

Report on
Workshop on Exploration and Assessment of Geothermal
Resources

September 21-22, 2010, Reno, NV

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Overview

The Great Basin Center for Geothermal Energy (GBCGE), in collaboration with the DOE Geothermal Technology Program office (DOE-GTP) and the Geothermal Energy Association (GEA), convened a 1.5 day workshop of invited geothermal professionals to discuss the state of knowledge of exploration for geothermal resources. This workshop was envisioned as the first to assess the current state of knowledge regarding existing data and methodologies needed to discover blind or hidden geothermal systems and to characterize known systems with high potential. The Charter and Agenda are provided in Appendix 1 and a list of final attendees in Appendix 2. Thirty-eight people participated with broad representation by the industry, government agencies, and academic communities. Many of the attendees have a long history and knowledge base in geothermal exploration.

The goal was to provide an assessment of where data and technologies stand with regard to exploration, provide input to the “Exploration Best Practices” report being generated at NREL, provide feedback to DOE program managers and their current road-mapping activity, and assess the need for future focused workshops.

This group of experts had spirited and lively discussions over the day and a half reviewing the existing success of current exploration techniques in Geology and Structure, Geophysics, Remote Sensing, Geochemistry, Temperature Distribution, and Reservoir Characterization. We discussed hurdles and barriers to exploration and established a list of future recommended focused workshops. This report summarizes the significant points and recommendations from the meeting.

Summary of Findings

Historical Perspective

- The industry-coupled drilling program, Cascade program and GRED’s were effective in establishing new geothermal targets.
- These programs laid the groundwork for many current, high-priority targets, though not all are producing power.
- The knowledge and information resulting from these programs was useful for both DOE and industry.
- Unfortunately, summary reports from these early programs are not available, and data from GRED-1-3 is proprietary.
- There are several reports in progress that really need to get out to the community quickly, and a permanent repository of information needs to be identified.
- DOE is a “Science & Technology” agency, yet goals are often touted as xMW by a particular date. This metric only works if supported by the electrical market. It was widely agreed that we need to define another metric.
- Both the mining industry and oil and gas provide analogies. Studies of minerals systems and alteration provide links to understanding geothermal systems and exploration techniques are similar to those used in oil and gas exploration.
- Exploration/system models are in the earliest stages of development, where mining or oil/gas were ~ 50+ years ago.

- Education and a new generation of “geothermalists” is required to move the field forward.

Current ARRA Projects

- Many of these were delayed due to contracting issues at the outset, we should not let this administrative delay impact the perception of actual progress.
- Maintain vigilance in presenting the program as a sustained effort over a long period of time.
- Industry does not have the financial resources to support large internal R&D groups. At this stage of development, DOE is looked to for fundamental R&D to facilitate characterization of known resources and development of new and existing resources and technologies.
- Conventional technologies and systems are not well understood and therefore need as much (or more) investment as “innovative” approaches.

Geology and Structure

- Recent efforts have identified a number of favorable structural settings in the Great Basin.
- A detailed structural model is critical to developing a geothermal field.
- Fault control of fractures and permeability are key features that need to be well understood.
- There is a strong need to extend this type of characterization beyond the Great Basin to additional regions, such as the Cascades, Rio Grande Rift, Snake River, and Imperial Valley.
- Work in the Great Basin has only scratched the surface and much additional work is needed.
- Large scale crustal dynamic studies may help to identify regional heat anomalies.
- Strain history can be as important as the current strain rate.
- Detailed modeling that couples the well bore to the structural model is needed.

Geophysics

- 2D/3D seismic techniques are now showing promise after long-term investment in techniques and interpretation in various settings.
- There is a time lag between developing new techniques and their utility/applicability.
- Seismic techniques have been locally successful in the Great Basin, but more work is needed to determine the best techniques for imaging through volcanic sequences.
- Conductivity at depth is a reliable indicator of fluids and a vital link to hydrogeology.
- Self-Potential (SP) is used for shallow fluid flow, but is not always reliable.
- Deep DC electrical resistivity has been mostly replaced by magnetotellurics (MT).
- Large scale gravity helps provide regional structure but detailed gravity is still needed for exploration within individual fields and selecting sites for geothermal wells.
- TDEM/MT/CSAMT are most commonly used worldwide for ground resistivity, CMST is less expensive.

