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Geothermal Play Fairway Analysis: Phase I Summary

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ABSTRACT

The United States Department of Energy Geothermal Technologies Office released a Funding Opportunity Announcement in 2014 targeting studies to collect data in unexplored or underexplored regions, generate geothermal development favorability maps, and demonstrate methodology to quantify uncertainty. Eleven projects were selected for cooperative agreement awards. After a period of performance of one year, during which only existing data could be evaluated, each awardee presented project results for a competitive Downselect following the completion of Phase I. This paper summarizes and reviews the outcomes of Phase I activities. A comparison of play definition, Risk Factor development, Common Risk Segment Map construction, uncertainty quantification, Favorability Map generation, identification of areas for follow up work, and a preliminary application of the Geothermal Resource Reporting Metric is presented.

1. INTRODUCTION

The United States Department of Energy Geothermal Technologies Office released a Funding Opportunity Announcement (FOA) in 2014 targeting studies to collect data in unexplored or underexplored regions, generate geothermal development favorability maps, and demonstrate methodology to quantify uncertainty. Phase I activities utilized existing data only and were carried out over a year-long period of performance from October 2014-October 2015. The FOA specified a Phase I focus on techniques of data integration, GIS/map format representation, methods of uncertainty quantification, ranking/grading process, and identification of data gaps (Figure 1).

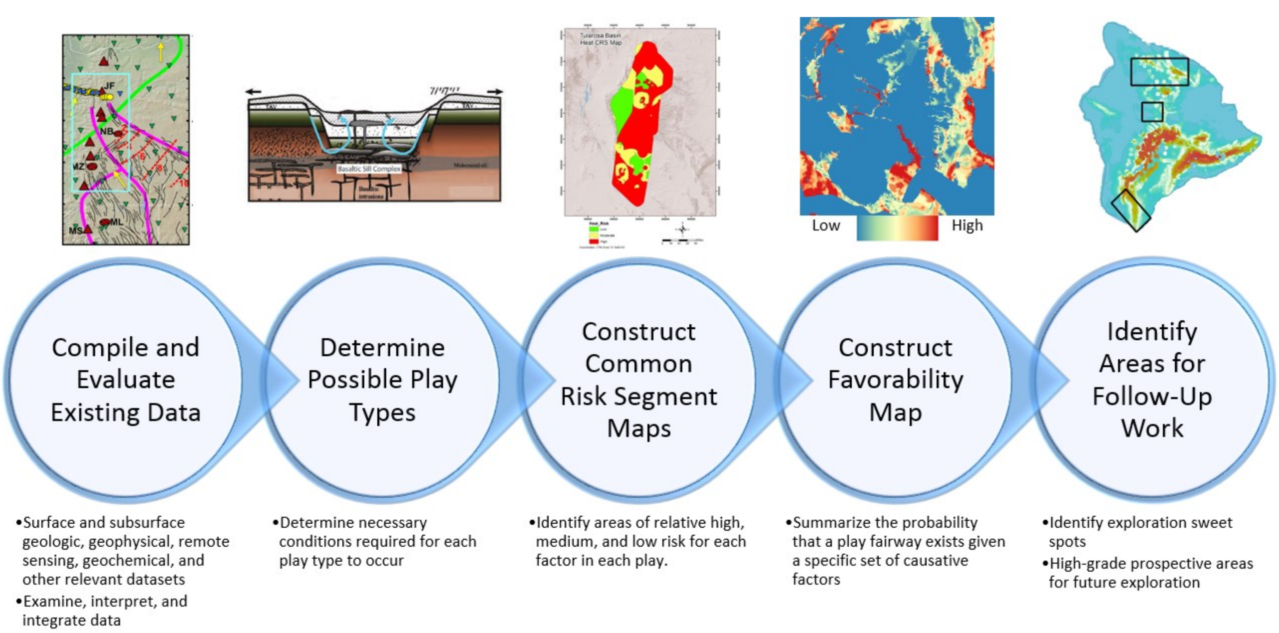

Figure 1. Flow chart showing the general steps of Play Fairway Analysis. Examples of each step are shown graphically above, and as bullets beneath each step. Please refer to each project individually for specific details—not all Phase I awardees followed the order shown in this figure.

