PROCEEDINGS, Thirty-Ninth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 24-26, 2014
SGP-TR-202

Geothermal Exploration Case Studies on OpenEI

Katherine R. Young, Mitchell Bennett, Darren Atkins

National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401

katherine.young@nrel.gov

Keywords: exploration, case studies, OpenEI, occurrence model, play type, database

ABSTRACT

The U.S. Geological Survey (USGS) resource assessment by Williams et al. (2008) outlined a mean 30 GW_e of undiscovered hydrothermal resource in the western United States. One goal of the U.S. Department of Energy's (DOE) Geothermal Technology Office (GTO) is to accelerate the development of this undiscovered resource. DOE has focused efforts on helping industry identify hidden geothermal resources to increase geothermal capacity in the near term. Increased exploration activity will produce more prospects, more discoveries, and more readily developable resources. Detailed exploration case studies akin to those found in oil and gas (e.g., Beaumont and Foster, 1990-1992) will give developers models for identifying new geothermal areas, and guide efficient exploration and development of these areas.

To support this effort, the National Renewable Energy Laboratory (NREL) has been working with GTO to develop a template for geothermal case studies on the Geothermal Gateway on OpenEI. In 2012, the template was developed and tested with two case studies: Raft River Geothermal Area (http://en.openei.org/wiki/Raft_River_Geothermal_Area) and Coso Geothermal Area (http://en.openei.org/wiki/Coso_Geothermal_Area). In 2013, ten additional case studies were completed, and Semantic MediaWiki features were developed to allow for more data and the direct citations of these data. These case studies are now in the process of external peer review.

In 2014, NREL is working with universities and industry partners to populate additional case studies on OpenEI. The goal is to provide a large enough data set to start conducting analyses of exploration programs to identify correlations between successful exploration plans for areas with similar geologic occurrence models.

1. INTRODUCTION

Detailed exploration case studies for geothermal plays, similar to those completed by Beaumont and Foster (1990-1992) for oil and gas plays, will give operators an accessible portal for gathering and serving consistent information that can be utilized for exploring for geothermal drilling prospects. This collection of case studies provides detailed information, where each case study is broken down into queriable properties, making this information even more powerful in planning future exploration efforts in new areas.

The goal of this effort is to develop a template for geothermal case studies on a crowd-sourced platform to allow for contributions from the entire geothermal community. Information collected for the case studies includes historical information regarding exploration and development in an area, as well as current information about reservoir characteristics and facility production. The initial focus is on populating case studies for developing and operational geothermal areas in the U.S. that can then be used as a basis for discovering new areas, and guiding efficient exploration and development of those areas.

In 2012, the initial template was built on OpenEI and populated with case studies for two areas: Coso Geothermal Area and Raft River Geothermal Area. Feedback from industry experts on this initial template led to improvements in 2013 (see the OpenEI and the Case Studies Template section) and the completion of an additional ten case studies (see Selection of Geothermal Areas section). In addition to completing the case studies, we also developed methodologies and data input templates for the future student contributions. Using these templates and methodologies, the Geothermal Case Studies Challenge was created in the last quarter of 2013.

This paper outlines the methodology developed for the preparation of case studies by a wide variety of students, the selection of the initial areas to serve as example completed case studies, key feature improvements to the OpenEI platform and the Geothermal Area Case Studies template, and information about future direction of the OpenEI Case Studies effort.

2. METHODOLOGY

In developing the methodology for completing case studies, the objective was to create a process that could be used in the future by students completing additional case studies. We wanted to be able to develop consistently accurate, queriable case studies, with input from geothermal experts who know the areas well, but with minimal impacts on the experts' schedules. For the data to be easily accessible, it was important to create a template (and associated form) on OpenEI, a Semantic MediaWiki[1] platform, to solicit crowd-

[1] Semantic MediaWiki (SMW) is a free, open-source extension to MediaWiki – the wiki software that powers Wikipedia – that lets you store and query data within the wiki's pages. https://semantic-mediawiki.org

sourced information sharing. Some of the advantages of cataloging this information on OpenEI include the ability to: (1) crowd-source information, (2) easily search for the information needed, (3) query information to compare various techniques, and (4) link these data to other databases on OpenEI (e.g., the NEPA database).

