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Innovative Exploration Technologies: A Retrospective

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ABSTRACT

The mission of the Hydrothermal Program of the Geothermal Technologies Office has been to reduce exploration, development, and deployment risk by improving the characterization of the subsurface in pre-drilling and preliminary borehole exploration technologies. Historically, the "success" of DOE-funded geothermal exploration efforts has been measured and reported in variable ways. These have included: the ability of a project to meet its self-defined goals, objectives and deliverables; and the degree to which a project advances the state of knowledge in a particular area. Moving toward a way to evaluate project success in a more quantifiable sense is desirable. This paper provides an overview of recent efforts to evaluate the success of Innovative Exploration Technology (IET) projects that were funded through the American Recovery and Reinvestment Act (ARRA) between 2009 and 2015. This effort expands upon outcomes and impacts conversations with the Technical Monitoring Team, as well as the Exploration task of the Geothermal Vision Study that is currently underway. This effort aims to summarize, categorize, and evaluate the proposed work, completed work, and lessons learned for each of the 25 IET projects. This paper provides an introduction and preliminary progress on the IET retrospective—more comprehensive results and analysis will be incorporated in the forthcoming Geothermal Vision Study and potentially other future publications.

1. INTRODUCTION

The U.S. Department of Energy issued a Financial Assistance Funding Opportunity Announcement (FOA) entitled "Recovery Act: Geothermal Technologies Program" on May 27, 2009. DE-FOA-0000109 included three topic areas: 1) Validation of Innovative Exploration Technologies (IET); 2) Geothermal Energy Production from (a) Low Temperature Resources, (b) Coproduced Fluids from Oil and Gas Wells, and (c) Geopressured Resources; and 3) Geothermal Data Development, Collection, and Maintenance. This study focuses on evaluating the results of Topic 1.

The intent of IET was to reduce early stage exploration risk by funding "activities to locate undiscovered geothermal systems and increase the reliability of site characterization to prioritize sites for energy production." Proposed "innovative site characterization techniques" included: geophysical studies, geochemical studies, geologic models and tools, temperature gradient holes, remote sensing, and data processing." Validation of innovative exploration technologies would be accomplished by identifying "undiscovered geothermal resources and confirming geothermal resource capacity by drilling and characterizing slimhole geothermal exploration wells." Production drilling was also permissible, with the caveat of satisfying the Recovery Act program policy factor to create/preserve jobs in an expeditious manner, given the typically long time periods often associated with any necessary environmental assessment work. Projects were required to include plans to drill at least 2 wells.

Project management was divided into as many as 3 phases: I) Resource Evaluation, II) Drilling, and III) Well Testing. Phase I was envisioned to include geologic field work and interpretation, geophysical survey acquisition and processing, geochemistry sampling and analyses, geomechanical studies, drilling of temperature gradient wells, remote sensing, and any other appropriate surface studies, acquisition and reanalysis of previously collected data, and integration of the results. By the end of Phase I, awardees were expected to have selected target locations by incorporating innovative techniques for exploration, and to have identified the required permits to move forward. Phase II was contingent on NEPA regulations and envisioned to include site access and development, rig mobilization and de-mobilization, drilling, mud logging, casing and cementing, coring, running geophysical or production logs, limited flow testing, fluid sampling work, and other appropriate drilling/well-related activities and evaluations. By the end of Phase II, awardees were expected to evaluate the resource. Phase III was envisioned to include acquisition/rental of appropriate well and surface equipment for an extended flow test, appropriate logging, sampling and monitoring of the testing, interpretation of the test data, integration of the well-test results with the previous geological, geothermal, and hydrological models, validation of innovative exploration technology/method, and final assessment of the site capacity for head extraction from the geothermal resource. By the end of Phase III, awardees were to quantify the amount of additional resources discovered by drilling.

The FOA was open for 56 days; final applications were due on July 22, 2009. Following the standard EERE Merit Review process, the Merit Review Committee recommended applications to be selected for award negotiation on August 31, 2009. Twenty five projects were selected for Topic 1 IET funding. A few projects began work in October 2009, the rest in early 2010. The period of performance for ARRA funding expired in 2015—the last project completed work in September 2015.