Awardees were asked to elaborate on the value added by their work, how industry could use the results, and the expected operational and economic impact of concentrating future exploration efforts on the areas identified. More information about the FOA, proposed work, and initial progress of the 11 projects selected can be found in Weathers et al, 2015.

2. OUTCOMES TO DATE

2.1 Definition of Play

Awardees were asked to define the types of geothermal plays anticipated in their respective areas of study, as well as the commercial viability of the play (DE-FOA-00000841). A geothermal "play" is the "combination of unique geophysical, geologic, structural and/or stratigraphic elements that have resulted in a geothermal resource," and may be based on known geothermal systems or concepts (Notice of Intent, DE-FOA-00000841).

In general, awardees defined a geothermal play as being some combination of heat, permeability and fluid, although other factors, such as a seal, land access, or depth, were included in the play definition by some awardees (Figure 2). Many awardees also included a play category, for example "Basin and Range", "transitional", or "transtensional strike-slip".

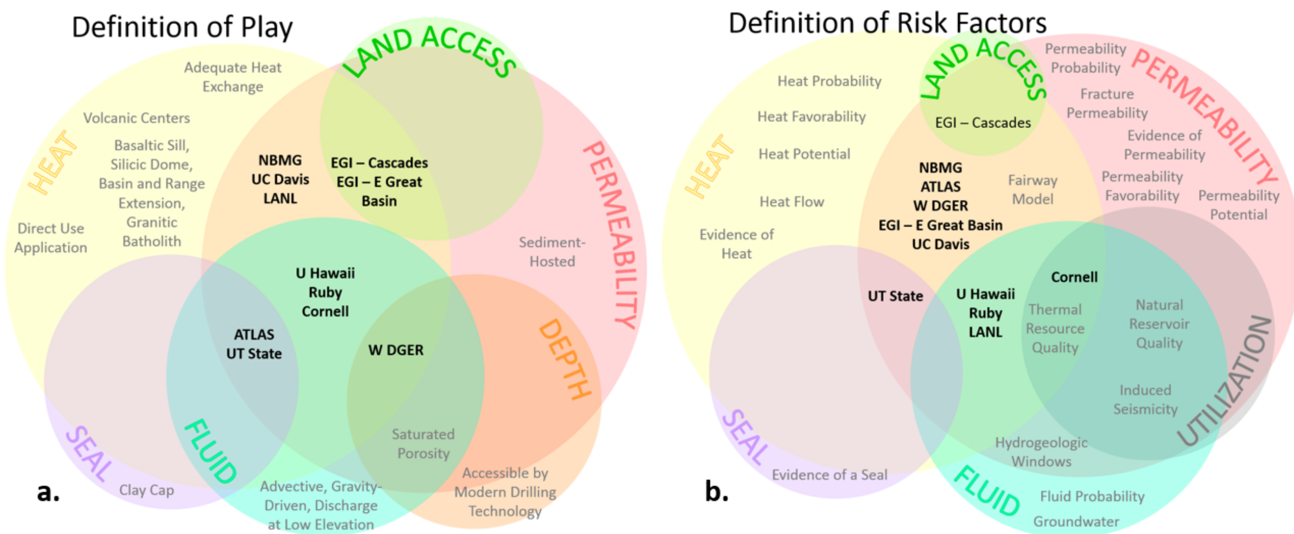

Figure 2. Venn diagrams showing the overlap of several categories of concepts that were used to define (a.) a geothermal play and (b.) Risk Factors. Awardees are indicated in black text; examples of concepts are indicated in gray text. Categories defining play and Risk Factors are nearly identical ("depth" is exchanged for "utilization"). Roughly half of the awardees shift categories between definitions, the rest remain in the same categories.