A case study template and user input form has been developed through iterative modifications, based on input from those populating the case studies and expert review of these studies and templates. This template and its form are continually updated as additional feedback is received from the user community. Though the OpenEI template for the case studies may seem restrictive at first, adhering to this template allows for consistent information to be gathered for each geothermal area, and for that information to be queryable across areas listed in the collection. The template includes:

Data – a variety of data can be collected for each area, including information on power production, well fields, geology, reservoirs, and geochemistry.

Narratives – three types of narratives are outlined in the template: (1) General (e.g., area overview, history and infrastructure), (2) Technical (e.g., exploration history, well field description, R&D activities), and (3) Geological (e.g., area geology, hydrothermal system, heat source, geochemistry).

Exploration Activity Catalog – a catalog of exploration activities conducted in the area (including the techniques applied, date of the activity, and reference(s)) is provided.

NEPA Analysis – case studies contain a catalog of NEPA analyses conducted in the area (that have been catalogued in the OpenEI NEPA database), including metadata (e.g., dates, offices, timelines), relevant documents (e.g., applications, reports, decision documents), and potential impacts and mitigations (both industry proposed and agency imposed).

Research for the case studies begins with development of chronological timelines of activities and a reference list that can be sent out to industry experts for review. Templates were developed for populating these lists for uniformity of data input and ease of upload into OpenEI.

Expert reviewers are generally selected based on having previously published about the specific area; they are sent the timelines, reference list, and a list of questions to quickly guide the review of these items. The goal of this first review is to identify any errors or omissions early in the process without extensive time commitments from reviewers.

With this initial feedback from experts, case studies narratives can be written and then circulated to the experts for a second review. Expert comments will again be incorporated before the final posting of the narrative and scripted upload of the references and exploration activities lists to the OpenEI platform.

3. SELECTION OF GEOTHERMAL AREAS FOR EXISTING CASE STUDIES

In selecting the initial locations for testing the case study templates, we started by reviewing the list of operating and heavily explored geothermal areas in the United States. Our criteria for selection of the ten areas studied in 2013 included representing of a diverse set of geothermal regions and occurrence models, choosing well-studied areas with a significant number of publications, and selecting areas with a relatively recent development history. One non-operational site was also selected to be sure the template accommodates non-operational areas. The resulting list is shown in Table 1. The case studies developed for these sites will serve as examples in the development of future case studies.

Table 1: List of geothermal resource areas selected for case study reviews in 2013.

Type[1]	Startup Year	Geothermal Region[2]	Area	Power Plants
B	2012 2013	Northwest Basin & Range	Neal Hot Springs	Neal Hot Springs Facility
C	None	Rio Grande Rift	Valles Caldera (Fenton Hill), Sulphur Springs, Redondo	
C	1984	Walker Lane Transition Zone	Long Valley Caldera	Mammoth Pacific I & II (Casa Diablo)
D	2009	Gulf of California Rift Zone	North Brawley	North Brawley Facility
E	1988	Central Nevada Seismic Zone	Dixie Valley	Dixie Valley Facility
E	1984	Northern Basin & Range	Roosevelt Hot Springs	Blundell I & II Facilities
E	2009	Northwest Basin & Range	Blue Mountain	Blue Mountain -Faulkner
E	2009	Northwest Basin & Range	Salt Wells	ENEL Salt Wells Facility
E	2006	Alaska	Chena	Chena Hot Springs Facility
F	1993	Hawaii	Kilauea East Rift Geothermal Area	Puna Geothermal Facility

[1] Type refers to the Brophy Occurrence Model Types (http://en.openei.org/wiki/Brophy_Occurrence_Models). Could this be in References? In the parentheses, it could say "see References". Type A: Magma-heated, Dry Steam Resource; Type B: Andesitic Volcanic Resource; Type C: Caldera Resource; Type D: Sedimentary-hosted, Volcanic-related Resource; Type E: Extensional Tectonic, Fault-Controlled Resource; Type F: Oceanic-ridge, Basaltic Resource (Williams et al., 2011).