This study provides an overview of the 25 projects and more detailed analysis on a subset of 8 projects that more or less completed the proposed work. For this subset, proposed work, completed work, lessons learned, and the change in geothermal resource reporting over the award period of performance are documented. More comprehensive evaluation along these lines is being conducted for all 25 Topic 1 IET projects, and will be incorporated in the forthcoming Geothermal Vision Study and potentially other future publications.

2. CATEGORIES AND TYPES OF PROJECTS FUNDED

2.1 Awardee Sector

The majority of IET funds ($28 M Federal Share) supported work proposed by companies in the geothermal industry, and the remaining funds supported work by universities ($11.2 M), activities on tribal lands ($9.8 M), and work by municipalities ($5 M) (Table 1).

Award Number	Project Title	Prospect / Field	State	Awardee	Start Date	End Date	Federal Share	Cost Share	Total Project Cost
EE0002827	Innovative Research Technologies Applied to the Geothermal Resource Potential at Ft. Bliss	Ft. Bliss	NM	El Paso County	1/29/2010	8/31/2014	$5,000,000	$4,812,500	$9,812,500
EE0002828	Direct Confirmation of Commercial Geothermal Resources in Colorado using Remote Sensing and On-Site Exploration, Testing and Analysis	Pagosa Springs	CO	Flint Pagosa Verde LLC	1/29/2010	9/31/2015	$2,435,407	$1,416,732	$3,852,139
EE0002829	Away From the Range Front: Intra-Basin Geothermal Exploration	Gabbs Valley	NV	GeoGlobal Energy LLC	1/1/2010	12/5/2011	$0	$45,662	$45,662
EE0002830	Effectiveness of Shallow Temperature Surveys to Target a Geothermal Reservoir at at McGee Mountain, Nevada	McGee Mountian	NV	Geothermal Technical Partners, Inc. (Caldera)	1/15/2010	6/30/2012	$1,609,275	$1,619,666	$3,228,941
EE0002831	Application of a New Structural Model and Exploration Technologies to Define a Blind Geothermal System (An Alternative to Grid-Drilling for Geothermal Exploration): McCoy, Churchill County, Nevada	McCoy	NV	Magma Energy Corp.	10/21/2009	5/31/2012	$238,193	$263,265	$501,458
EE0002832	A 3D-3C Reflection Seismic Survey and Data Integration to Identify the Seismic Response of Fractures and Permeable Zones over a Known Geothermal Resource: Soda Lake, Churchill County, Nevada	Soda Lake	NV	Magma Energy Corp.	1/29/2010	5/31/2012	$935,247	$2,550,135	$3,485,382
EE0002833	Geothermal Exploration of Newberry Volcano, Oregon	Newberry Volcano	OR	Newberry Geothermal Holdings, LLC (Davenport)	11/1/2009	12/31/2012	$1,482,475	$1,810,911	$3,293,386
EE0002834	Pumpernickel Valley: Sub-soil Gas and Fluid Inclusion Exploration and Slim Well Drilling	Pumpernickel Valley	NV	Nevada Geothermal Power Company	1/29/2010	4/30/2013	$71,949	$53,042	$124,991
EE0002835	Crump Geyser: High Precision Geophysics & Detailed Structural Exploration and Slim Well Drilling	Crump Geyser	OR	Nevada Geothermal Power Company	3/1/2010	7/31/2015	$837,040	$658,804	$1,495,844
EE0002836	Merging High Resolution Geophysical and Geochemical Surveys to Reduce Exploration Risk at Glass Buttes, Oregon	Glass Buttes	OR	ORMAT Nevada, Inc.	3/31/2010	6/30/2015	$1,439,038	$561,811	$2,000,849
EE0002837	Blind Geothermal System Exploration in Active Volcanic Environments: Multi-phase Geophysical and Geochemical Surveys in Overt and Subtle Volcanic Systems, Hawai'i and Maui	Ulupalakulu Ranch (Maui)	HI	ORMAT Nevada, Inc.	10/29/2009	6/30/2015	$473,784	$167,086	$640,870