2.2 Risk Factors

The analysis required to describe geothermal favorability can be broken down into two steps: 1) the development of Risk Factors, and 2) the combination of Risk Factors. A Risk Factor is a concept that describes geothermal favorability viewed from the value of information perspective. For example, the specific aspect of heat—perhaps a combination of heat flow and geothermometry—that delineates the difference between a prospective area and an area that is not favorable.

In general, Risk Factors were developed by defining relationships between inputs that were indicative of favorable geothermal conditions. Which inputs were used, the method of evaluating and/or combining inputs, and which conditions were considered essential to defining favorability varied widely. Some examples of the Risk Factors that were developed are "heat potential," "degree of exploration," and "seal evidence" (Figure 2).

Risk Factors were generally combined by weighting, with the weights based on expert input or data confidence. In some cases the Risk Factors were converted to numerical inputs and the combination of Risk Factors was a numerical favorability score. In other cases the Risk Factors were graphically overlaid, and the combination represented the spatial extent of a particular favorability category.

The ultimate result of combining Risk Factors is visualized as a Common Risk Segment Map. Most projects created multiple Common Risk Segment Maps, typically one for each category considered in the play definition. For example, one Common Risk Segment map for heat favorability, one for permeability favorability, and one for fluid favorability.

2.3 Uncertainty Quantification

The way awardees handled uncertainty quantification fell into four categories: 1) evaluation of input data, 2) evaluation of the development of each Risk Factor, 3) evaluation of the development of each Common Risk Segment Map, and 4) evaluation of the development of the Favorability Map.

Input data uncertainty was judged by the spatial coverage, resolution, collection methods, recency of collection, and presence of multiple co-located datasets. Every project used expert knowledge to evaluate data or outcomes at some level. A variety of approaches, including Bayesian analysis, Fuzzy Logic, Multi-Criteria Decision Making, and "expert elicitation" were used to grapple with data scarcity and reliability in data inputs. In some cases, data inputs were weighted, a heavier weight representing more reliable or complete data inputs.

Uncertainty in individual Risk Factors was generally handled by weighting the Risk Factor. In some cases, a separate uncertainty map for each Risk Factor was constructed. Some awardees made a separate Uncertainty Map to accompany the Common Risk Segments Maps or Favorability Map, while others rolled uncertainty into these maps by lowering the favorability ranking of areas with less certain data.

2.4 Favorability Map

The Favorability Map is the ultimate deliverable of Play Fairway Analysis. The Favorability Map shows the range of favorability over the study area based on the Play Fairway Analysis, and highlights area of interest for follow-up work. Many awardees submitted maps using a graduated color scale over the entire area of study to show favorability, and outlined areas for follow-up studies in a contrasting color. Other awardees identified solid-filled polygons of graduated color, or points of graduated color to represent the range in favorability. Some awardees chose a rainbow color scheme where red indicated high favorability (grading to blue for lower favorability); others used a stoplight-type color scheme where green indicated high favorability, yellow medium favorability, and red low favorability. Color schemes and symbology for the Favorability Maps shown in Figure 3 have been standardized for this report.

