeability of the reservoir rock, often driven by the degree to which the formations are fracture-dominated, largely controls the accessibility and potential recovery of the heat.
- **Fluid Chemistry**: The geothermal brines and/or gases may be so corrosive or deposit such significant scales that specific tools or materials may have to be used, and special treatments may often be necessary, potentially increasing project costs.

Technical Grade Attributes

Attributes important to the feasibility of extracting the geothermal resource, such as depth to the reservoir, could be overcome by technology advancements, and are thus used to describe the *Technical Grade*. Even though these attributes are related to a system's geologic features, the influence of these items in developing geothermal resources may vary as technology improves. Technical feasibility can be described by the challenges of producing the resource. By nature of technical advancement, the same geologic conditions can become technically feasible through incremental and/or radical innovations. The technical grade is a combination of attributes describing the fundamental areas of technical challenges to resource development.

- **Resource Access:** Consideration of physical barriers to reach a resource (e.g., weather, topography, elevation/slope, volcanic hazards), requiring advanced or specific tools or materials that potentially increase project costs.
- **Heat Extraction**: Technologies for permeability stimulation, downhole pump capabilities, and the availability of external fluid for recharge are all critical to determining how much heat may be extracted from the reservoir.
- **Power Conversion**: Specific generation technologies, such as for low temperature systems or EGS, as well as component technologies, such as air cooling, are all influential in determining whether the geothermal heat extracted can be efficiently and economically put to use for power generation.
- **Drilling:** The reservoir depth and rock properties strongly determine drilling and project development costs.

Socio-Economic Grade Attributes

Socio-economic Grade attributes describe a resource's characteristics, such as land access, transmission availability, and local demand, which are unrelated to the subsurface.

- **Land Access**: Leasing and real estate laws and policies, as well as local opposition, add additional complexity to beginning and/or continuing resource development.
- **Permitting**: Permitting requirements, certainty, complexity and timelines can vary from location to location. Challenges in obtaining the necessary permits can create the potential for temporary or permanent delays in resource development.
- **Transmission**: Existing transmission lines may be far from potential geothermal areas, and even if they exist, they may require costly upgrades to take power generated from a new geothermal development.
- **Demand**: The appetite for new power, demonstrated by utility willingness to sign power purchase agreements, can be seen as a proxy for project competitiveness in comparison to other energy-generating options.

Attribute Indices

The GRRM Protocol expands upon the concept of grade by considering not only the attributes listed above, but also how the attribute is measured, and what is known about the quality of the data collected. We break each attribute into three separate indices describing distinct features of each attribute:

- **Character Grade**: Describes the character itself – i.e., what is the intrinsic measurement that best describes the geothermal reservoir?
- **Activity Index**: Qualitatively ranks activities used to assign the character index appropriate for each attribute – i.e., how well is the level of this attribute grade known?
- **Execution Index**: Compares the diligence with which the technique was executed for a given activity – i.e., how much do we know about the quality of execution of that technique?

Just as each attribute is assessed independently from other attributes for the purpose of the Protocol, these indices are also independently evaluated for each attribute. The GRRM Protocol Background Document (Young et al., 2015b) gives an overview of the concepts of Character, Technique and Execution Indices. For more detail on these indices, please see the Assessment Tool documents of the GRRM Protocol (Young et al., 2015b).

Character Grade

For each attribute, the *Character Grade* uses quantitative and qualitative measurements describing the current project within the range of possible outcomes encountered in geothermal resources and projects. For example, a resource with a high temperature measurement is given a temperature character grade of A, while a resource with a low temperature would be assigned a temperature character grade of E. Table 1 lists the proposed character grades for selected attributes associated with the Geological Grade. Similar tables associated with the Technical and Socio-Economic Grades are being developed and reviewed at the time of this publication (June 2015).

Table 1. Character Grades of Geological Attributes.