EE0002838	Conducting a 3D Converted Shear Wave Project to reduce exploration risk at Wister, CA	Wister	CA	ORMAT Nevada, Inc.	10/29/2009	6/30/2015	$3,628,176	$3,219,587	$6,847,763
EE0002839	Advanced Seismic Data Analisys Program ('Hot Pot Project') - Alytical Techniques of Coherency First Arrival Data Processing and Full Waveform Inversion Velocity Model and Validation by Drilling Wells	Hot Pot	NV	OSKI Energy LLC	1/29/2010	12/31/2013	$475,977	$509,520	$985,497
EE0002840	Application of 2D VSP Imaging Technology to the Targeting of Exploration and Development Wells in a Basin and Range Geothermal System, Humboldt House-Rye Patch Geothermal Area, Pershing County, Nevada	Rye Patch	NV	Presco Energy, Inc.	1/29/2010	1/31/2014	$2,171,847	$1,832,036	$4,003,884
EE0002841	Innovative Exploration Techniques for Geothermal Assessment at Jemez Pueblo, New Mexico	Pueblo of Jemez	NM	Pueblo of Jemez	1/29/2010	8/31/2014	$4,995,844	$100,000	$5,095,844
EE0002842	Comprehensive Evaluation of the Geothermal Resource Potential within the Pyramid Lake Paiute Reservation	Pyramid Lake	NV	Pyramid Lake Paiute Tribe	2/1/2010	9/30/2013	$4,791,905	$0	$4,791,905
EE0002843	New River Geothermal Research Project, Imperial County, CA	New River	CA	Ram Power, Inc.	4/29/2010	10/30/2013	$400,000	$1,476,326	$1,876,326
EE0002844	Silver Peak Innovative Exploration Project	Silver Peak	NV	Ram Power, Inc.	10/29/2009	8/30/2011	$490,237	$1,111,184	$1,601,420
EE0002845	Alum Innovative Exploration Project	Alum	NV	Ram Power, Inc.	10/29/2009	8/30/2011	$2,590,491	$2,676,569	$5,267,060
EE0002846	Validation of Innovative Exploration Techniques Pilgrim Hot Springs, Alaska	Pilgrim Hot Springs	AK	University of Alaska Fairbanks	3/1/2010	6/30/2014	$4,272,651	$1,989,216	$6,261,867
EE0002847	Finding Large Aperature Fractures in Geothermal Resource Areas Using a Three-Component Long-Offset Surface Seismic Survey, PSInSAR and Structural Kinematic Analysis	San Emidio	NV	US Geothermal, Inc.	1/29/2010	9/30/2014	$3,772,560	$4,156,742	$7,929,302
EE0002848	The Snake River Geothermal Drilling Project: Innovative Approaches to Geothermal Exploration	Snake River Plain	ID	Utah State University	1/29/2010	6/30/2013	$4,640,110	$1,927,146	$6,567,256
EE0002849	Validation of Innovative Exploration Technologies at the Colado, Nevada, Geothermal Prospect	Colado	NV	Vulcan Power Company	1/29/2010	6/24/2011	$2,299,237	$285,152	$2,584,389
EE0002960	Detachment faulting and Geothermal Resources - An Innovative Integrated Geological and Geophysical Investigation in Fish Lake Valley, Nevada	Pearl Hot Spring	NV	University of Texas	1/29/2010	12/31/2014	$5,000,000	$7,483,363	$12,483,363
EE0004042	Caldwell Ranch Exploration and Confirmation Project, Northwest Geysers, CA	Caldwell Ranch	CA	Geysers Power Company, LLC (Calpine)	8/12/2010	3/31/2013	$0	$0	$0

Table 1. Summary table of 25 IET projects showing project, awardee, and cost details. A total of $54,051,443 of Federal funds supported the IET portfolio; awardees contributed $40,726,453 for a grand total of $94,777,896 over 6 years.

Figure 1. Summary map of IET project locations. Orange markers indicate projects that drilled, blue markers indicate projects that did not.