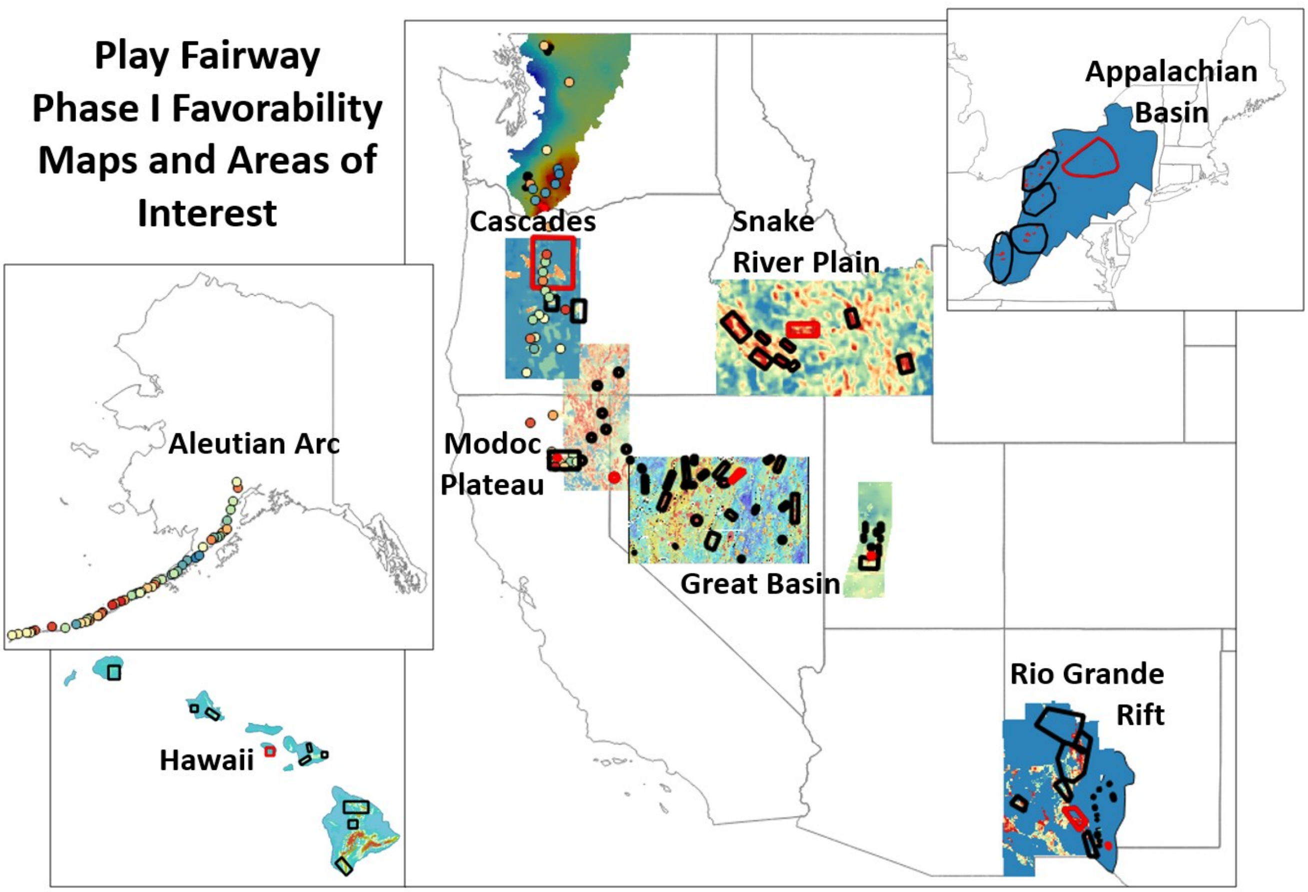

Figure 3. Summary map of the United States showing the Favorability Maps (colors standardized) from each of the 11 Play Fairway projects. Red-orange indicates high favorability, yellow-green is medium favorability, and blue is low favorability. Areas of interest for follow up work are outlined in black. One area of interest from each project is outlined in red—these are the areas used for the initial GRRM analysis. Please refer to individual project reports and awardee publications for more details about project specifics. The 6 projects being negotiated for Phase II activities are shown in Table 1.