	Temperature	Volume	Permeability	Fluid Chemistry
A	>300°C or steam	>20 km^3	Very High	Ideal
B	230 - <300°C	>10 - 20 km^3	High	Favorable
C	150 - <230°C	>5 - 10 km^3	Medium	Challenging
D	90 - <150°C	>2.5 - 5 km^3	Low	Difficult
E	<90°C	<= 2.5 km^3	Very Low	Acidic/Caustic

Activity Index

The *Activity Index* describes the common activities used to understand the character attributes - both directly (measured values) and indirectly (by proxy). For example, exploration methods to evaluate temperature include remote sensing, surface hydrothermal manifestations surveys, geothermometry, and downhole temperature measurements. The GRRM Protocol lists the techniques and their associated index values, ranked by the likelihood that the techniques represent the actual attribute being described.

We expect that exploration programs will use more than one technique for estimating an attribute's character and therefore the criteria developed accommodate such combinations. Table 2 provides an example of activity indices for the temperature attribute. Details of the activity indices for all attributes are provided within the related Assessment Tools of the GRRM Protocol (Young et al. 2015b); for example, the Geological Assessment Tool describes the activity indices for the temperature, permeability, volume and fluid chemistry attributes.

Table 2. Activity Indices of the Temperature Attribute.

	Temperature Technique Indices	
A	Measured temperatures:	Downhole temperature probe readings (well(s) drilled into reservoir)
B	*Estimated temperatures:*	Geothermometry (geothermal brines and gases)
C	*Estimated temperatures:*	Geothermometry (immature or mixed fluids, inconsistent results between geothermometers)
D	*Extrapolated temperature:*	TGH/well(s); alteration mineral assemblages; stable isotope or fluid inclusion compositions
E	Regional heat flow data	

Table 3. Execution indices of the Temperature Attribute for the activity Subsurface Temperature Probe Readings.

	Temperature Execution Indices
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	• Results taken from previous third-party studies of the area (either from literature or contractors) with little or limited information on survey methods, replication, or error.
D	• Probe *not* allowed to equilibrate. • Cuttings and/or geophysics have *not* confirmed measurement within the reservoir.
E	• Assumed from studies of analogous geothermal settings, or extrapolated from studies of nearby areas.

Execution Index

The *Execution Index* describes how well an activity was implemented. Potential errors and uncertainties in data collection may be associated with certain information sources. For each technique used to measure an attribute, the execution indices reflect an understanding of how much is known about the data, and provide a baseline understanding of how the data were verified in relation to the best practices associated with a given technique.

For example, results of sulfate-water oxygen isotope geothermometry could show little variation, resulting in temperatures with few outliers and suggesting high confidence in the results. However, these 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 less reliable. In this case, a moderate value of the execution index could be assigned to represent this mixed confidence in the geothermometry conclusions. Table 3 provides an example of execution indices for one activity (subsurface temperature probe readings) used to estimate temperature.

Visualizing Resource Grades

Resource grades can be visualized using a polar area chart (Figure 1), where each quadrant represents one of the four attribute grades for a category and is subdivided to show the values for the character, activity, and execution indices.

The diagram allows for quick assessment of the strengths and weaknesses of an area by scanning the darkly shaded wedges. In Figure 1, the temperature and volume resource grades of the reservoir are high, the permeability is about average, and the fluid quality/quantity is low.

By reviewing the lightly shaded areas, one can get a glimpse of the certainty of these values and understand where additional work may be needed to better understand the geothermal system. For example, the lightly shaded areas in Figure 1 show uncertainty in volume and fluid permeability.

In the context of GTO's need for metrics, the polar area chart 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. For example, GTO could be able to clearly identify whether changes in the reported temperature are due to better measurements from new techniques. The chart allows users to quickly identify increases in information from one period to the next and may illustrate differences between seemingly similar projects (e.g., two projects with the same character indices may have vastly different activity and execution indices).

Each of the three categories (geological, technical, socio-economic) will have its own, similar polar area chart showing the respective character grade and certainty wedges. The color key for each of these charts is shown in Figure 2. Detailed polar area charts for each category are provided in the Protocol documents (Young et al., 2015b).