2.2 Award Location

All IET projects took place in the western United States (Figure 1). The majority (13) of projects explored/drilled in Nevada, which was where most of the awardees in industry were located. A handful of projects studied areas in Oregon (3), California (3), and New Mexico (2). And a single project was funded in Colorado, Hawaii, Alaska, and Idaho, respectively.

2.3 Proposed Technologies

Proposed work, as represented by the funding applications for each project, can be categorized into subsets of techniques in the following areas: 1) geochemistry, 2) drilling, 3) remote sensing, 4) geology/stress analysis and modeling, 5) potential field geophysics, and 6) seismic geophysics. Of the technologies proposed, the largest category is potential field geophysics—29% of awardees proposed data collection. Seismic data acquisition or processing was a close second at 27%. Thirteen percent of proposed work was remote sensing, 12% each for drilling and geology, and geochemical studies comprised 8% of proposed work. The most commonly proposed activity was reflection or refraction seismic data acquisition; gravity data acquisition was the next most proposed activity.

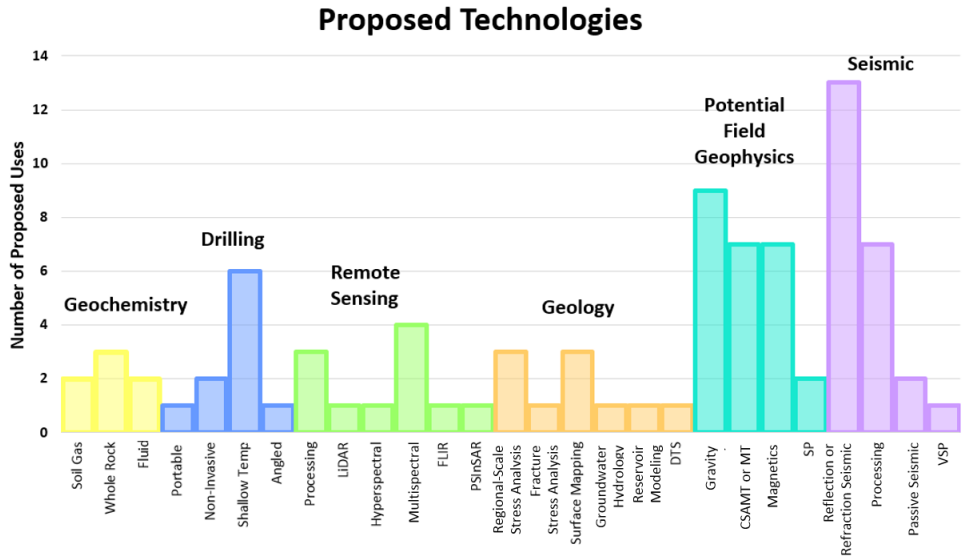

Figure 2. Summary of proposed work by technology category. Components of the category are shown along the x-axis. The most commonly proposed category of activities was potential field geophysics, and the most commonly proposed activity was seismic reflection or refraction data acquisition.

3. OUTCOMES

A summary of the work completed by IET funds recipients from 2009-2015 is presented in the following sections. All information for this study was gleaned from awardee reporting; no additional outside research or fact-checking has yet been conducted. Ongoing work will further flesh out and refine this summary.

3.1 Project Progress

Of the 25 projects awarded, about two-thirds (17) completed the work proposed in Phase I. Most (10) of these also completed Phase II); only 4 projects completed work through Phase III. Awardees reported two main factors that prevented project progress: 1) company/market instability, and 2) unfavorable permitting circumstances. Of the 8 projects that didn't complete Phase I, two projects were not able to move forward due to unforeseen permitting issues, one proposed a direction DOE was not able to support, one was associated with a company that pulled out of the geothermal market, and the remaining four projects had company stability issues related to new leadership and/or lack of support from their parent company. After completing Phase I, some projects did not request to continue to Phase II. The two projects that started Phase II but did not finish were either not able to transfer an unsuccessful project to another entity, or the company pulled out of the geothermal market. After completing Phase II, some projects did not request to continue to Phase III. The single project that started Phase III but did not finish was hampered by the inability of the company to provide the required cost share needed to complete the project.