2.5 Areas for Follow-Up Work

Awardees identified a total of 96 areas for follow-up studies. Each project considered multiple follow-up areas—anywhere from 3 to 24 areas per project. Most projects ranked a handful of areas of interest on a scale from most favorable to least favorable; a few summarized all possible areas. These areas of interest represent the first pass at identifying play fairways. Additional exploration data will be collected in Phases II and III to fill data gaps, refine methodology, define play fairways, and identify prospects within each play

Award Number	Study Area	Awardee	Select Area of Interest for Preliminary GRRM Analysis	Selected for Phase II
EE0006725	Cascades & Aleutians	ATLAS Geosciences, Inc.	Sugarloaf	No
EE0006726	Appalachian Basin	Cornell University	Corning-Ithaca	No
EE0006727	Central Cascadia Back-Arc	University of Utah - EGI	Near Mt Jefferson (to N and E)	No
EE0006728	Washington Cascades	Washington Department of Geology and Earth Resources (W DGER)	Wind River Valley	Yes
EE0006729	Hawaii	University of Hawaii	Lanai (G)	Yes
EE0006730	Tularosa Basin	Ruby Mountain Inc.	McGregor Range	Yes
EE0006731	Central Nevada	Nevada Bureau of Mines and Geology	Crescent Valley	Yes
EE0006732	Eastern Great Basin	University of Utah - EGI	Cinder Knoll	Yes
EE0006733	Snake River Plain	Utah State University	Camas Prairie - Mount Bennett Hills (B-1)	Yes
EE0006734	Modoc Plateau	University of California Davis	Bonham Ranch	No
	Southwest New Mexico	Los Alamos National Lab (LANL)	Rincon	No

fairway.

Table 1. Summary of Phase I study areas, awardees, select areas for follow-up studies, and status regarding Phase II. The areas for follow-up studies listed here are used for the preliminary GRRM analysis.

3. GRRM BASELINE GRADES

Awardees were asked to identify area of interest for this study (Figure 3, Table 1). These areas were used as case studies to test the Geothermal Resource Reporting Metric (GRRM) being developed at NREL (Young et al 2015 publications and Badgett et al 2016). The GRRM is a tool that aims to capture the state of knowledge of a geothermal resource in terms of geologic, technical, and socio-economic