All of the character attributes can be shown on a single summary chart (Figure 3). This chart shows only the character grades – not the activity or execution indices. Therefore, no uncertainty is illustrated in this figure.

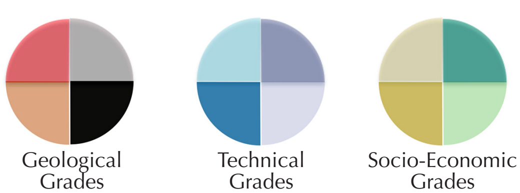

Figure 2. Color key for the polar area chart for each of the three categories: geological, technical and socio-economic. Each quadrant represents a different attribute and will be subdivided to show the character, activity, and execution index values. For detailed polar area charts for each category, see the Assessment Tools of the GRRM Protocol (Young et al., 2015b).

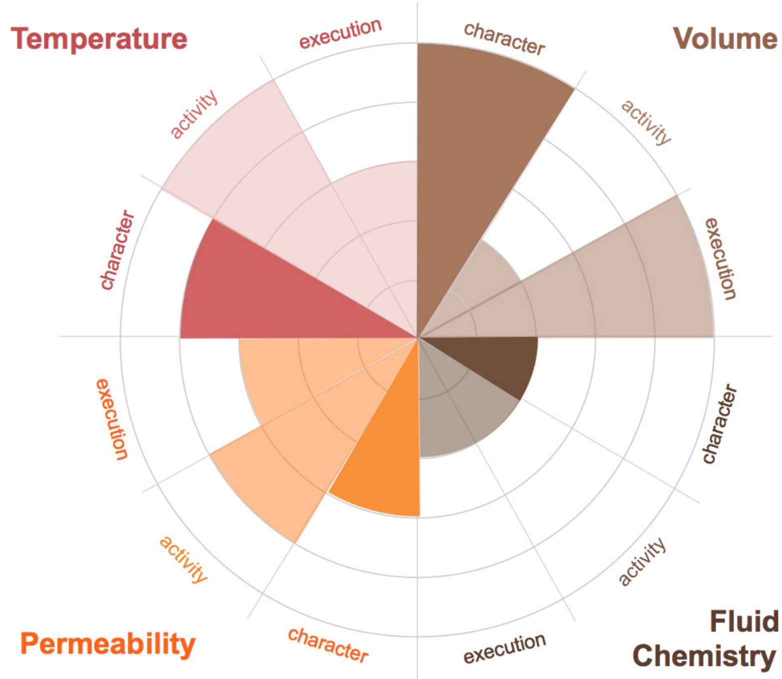

Figure 1. Example grade visualization of a hypothetical resource using a polar area chart showing the four geological attributes. Each quadrant represents a different geological attribute and is subdivided to show the character, activity, and execution index values. The darkly shaded wedges indicate the grade of the four resource attributes, while the lightly shaded wedges indicate certainty (activity and execution). E is located at the center of the circle, and A is located along the circumference of the circle – the larger the shaded area, the better the resource.