This study made an attempt to categorize the primary activity of each quarter, based on what the awardee reported in their respective Quarterly Reports (Figure 3). Five umbrella categories were developed: 1) Permitting, 2) Exploration, 3) Drilling, 4) Data Processing & Integration, and 5) Project Management. Permitting activities, which included conversations with the BLM, state, and other regulatory agencies, cultural and archeological surveys, and DOE NEPA review, were concentrated at the beginning of each awards period of performance. Many projects continued permitting activities to some extent throughout the life of the project. Exploration activities, including field data collection, usually commenced as soon as permits were obtained, or right away if permits were not necessary or already in hand. Drilling generally occurred once initial exploration activities were completed, and subsequent drilling followed iterative rounds of exploration. Some projects drilled right away; these were projects that were at an advanced exploration stage upon receiving DOE funds. Data Processing & Integration followed a similar trend to drilling, and was highly reported after initial exploration efforts, and continuing as more data was collected to fill gaps. The Project Management category describes all other planning or non-technical activities, and is a steady presence until the end of the project, when most awardees were focused on writing their Final Reports.

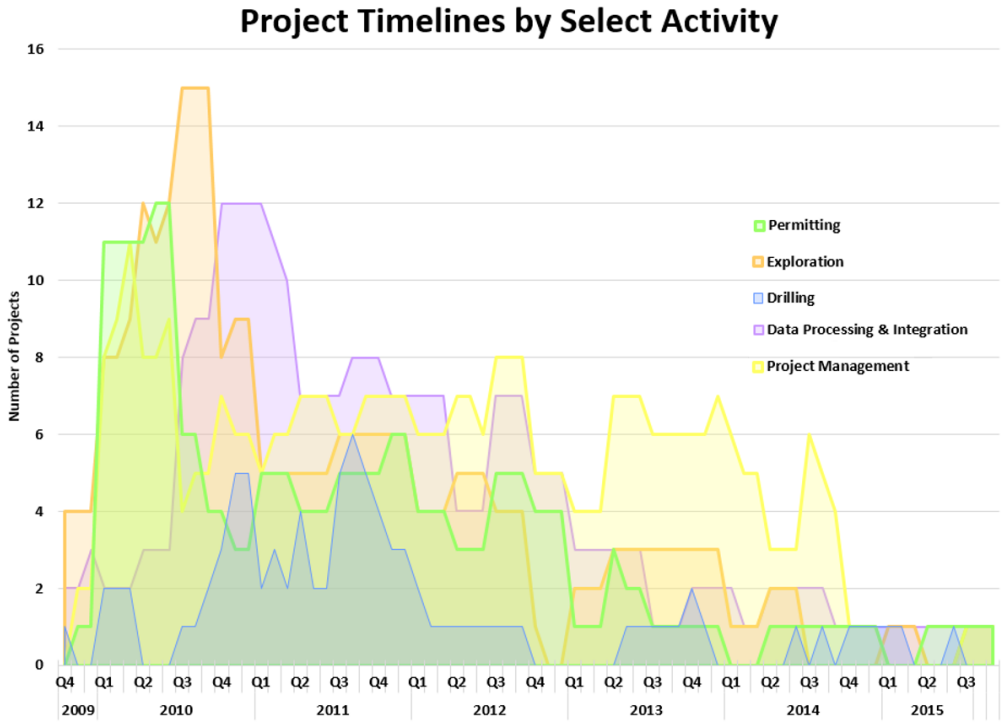

Figure 3. Summary of all activities of the combined IET projects over the ARRA funding timeline from October 2009-September 2015.

3.2 Exploration Drilling

The terminology used by awardees for describing exploration drilling is wildly variable. Some awardees describe exploration holes by the purpose, for example "temperature gradient", while others describe the hole by the diameter, for example "full-sized." An added complication is that an exploration hole diameter is often not constant from the surface to total depth—a hole may have a large surface diameter and telescope down to a much smaller diameter with increasing depth as drilling conditions become more difficult both due to

the specific equipment required and economy of operations. This study has categorized exploration holes by the diameter of the hole at total depth (Figure 4a).