- Integration of multiple techniques improves models and interpretation; it is unknown if these can be linked through physical principles.
- Geophysical parameters are well understood. However, the responses in some geologic settings are not well documented.
- A community assessment is needed to show which geophysical techniques are best in which setting using test cases.
- Advances in airborne resistivity and gravity will be beneficial.

Remote Sensing

- Widely viewed as a useful reconnaissance tool, available without permitting.
- Satellite and airborne mineral surveys have been effective at mapping the surface expression of structurally controlled hydrothermal fluids.
- A new application is to use mineral spectroscopy to identify fluid circulation underground.
- LiDAR images are widely viewed as a great new tool to identify small faults, and detailed topography provides better models and constraints on other geophysical data.
- InSAR may be used to identify current strain, but more work is needed. Has been demonstrated to be helpful in reservoir modeling.
- GPS/Geodetic techniques are very useful for regional strain.
- Thermal imaging has been used to identify surface heat anomalies in remote regions, however to date anomalies are always linked to a surface heat expression such as fumaroles.

Geochemistry

- Geothermometry has been very useful worldwide in identifying resources. However, the methods can be improved as the approach is mostly empirical.
- Assumptions regarding equilibrium, kinetic effects, and rate constants limit the applicability of laboratory measurements to natural systems.
- Cold water springs can be used to suggest anomalies, but more work is needed to understand the mechanisms that drive this.
- Subtle temperature changes in springs appear correlated with shallow temperature and possible fluid migration pathways.
- Data quality is strongly dependent on the lab that does the analysis & is often not vetted, but charge balance is good test of the data reliability.
- Extensive surveys in NV suggest many previously undiscovered resources.
- He isotopes show strong correlation with strain, suggesting a way to get at permeability with depth.
- Soil gas sampling has been used to identify potential resources.

Temperature Distribution

- Heat flow, temperature, and exploration drilling are critical measurements and tools.
- In order to know these important parameters, temperature and heat loss, we must drill.

- Heat flow maps strongly benefit from regional drilling programs of various oil & mining companies, plus surveys of private wells dubbed, “free holes”, in the past.
- New maps are being incorporated in modern spatial tools (Google).
- Bottom-hole temperatures improve resource assessment.
- New fiber optic methods survey temperature of the entire hole at once and with time variability.
- Modern tools: digital data bases, modeling software, portable logging tools make it easier to turn temperature gradient into heat flow.
- The temperature signature of deep resources will be subtle.

Reservoir Characterization

- Progressive temperature gradient drilling is very useful, but dependent on geologic environment.
- Association of faulting patterns and alteration needs more study to understand the permeability distribution, but the mining industry provides good analogs.
- Coulomb stress and slip tendency models can show strain over decades and also identify regions where induced seismicity is likely.
- The “reservoir” should be viewed not as a tank but as a flow through; the fluid is the medium.
- Reservoir models require multiple iterations: the measurements need to couple back into structural and geophysical models that then refine the reservoir model.
- EGS should be considered on a range of levels – most fields benefit from some kind of improvement, from small adjustments to a totally manufactured system.
- Natural seismicity data may provide additional value in characterizing a reservoir, but there is strong community concern if the mandate to monitor this is applied to all systems (not just EGS systems).

General Findings

- Need better metrics to define success. Data on the relative cost and success of using different exploration techniques is poor/weak.
- Need to publish outside GRC and Stanford workshops.
- Need for systems approach with access to all data integrating multiple data sets (Case Studies)
- Need exploration drilling
- NREL “Best Practices” should not ignore the cost of interpretation, and should discuss techniques by phase and by resource type.
- Need better characterization of all resources and the potential resource base.
- Need to better define what techniques work best in each geologic setting and those that work well in many or all settings.
- Much legacy data will be lost, the delivery of new data is dependent on the funded projects, long-term accessibility requires sustained funding.
- Timeline for data release needs to shorten, and make sure data from both past and current DOE programs gets out to the community.