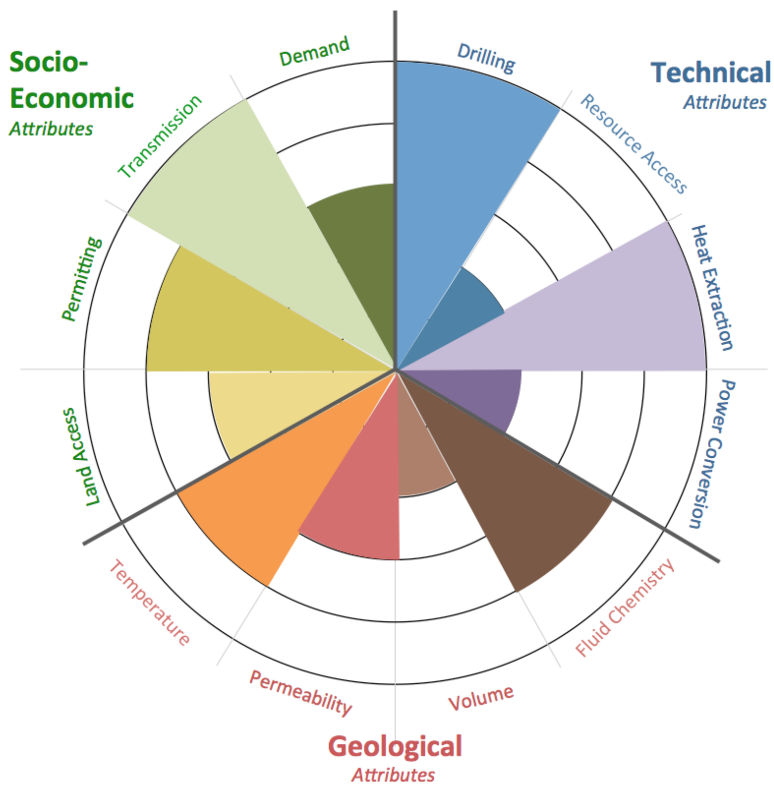

Figure 3. Summary Resource Grade Chart. The character grades for each of the twelve resource attributes are displayed in a single polar area chart. E is located at the center of the circle, and A is located along the circumference of the circle – the larger the shaded area, the better the resource. Since activity indices and execution indices are excluded from the diagram, no uncertainty is depicted.

V. Project Progress

Like geothermal grade, the GRRM breaks the concept of project progress into three assessments: geological, technical, and socio-economic. As projects progress from one phase to the next, they pass through "activity thresholds" – minimum activities required to qualify for the next project progress category. For example, the difference between an undiscovered resource and inferred resource is the completion of some form of field sampling.

Defining Project Progress

Project Progress is defined for each of the three assessment categories: geological, technical, and socio-economic. For each category, five levels of project progress are defined, with 5 representing the most advanced level of development. This section describes only the major concepts of the project progress levels. Further details on their application to projects can be found in the related geological, technical, and socio-economic Assessment Tools of the GRRM Protocol (Young et al., 2015b).

Geological Progress

The *Geological Progress* scale describes exploration activities at a project location. The scale is meant to indicate the amount of activity that has occurred in an area, and not whether or not those activities found a geothermal resource. The geological scale only allows forward movement because these exploration activities are not un-done at a location. The geological progress scale, and associated criteria, is shown below. For more detailed descriptions of the scientific reasoning behind selecting each step, please see the Geological Assessment Tool of the GRRM Protocol (Young et al., 2015b).

	Geological Progress		Qualifying Criteria
1	**Undiscovered**		For a resource to be considered "Undiscovered," the potential is estimated by *at least one* of the following activities: • field mapping - structural, surface manifestations, etc. • shallow heat flow studies (two-meter probe) • extrapolation of third-party data • remote sensing
		Field testing/sampling	
2	**Identified**	**Inferred**	For a resource to be considered "Inferred," *both* of the following criteria must be met: • Temperature is estimated using *at least one* of the following methods: – well-executed geothermometry – thermal gradient holes • Conceptual model of the reservoir is supported by data from surface geophysical surveys
		Slim / core hole into the reservoir	
3	**Identified**	**Measured**	For a resource to be considered "Measured," *all* of the following criteria must be met: • Temperature is measured at the reservoir level using a downhole probe in slimhole(s) drilled into the reservoir. – Temperature is corroborated using at least one of the following methods: – Downhole geothermometry • Assessment of lithology and mineral assemblages taken from cores and/or cuttings
		Full-diameter well / well test	
4	**Identified**	**Tested**	For a resource to be considered "Tested," *all* of the following criteria must be met: • At least one full-diameter well has been drilled • The reservoir permeability has been evaluated with *at least one* of the following methods: – flow tests and/or – pressure build up/draw down
		Multiple full-diameter wells drilled	
5	**Identified**	**Examined**	For a resource to be considered "Examined," the following criteria must be met: • Two or more full-scale wells must be drilled and flow tested

Technical Progress

The *Technical Progress* scale measures specific technical milestones in the development of a geothermal project. These technical milestones are chosen to mark technical progress for each project's phase; for example, testing of a well or a reservoir that produces sufficient flow for the project goals. Projects can also move backwards along this scale if, for example, the reservoir no longer produces at the anticipated rate. The Technical Assessment Tool of the GRRM Protocol, currently (as of June 2015) in early stages of development and review, will provide more detailed descriptions of the decision logic behind selecting these criteria (Young et al., 2015b).