[2] For a list of regions, see http://en.openei.org/wiki/Geothermal_Regions.

4. IMPROVEMENTS TO THE CASE STUDIES TEMPLATE

Over the past two years, a total of twelve case studies have been researched by NREL staff. These have been used to evaluate the usability and content model and to vet with industry experts. Though many improvements have been made to the templates in the past year, there are two we note here: improving the referencing capabilities and adding unit conversions.

4.1 Improved References

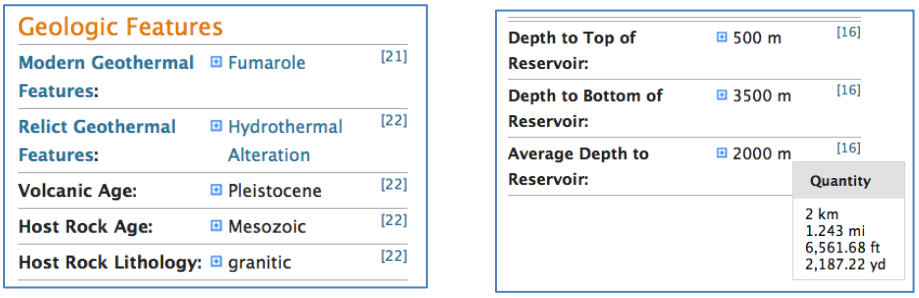
Historically, citations for information on wiki pages have been allowed in text portions of the page, but contributors were allowed to provide the citation in whatever format they chose. This format allows for inconsistencies among pages. As part of the template improvements for these case studies, a reference mechanism was developed for use on all OpenEI pages. The citations are collected via a user-friendly form and are automatically formatted consistently throughout OpenEI wherever the reference is cited. Contributors need only to type the name of the document when adding a citation for the full citation to be referenced and formatted consistently.

More importantly, previous wiki platforms have never before allowed for direct citation of data. Semantic MediaWiki's key advantage over normal wiki pages is the semantic linking of page properties. The ability to provide citations for these properties is vital to validating the accuracy of the information. The OpenEI team developed a methodology for adding user-friendly data citation capabilities to forms and back-end syncing of citations to data points. The result is the Case Study template on OpenEI now allows for the referencing of individual data points (e.g., all data in tables now have unique references), as shown in (a) (b)

Figure 1a. For example, the Coso Geothermal Area page has properties for geologic features, which cite reference number 22, footnoted on the wiki page to be Adams, et al (2000) *Geologic History of the Coso Geothermal System*. This new feature increases the credibility of cited data in all of the geothermal wiki pages on OpenEI, including Exploration Techniques, Geothermal Resource Areas, and Energy Generation Facilities pages.

4.2 Unit Conversion

Data unit input options and display have also been improved. Data stored in common units (like ºC) are now semantically interpreted into classifications (like "Temperature") that automatically translate their values into a predetermined set of relevant units (like ºF and ºK). As a result of these enhancements, data that are accessible via queries can be displayed in any unit the user desires. Mousing over the value will also display the value in multiple different units, as shown in Figure 1b. This new feature increases the accessibility, reusability, and scientific relevance of data on OpenEI.



(a) (b)

Figure 1: Screen captures of new OpenEI template capabilities for the Coso Geothermal Area case study. Figure (a) demonstrates the ability to provide a citation for each piece of data. Figure (b) demonstrates the ability to display values in different units.