Sixteen projects drilled, bored or pushed some kind of exploration hole: 192 Micro holes, 27 Small Diameter holes, 12 Intermediate Diameter hole, 9 Slimholes, and 9 Large Diameter holes—a total of 249 holes (Figure 4b). Five of these holes represent side-tracks or re-drilling of existing wells. Micro holes consisted largely of 2m probe, Hydroprobe, or Geoprobe shallow temperature surveys.

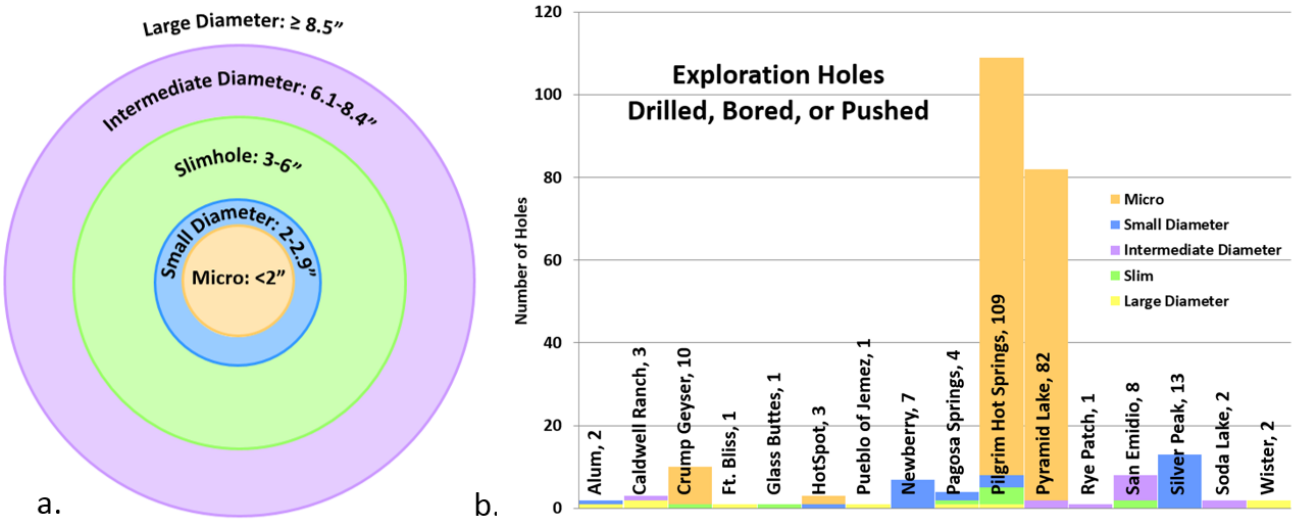

Figure 4. a.) In this study, exploration wells are described by the hole diameter at total depth. b.) Summary of the 16 projects that drilled, bored, or pushed holes into the ground, with the number of wells following the project location.

3.1 Technologies Used

A subset of the innovative exploration technologies initially proposed by awardees were actually used. However, a wide range of conventional exploration methods were applied to new areas or used in a non-conventional way (i.e. for geothermal exploration as opposed