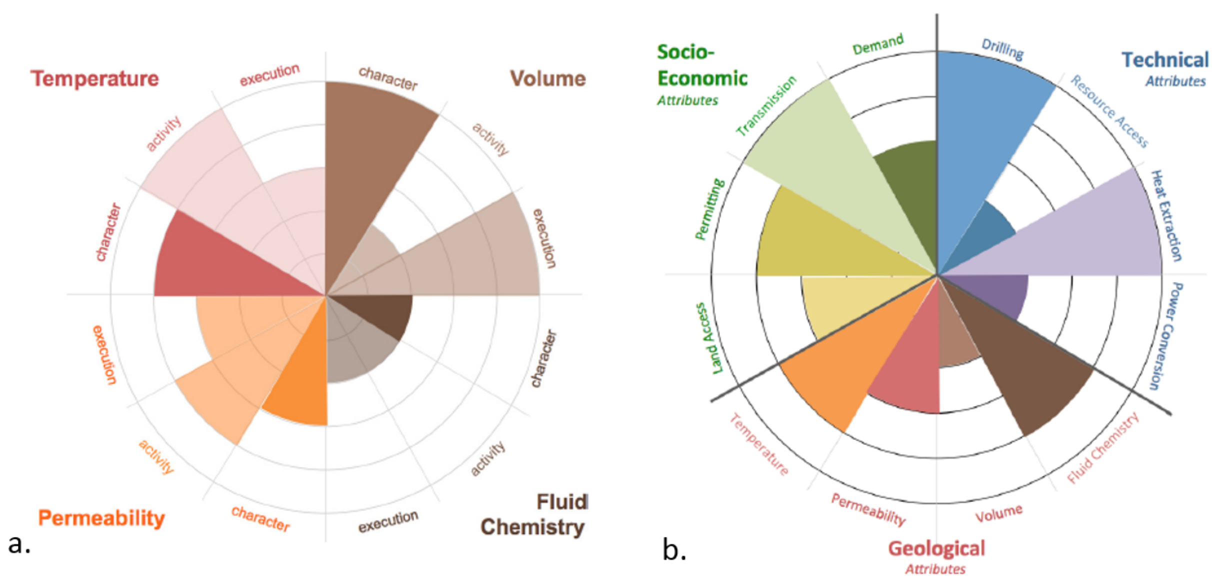

Figure 4. From Young et al, 2015 a.) Example grade visualization of a hypothetical resource using a polar area chart showing the four geological attributes. Each quadrant represents a different geological attribute and is subdivided to show the character, activity, and execution index values. The darkly 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. b.) 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.

categories. This metric provides a holistic view of a resource in terms of all the factors that could affect development: land access, permitting, transmission, energy demand, past drilling, drilling logistics, heat extraction technology, power conversion, resource temperature, reservoir permeability, reservoir volume, fluid chemistry etc. The grades assigned by the metric may be visualized with a polar area chart that shows the grade and associated uncertainty (character, activity, and execution) for each Category, or by a Summary Resource Grade Chart, which shows character grades without depicting uncertainty (Figure 4).

This study presents a preliminary GRRM assessment of one area of interest from each of the eleven projects, with the caveats that: information is entered into the metric as reported by awardees in the Phase I Report (no outside research was done), the metric is in a state of ongoing refinement, and individual project documentation often does not address all metric components. Where reported data did not satisfy the metric, and educated guess was made; where data was altogether absent, no grade was assigned. This baseline analysis represents a way to visualize and track project progress over time. Incremental improvements in the understanding of a specific attribute or sub-attribute can be captured as a project moves from beginning to end. In the case of Play Fairway projects, DOE may track the outcomes of funding by noting how the categories change before and after funding. For awards completing multiple Phases, a GRRM analysis could be completed at the beginning of the project (i.e. in the application for funding) and at the end of each subsequent Phase as part of the Phase or Final Report.

Preliminary grades for each area of interest in each category are shown in the Summary Resource Grade Charts of Figure 5. This assessment is separate from and should not be confused with the competitive Downselect Criteria described in DE-FOA-00000841 that was used to decide which projects would continue to Phase II.