Socio-Economic Progress

The *Socio-Economic Progress* scale measures specific socio-economic milestones in the development of a geothermal project. These milestones mark success at each phase, for example permitting of a well or a reservoir, completion of environmental analyses, or completion of a power purchase agreement. Projects can also move backwards along this scale if, for example, the power purchase agreement falls through. The Socio-Economic Assessment Tool of the GRRM Protocol, currently (as of June 2015) in early stages of development and review, will provide more detailed descriptions of each step (Young et al., 2015b).

Visualizing Project Progress

Project progress can be visualized on a three-dimensional project development grid, with geological progress shown on the x-axis, technical progress on the y-axis, and socio-economic progress on the z-axis, as shown in Figure 4. Each project can be represented as a cube within this grid, and can move independently along each of the three axes as project development progresses.

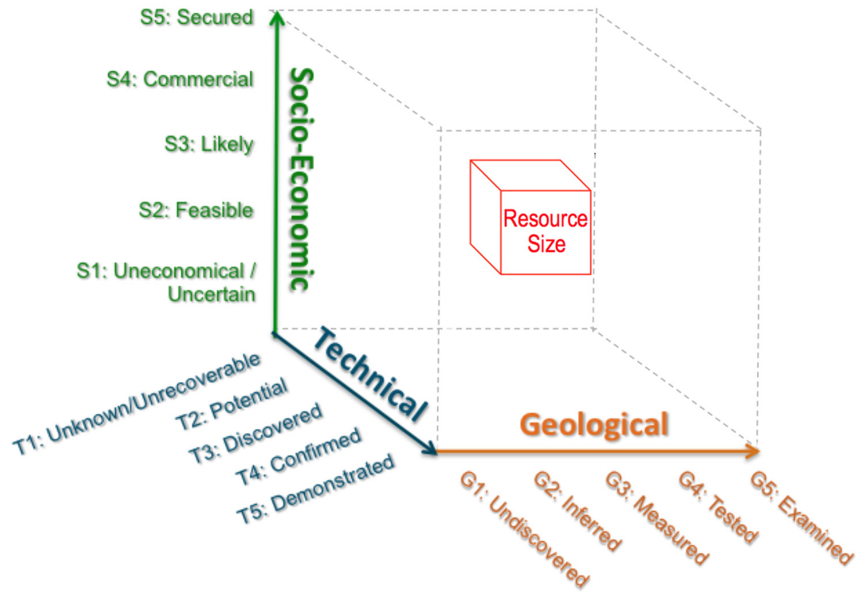

Figure 4. Project Development Grid. Each of the three categories is represented along an axis. Geological progress is shown on the x-axis, technical progress is shown on the y-axis, and socio-economic progress is shown on the z-axis. Each project can be represented as a cube within this grid, and can move independently along each of the three axes as project development progresses.

VI. Resource Size

The quantity of recoverable heat for a geothermal resource – the resource size – is often calculated in early stages of project development using the USGS heat-in-place volume method (Williams et al., 2008a). While its accuracy has been debated, suggestions have primarily focused on revisions of the assumptions, and not on fundamental changes to the concept (e.g., Garg and Combs, 2015).

The Resource Size Assessment Tool of the GRRM Protocol (Young et al., 2015b) contains information for providing consistent resource size estimates to GTO across all projects. As more information is gathered at a geothermal location during the process of exploration, conceptual and numerical reservoir models are typically constructed, integrating multi-dimensional reservoir characteristics.