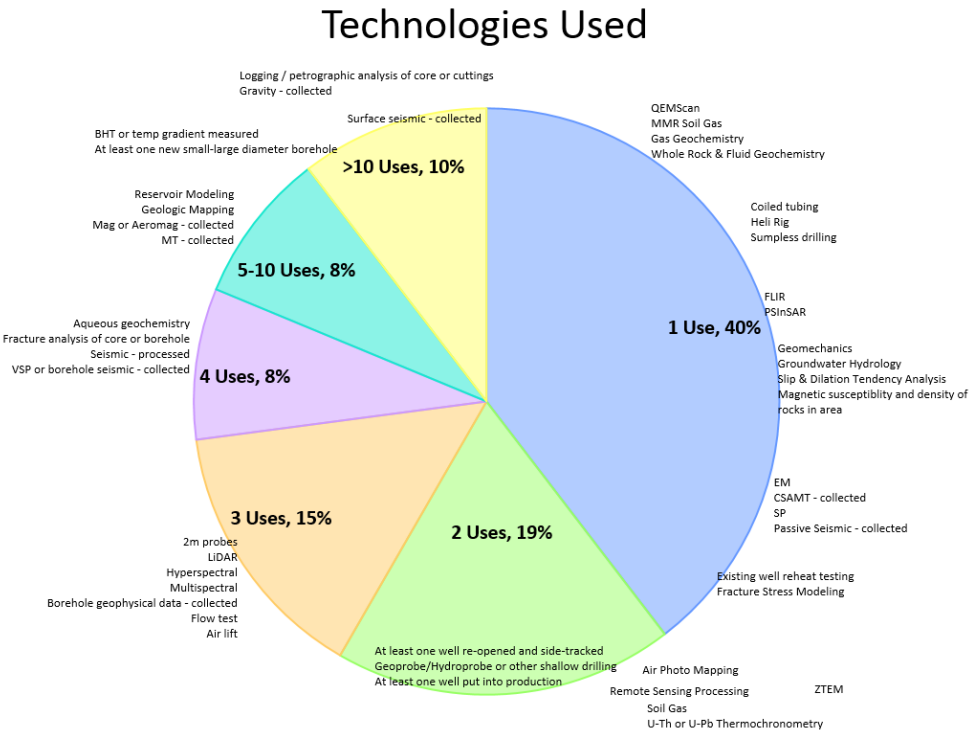

Figure 5. Summary of the most used exploration technologies, organized by degree of use. Examples of the technology for each category, taken from awardee self-reporting, are included near the category pie slice.

to oil or mineral exploration). Analysis is currently underway to examine the state of technology before and after ARRA funding in the categories of section 2.3 Proposed Technologies. A more thorough description of innovation and advancement is forthcoming. A preliminary summary of the most used technologies is presented in Figure 5.

4. IMPACTS

Eight IET projects have been selected 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 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 6).