Hurdles and Barriers

- ❖ Data Gathering
 - Data gathering tools not portable (geophysics, geochemistry)
 - Depth limitations
 - Clarity of signals
 - Lack of infrastructure to gather data
- ❖ Data Sets
 - Data is not publicly available
 - Data not always accurate – constant QA
 - Lack of methodical, wide-spread application of data gathering techniques
 - Data not available for regions other than Great Basin
 - Even Great Basin could be better known
 - Remote sensing data sets are enormous
 - Areas exist with undiscovered resources – need to be identified
- ❖ Data Processing
 - Need more hand-held devices for data processing in the field
 - Data processing tools that combine multiple exploration techniques do not yet exist
 - Lack of modeling tools/methods for data interpretation
 - Lack of methodical characterization of all known resources (ex: UNR B&R, Cox & Singer)
 - Lack of confirmation of methods
- ❖ Data Expertise
 - Not enough knowledgeable, experienced geothermal experts
 - “Best exploration tool is a knowledgeable geologist”
 - Small community – not enough publishing outside GRC/Stanford
 - “Success” not defined
- ❖ Policy/Management
 - Using DOE funds has become logistically more complicated/time consuming to manage
 - Gov’t-funded projects data not released in a timely manner
 - No guarantee of BLM lease once exploration has commenced (\$ spent)
 - Need facilitated market for geothermal
 - Lack of sustained government support
 - Lack of available transmission lines– exploration needs to feed into this
 - Lack of land management policy to facilitate RE development
 - Geothermal industry needs to bring geothermal to Federal agencies for planning processes
 - R&D research from DOE requires cost-share (universities /labs cannot provide); OS does not require; limits what can get done
 - Geothermal regulations/rules not updated
 - ARRA required reporting complicated, unrealistic wage requirements

- ❖ Permitting
 - Permitting requirements/Laws (e.g. water rights) different for each state
 - Unclear/untested permitting regulations –lack of reciprocity
 - some states permitting not well known – by developers or by permitting agencies
 - Inter-agency conflicts
 - (e.g. geothermal vs. water well; water right vs. mineral right; private/BLM land regulations differ)
 - Lack of trained government officials; lack of workshops to train these agencies
 - Permitting process can be lengthy
 - delay project, increase cost of money
 - NEPA
 - Regulations vary even within BLM lands

- ❖ Economic
 - High up-front risk/cost
 - Difficulty in obtaining financing and PPA sometimes required for financing
 - Cannot get commercial financing for exploration
 - Lack of guaranteed market (e.g. FIT)
 - Current incentives don't promote exploration due to long lead times
 - Incentives such as the PTC and ITC tied to power production or power plant construction, which occurs a decade or more later and often by a different entity

- ❖ Communication
 - Public perception of geothermal
 - unknown RE technology, or perhaps negative mindset (EQ)
 - DOE perception of geothermal and success of industry support

Overall Recommendations

- The Department of Energy (DOE) should set a goal of identifying within the next ten years sites capable of producing 50,000 - 100,000MW of geothermal power (5-10% of total US power generation), utilizing the full range of technologies, through a sustained national exploration effort, significantly supported by long-term federally funded programs.
- There should be a follow-on workshop to specifically examine the lessons learned from exploration efforts in the Great Basin, the applicability of those lessons to other regions, and the steps needed to continue and enhance geothermal exploration in the Great Basin.
- DOE should support active geothermal exploration efforts in other promising geologic regions, including government funded broad-area exploration and resources assessment for undiscovered, blind-systems.
- DOE should support characterization of favorable settings and major parameters (e.g., structural, stratigraphic, geophysical, and geochemical) of known geothermal fields to facilitate discovery of blind (or hidden) systems, as well as expansion of known systems.
- There should be an evaluation and assessment of cost-shared government-industry exploration efforts in the past, and an analysis of the best approach to increase such collaboration in the future and achieve the DOE exploration goal.
- Both industry and the federal government need to recognize that sharing appropriate geothermal resource data is important to advance geothermal energy production and improve the scientific underpinning of geothermal exploration.
- DOE has in the past validated exploration techniques, and should resume its efforts in this area to help define which ones work best in different geologic settings and in what combinations.