5. SUMMARY AND FUTURE DIRECTIONS

The goals of this project over the past two years were to develop a functional template and to populate this template with example case studies. These activities are now nearing completion.

5.1 Case Studies Challenge

The goal in 2014, and in the future, is to encourage crowd-sourcing of information to populate case study data, activities, narratives, and references for more areas worldwide. For this purpose, we have established the Geothermal Case Studies Challenge (http://en.openei.org/wiki/CSC).

Conducting a student challenge that contributes to these case studies has many benefits. It allows students to participate in a project that directly contributes to industry's body of knowledge; it connects students with industry members for potential internship and job opportunities; it exposes students to the benefits of contributing to and utilizing crowd-sourced information; and it allows the database to continue to grow, providing detailed information about a growing number of geothermal areas. This effort saves geothermal companies time and money, as the type of information contained in the case studies are synonymous with the preliminary analysis conducted by most as a first step in reconnaissance of an area.

For the case study challenge in 2014, students can select from a list of U.S. geothermal sites (http://en.openei.org/wiki/CSC/Areas#top) as outlined by the USGS in support of their recent geothermal resource assessment (Williams et al., 2008). Students may also propose to work on a non-listed site if they choose.

Templates described above are provided for cataloguing references, exploration activities, area data, and narratives so that their incorporation into the OpenEI templates is as seamless as possible. Students are expected to work with industry experts and with their advisors to produce consistently high-quality reports. Scoring rubrics have been provided so that students can work on improving the quality of their case study materials prior to submission.

5.2 Future Analysis

Geothermal resources can be examined using any number of properties, such as temperature, structural control, geothermal region, or occurrence model. As an example, a property of "Brophy Occurrence Model" (Williams et al., 2011) has been assigned in OpenEI to over 75 operating systems worldwide. Analyses can be conducted for areas of the same model looking at exploration histories, data, and exploration plans to identify successful methods for exploring a similar resource.

The OpenEI template can be easily updated and modified as new information and classification schemes are developed. For example, a catalog of play types is currently planned for presentation by Moeck and Beardsmore at the Stanford Geothermal Workshop in 2014. This catalog could easily be incorporated into the current template, and data could be uploaded to allow the information to be available for use in a query.

The goal of assembling these case studies is to be able to explore and analyze exploration data and information in a variety of areas to identify correlations among successful exploration programs for areas with similar geologic occurrence models and guide efficient exploration of new systems.

6. ACKNOWLEDGMENTS

This work was conducted with funding provided by the Assistant Secretary for Energy Efficiency and Renewable Energy, Geothermal Technologies Program, of the U.S. Department. We are grateful to Colin Williams (USGS) and Paul Brophy (EGS Inc.) for their input in the OpenEI templates, and to all experts who have previously provided (or may in the future provide) time in reviewing the many case studies in the collection.

REFERENCES

Adams, M.C., J.M. Moore, S. Bjornstad, and B.I. Norman, Geologic History of the Coso Geothermal System, Proceedings, World Geothermal Congress, Kyushu - Tohoku, Japan, 2000.

Beaumont, E.A. and N. H. Foster (Eds), *Atlas of Oil and Gas Fields , Volumes I-VII*, AAPG Treatise series, (1990-1992).

Moeck, I.S. and G. Beardsmore, A New 'Geothermal Play Type' Catalog: Streamlining Exploration Decision Making, Thirty-Ninth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2014).

Williams, C., M.J. Reed, R.H. Mariner, J. DeAngelo, and S.P. Galanis, Jr.: Assessment of Moderate- and High-Temperature Geothermal Resources of the United States, Fact Sheet 2008–3082, U.S. Geological Survey, Menlo Park, CA, (2008).

Williams, C., M.J. Reed, and A.F. Anderson: Updating the Classification of Geothermal Resources, *Presentation*, Thirty-Sixth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2011), p. 23. http://en.openei.org/wiki/Updating_the_Classification_of_Geothermal_Resources_-_Presentation