The Protocol allows for the reporting of resource size in several different units, including Joules, BTUs, MWt, and MWe (assuming certain conversion efficiencies). This diversity allows for the variety of potential geothermal end uses, from direct-use applications, such as space heating and drying applications, to electricity production.

VII. Applications

This reporting Protocol is written for use by the GTO. The methodology is intended to be sufficiently technical to be of use to industry professionals, and to the GTO in developing metrics, setting baseline values, evaluating funding applications, and in summarizing and reporting results. Therefore, the language in the Protocol documents is also intended to be understood by non-technical audiences, including the U.S. Congress and the general public.

For individual GTO project managers, identifying resource grade and project progress at a given location are important to understanding the success of emerging technologies. This Protocol provides a comparable basis for evaluating projects based on three components of resource grade: geological, technical, and socio-economic. This type of grading system, previously non-existent in the geothermal industry, is critical to conveying the impacts of GTO research.

For GTO decision makers, identifying overall portfolio success is key to justify ongoing RD&D funding and to target future funding efforts. Differentiating geothermal resources by resource grade allows for selecting research areas directed at overcoming the largest barriers, impacting the greatest amount of resource. Objectively and quantitatively reporting project progress is critical to convey the impacts of GTO's efforts.

VIII. Conclusions and Next Steps

The GTO is required to track and report on the impacts of public funding on technology research, development, and deployment. Initial progress has been made in developing a geothermal resource reporting methodology to aid in these tasks. This paper briefly reviews the concepts of the methodology in its current status, and provides the framework for how these concepts are recorded at different stages of geothermal exploration and development.

The next steps for this project (June through September 2015) include updating the Geological Assessment Tool Protocol document (Young et al., 2015b) based on feedback received during the May 2015 GTO Peer Review (Westminster, CO), to be posted for additional review and comment in July 2015. We also plan to vet early drafts of the Technical and Socio-Economic Assessment Tools through in-person discussions, workshops, and draft document comments.

In 2016, if funding is received, we plan to finalize the Technical and Socio-Economic Assessment Tools and begin the trial period. During this period, the Protocol will be tested on GTO's previous and current portfolio of RD&D projects, and refined, as necessary, to overcome any issues identified in implementation of the Protocol. We welcome any feedback and suggestions from all stakeholders.

The information provided in this paper and the discussed Protocol (Young et al., 2015b) is currently under review. We plan to continue to test and update these materials throughout 2016.

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), Brittany Segneri (New West Technologies), 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 Recovery and Reinvestment Act [ARRA] of 2009**,** Pub. L. No. 111-5, 123 Stat. 115, 516,Feb. 19, 2009. http://www.gpo.gov/fdsys/pkg/PLAW-111publ5/html/PLAW-111publ5.htm.

DiPippo, R., 2004. Second Law assessment of binary plants generating power from low-temperature geothermal fluids. Geothermics. 33, 565–586.

Garg, S.K. and Combs, J.,2015. A reformulation of USGS volumetric "heat in place" resource estimation method. Geothermics, 55,150–158.

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.

McKenzie, W.F., and Truesdell, A.H., 1977. The Oxygen Isotope Compositions of Dissolved Sulfate and Water From Hot Springs and Shallow Drillholes. Geothermics, 5, 51–61.

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. http://www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/pub/UNFC2009_Spec_ES42.pdf.

United Nations Economic Commission for Europe and International Geothermal Association [UNECE and IGA], 2014. Memorandum of Understanding. http://www.unece.org/fileadmin/DAM/oes/MOU/2014/MoU-UNECE_IGA.pdf.

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

Young, K.R., Wall, A.M., Dobson, P.F., Bennett, M., and Segneri, B., 2015a. *Measuring Impact of U.S. DOE Geothermal Technologies Office Funding: Considerations for Development of a Geothermal Resource Reporting Metric*. 2015 World Geothermal Congress, Melbourne, Australia, paper 16071, 15 pp.

Young, K.R., Wall, A.M., and Dobson, P.F., 2015b. *Geothermal Resource Reporting Methodology Protocol.* Draft 2015.