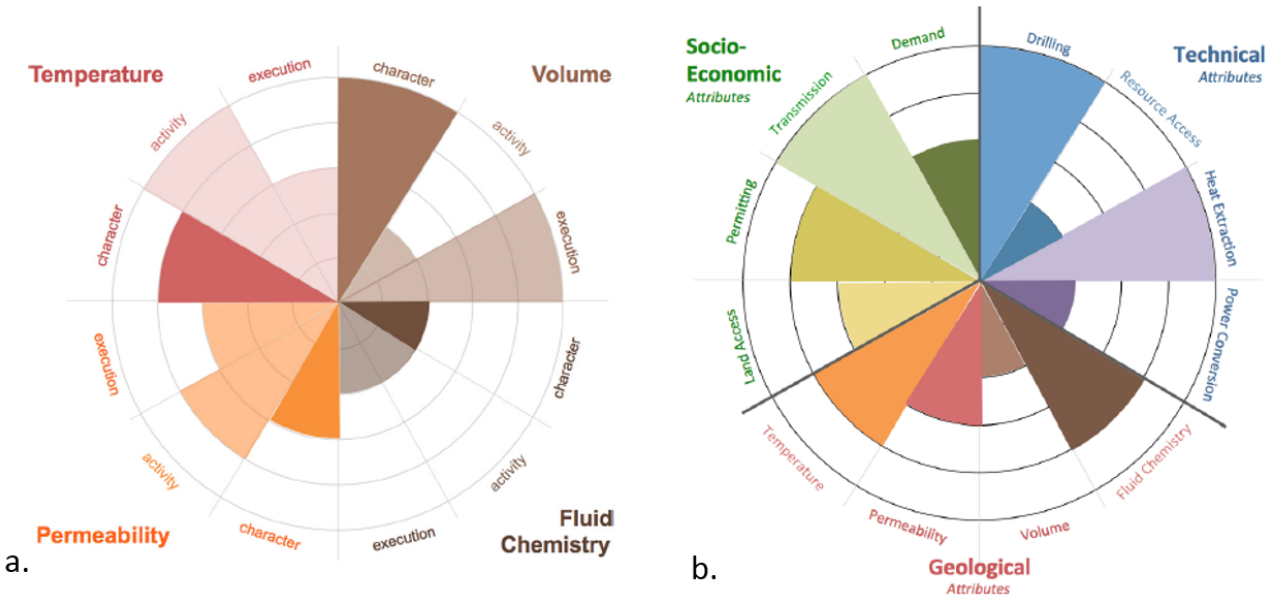

Figure 6. From Young et al, 2015 a.) Example grade visualization of a hypothetical resource using a polar area chart showing the four geological attributes. Each quadrant represents a different geological attribute and is subdivided to show the character, activity, and execution index values. The darkly 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.

This study presents a preliminary GRRM assessment of the 8 project prospects before and after DOE funding, with the caveats that: information is entered into the metric as reported by awardees in the Final or latest project 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.

The results of the preliminary GRRM analysis are show in Figure 7. Some initial takeaways include: 1) DOE funding advanced the state of characterization or certainty in some category for all projects that completed work; 2) some grades have improved, while others have downgraded; and 3) often awardees focused on reporting geologic information more than information that would fall into the Technical or Socio-Economic Categories. Continuing analysis is attempting to better define the state of affairs both at the beginning and end of each project, as well as to assess trends in factors that have changed and why.

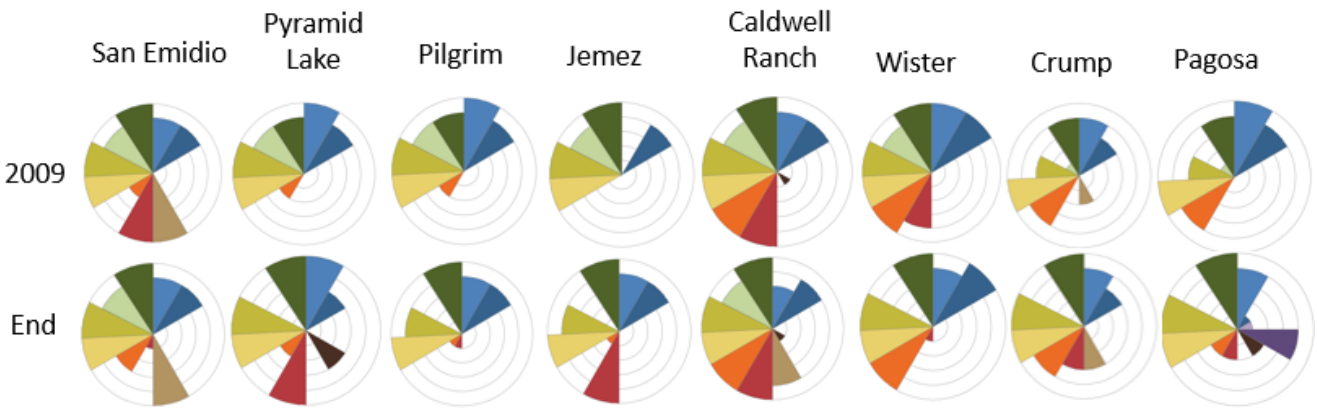

Figure 7. Preliminary GRRM analysis of 8 IET projects at the beginning of the period of performance and at the end of the period of performance. Red, orange, and brown colors represent the Geological category; blues and purples represent the Technical category; greens and yellows represent the Socio-Economic category. See Young et al 2015 publications and Badgett et al 2016 for more details on the metric.

3. SUMMARY AND CONCLUSIONS

This study provides a general overview of the 25 IET projects that were funded starting in 2009 under the ARRA. This study attempts to present a taste of ongoing research related to the evaluation of success of past DOE-funded projects, which will also be more comprehensively assessed in the Exploration task of the Geothermal Vision Study that is currently underway. The IET projects are summarized and categorized, and a preliminary evaluation of proposed work, completed work, and preliminary GRRM analysis on a subset of eight projects has been presented.

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