Future Workshops/Meetings

- DOE Roadmap Meeting (Thurs. 10/28 @ GRC)
- Session on Geothermal Exploration at AGU (V13B, V23D, Dec 13 & 14, 2010)
- Follow-on exploration workshop. Implementation and limitations of existing techniques.
- Great Basin Lessons Learned. What do we know and how to apply this in new regions.
- DOD/Federal Cooperation
- Direct Use focused workshop. Implementation, Expansion, Needs.

Appendix 1: Charter and Agenda

Charter Workshop on Exploration and Assessment of Geothermal Resources

September 21-22, 2010, Reno, Nevada

The Great Basin Center for Geothermal Energy (GBCGE), in collaboration with the DOE Geothermal Technology Program office (DOE-GTP) and the Geothermal Energy Association (GEA), will convene a 1.5 day workshop of invited geothermal professionals to discuss the state of knowledge of geothermal resources. A major goal of this workshop will be to assess existing data and methodologies needed to discover blind or hidden geothermal systems and to define known systems with high potential. The following topics will be discussed:

- What do we know about identifying and quantifying geothermal resources?
 - Success of past DOE programs such as GRED and cost share drilling
 - What are current DOE ARRA exploration projects focusing on?
 - What quality data exist and how good are current models?
 - What technologies are consistently used with success?
- What do we need to learn about identifying and quantifying geothermal resources?
 - What assumptions are made or preconceptions exist about resource availability?
 - What new information is needed to improve or validate current models?
 - What data, information, or technologies can improve the identification and quantification of resources, especially hidden or blind geothermal systems?
 - What recent innovations can be applied to advance our knowledge and understanding of geothermal resources?
- What are the hurdles or barriers to bringing more resources rapidly on line?
 - Science and Technical
 - Policy and Management
 - Economic
- What near-term recommendations can be made and what future meetings should be convened? Outcomes are expected to feed into:
 - NREL/LBNL Exploration Best Practices Study
 - DOE exploration roadmapping efforts

GBCGE will host the workshop Sept. 21, and 22 at the Redfield Campus. The Center will develop a list of invited participants to present summaries of key elements and discussion points noted above, with limited observers as needed to facilitate discussion. The outcome of this workshop will be a brief report delivered to Technology Development and Demonstration Program Managers at DOE-GTP.

Agenda: September 21-22, 2010
Workshop on Exploration and Assessment of Geothermal Resources
Redfield Campus, Nell J. Redfield Building A
18600 Wedge Parkway, Reno, Nevada

Tuesday 21 Sept., Room 214

- 8:00 am Shuttle Departs Hilton Garden Inn, 9920 Double R Blvd for Redfield
- 8:15 am Coffee and Bagels, Muffins etc
- 8:30 am *Welcome, introductions, goals and outcomes*
- 8:45 am *Identifying and quantifying geothermal resources: What has worked and what does not work?*
~ 25 min each Panel
- Success of past DOE & USGS programs such as GRED and cost share drilling
 - Renner, Benoit, Gawell, Moore, Reinhardt
 - What are current DOE ARRA exploration projects focusing on?
 - Reinhardt, Kennedy, Kasameyer, Williams & Industry Reps
 - Historical Industry Perspective
 - Benoit, Johnson, Capuano, Suemnicht & Industry Reps
- 10:00 – 10:15 am Short Break
- 10:15 – 12:30 am *Existing Data, Models, Systems*
- *What quality data exist and how good are current conceptual models for various types of systems (e.g., fault-controlled, magmatic, high vs. low enthalpy, EGS)?*
 - *20-30 min each Panel*
 - 10:15 – 10:45: Geology/Structure
 - Faults, Benoit, Monastero, Johnson, Suemnicht
 - 10:45 – 11:10: Geophysics (seismic, M/T, gravity)
 - Louie, Oppliger, Kasameyer
 - 11:10 – 11:30: Remote sensing
 - Martini, Calvin, Oppliger, Coolbaugh
 - 11:30 – 11:50: Geochemistry
 - Shevenell, Kennedy, Coolbaugh
 - 11:50 – 12:10: Temperature Distribution
 - Richards, Williams
 - 12:10 – 12:30: Reservoir Characteristics
 - Kasameyer
- 12:30 – 1:30 pm *Break for Lunch* – Box lunch brought in.