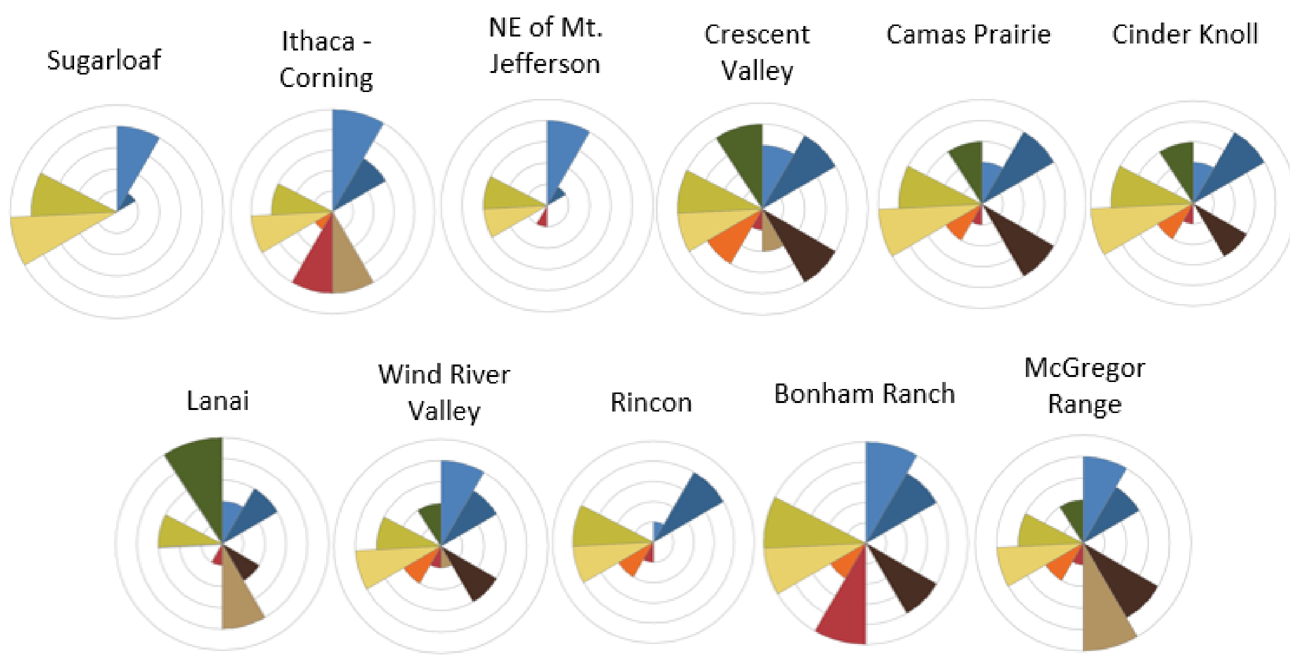

Figure 5. Preliminary GRRM grades for the eleven Play Fairway projects at the end of Phase I. Four attributes and many sub-attributes of the Geologic, Technical, and Socio-Economic categories were examined. Information represents what awardees have documented in their Phase I Reports, as well as educated guesses by the author. Some grades were left blank due to lack of data.

A few takeaways from this initial application of the GRRM are that many of the factors the GRRM measures were not reported by awardees, and that the sub-attribute grades for a given attribute vary widely in all categories. In particular, the "Permeability" attribute received consistently low grades from 9 out of the 11 projects scored.

4. SUMMARY AND CONCLUSIONS

This paper provides an overview and meta-analysis of Play Fairway Analysis projects at the end of Phase I. A summary of the gamut of Play Fairway Analysis approaches and methodologies employed in the 11 projects is presented. Additionally, an initial GRRM assessment of the current state of knowledge of one area of interest from each project has been conducted. More specific details about each individual project can be found in project reports and awardee publications. Six projects will continue to Phase II. Phase II activities will include new data collection and refinement of each project's methodology and Favorability Map.

GLOSSARY

Fairway: area within the study area that has the highest probability of success.

Favorability Map: a map showing the range of favorability (low-high) over the study area based on the Play Fairway Analysis. Areas that are highly favorable could logically be considered prospects for follow-up work.

Geothermal Play Fairway Analysis: a process of identifying areas of geothermal prospectivity for further study that narrows a basin- or regional-scale area of interest to several smaller areas of interest. Areas for follow-up work are defined by the quality and interpretation of existing data, and the consideration of other factors such as land access and economic development feasibility.

Geothermal Resource Reporting Metric (GRRM): a tool that aims to capture the state of knowledge of a geothermal resource in terms of geologic, technical, and socio-economic factors. Grades of A-E are assigned to each Attribute, Sub-Attribute, Activity Index, and Execution Index within each factor. The metric is currently being developed and is in a state of ongoing refinement. See Young et al and Badgett et al publications for more information.

Play: the combination of unique geophysical, geologic, structural and/or stratigraphic elements that have resulted in a geothermal resource. The occurrence model or set of conditions that define geothermal prospectivity. May be based on known geothermal systems or concepts.

Play Fairway: the area in a basin or region where examples of an individual play type are projected to exist and is defined by the geologic characteristics of the basin and of the play type.

Risk Factor: a concept that describes geothermal favorability viewed from the value of information perspective. For example, the specific aspect of heat—perhaps a combination of heat flow and geothermometry—that delineates the difference between a favorable area and an area that is not favorable.

Study area: geographic location of the basin- or regional- scale area of interest.

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