1:30 – 2:00 pm *What technologies are consistently used with success?*

- Hillesheim – Report on Exploration Best Practices
- Participant perspective: Single slide/Open Mike
- Discussion

2:00 – 3:00 pm *What do we need to learn about identifying and quantifying resources?*

- What assumptions are made or preconceptions exist about resource availability?
 - 2:00 – 2:30: Review Hidden Resources & Exploration Approaches - Coolbaugh
- What new information is needed to improve or validate current models?
 - 2:30 – 3:00: Open discussion lead by Calvin and Faulds

3:00-3:15 pm Short Break

3:15 – 5:15pm *Improvements and Innovations*

- What data, information, or technologies can improve the identification and quantification of resources, especially hidden or blind geothermal systems?
 - 3:15 – 3:30: Status of National Geothermal Data System (Snyder)
 - 3:30 – 3:45: Recommendations from IPGT (Renner)
 - 3:45 – 4:00: Known systems as proxies for new ones (Faulds)
 - 4:00 – 4:30: Open discussion lead by Gawell and Calvin, US specific needs?
- What recent innovations can be applied to advance our knowledge and understanding of geothermal resources?
 - 4:30 – 5:00: Participant perspective: Single slide/Open Mike
 - 5:00 – 5:15: Summary and Synthesis of ideas

5:15 pm Adjourn for the day

5:30 pm Shuttle Departs Redfield for Hilton Garden Inn

Wednesday, 22nd September, Room 221

8:00 am Shuttle Departs Hilton Garden Inn, 9920 Double R Blvd for Redfield

8:15 am Coffee and Bagels, Muffins etc

8:30-9:00 am *Review of first days major points and highlights*

9:00-10:15 am *With regard to exploration technologies, what are the hurdles or barriers to bringing more resources rapidly on line?*

- Open discussion by all participants facilitated by Gawell & Young
- ~ 25 min per area
 - Science and Technical
 - Policy, Management, Communication
 - Economic

10:15-10:30 am Short Break

10:30am *What near-term recommendations can be made?*

- Develop a list of specific recommendations

What future meetings should be convened?

- Decide a meeting timeframe and focus for the next steps and integration

Finalize deliverable and timeline of White Paper from this meeting, linked to:

- NREL/LBNL Exploration Best Practices Study
- DOE exploration roadmapping efforts

11:30 am Adjourn

11:45 am Shuttle Departs Redfield for Hilton Garden Inn

Appendix 2: Final List of Attendees

| Type of org | Name of Organization | Name of Org Representative | e-mail address |
|-------------|------------------------|-----------------------------|----------------------------------|
| Conveners | UNR/GBCGE | Wendy Calvin | wcalvin@unr.edu |
| Conveners | UNR/GBCGE | Jim Faulds | jfaulds@unr.edu |
| Conveners | GEA | Karl Gawell | karl@geo-energy.org |
| Agency | DOE | Tim Reinhardt | timothy.reinhardt@ee.doe.gov |
| Agency | DOE/Energetix | Chris Kelley | ckelley@energetics.com |
| Agency | LBL | Mack Kennedy | bmkenedy@lbl.gov |
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| Agency | NREL | Mike Hillesheim | Michael.Hillesheim@nrel.gov |
| Agency | NREL | Kate Young | Katherine.Young@nrel.gov |
| Agency | Navy | Michael Lazaro | michael.lazaro@navy.mil |
| | | | |
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| | | | |
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| | | | |
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| | UNR Support | Betsy Littlefield | eflittlefield@gmail.com |