EMD Geothermal Energy Committee Mid-Year 2012 Report

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Committee Activities

Geothermal Resources Council Annual Meeting – September 30 – October 3, 2012

A total of 214 presentations were made at the GRC annual meeting in Reno, Nevada. At least 20 articles related to geothermal energy in sedimentary environments were identified through the table of contents by title and recognition of various authors involved with this type of geothermal energy production. When presented, the papers are arranged within session topics. Although there may be additional presentations that fall within low temperature geothermal production or geothermal energy from sedimentary rock, these were the presentations that stood out from the others. A brief description of these presentations is presented here.

Case Studies – 3 papers

While previous geothermal studies involving Mississippi have focused in the southern part of the state and the Mississippi River flood plain, a study presented by **Cary Lindsey** has looked at the eastern north central Mississippi area in Oktibbeha County. Using well data from the Mississippi Oil and Gas Board website, wells with online log images were downloaded with the BHT data recorded for the county. During the data analysis stage, temperature correction values were applied to the data that improved the expected temperature found at depth, thereby improving upon past mapping of the region and increasing the likelihood that geothermal energy could be produced over a larger area than previously thought. By contrast the Denbury Resources well that demonstrated coproduced geothermal power production using the ElectraTherm Green Machine was farther south in the Summerland Field of Covington and Jones Counties.

Jumping to the 'Old World' region of Germany, **David Lentsch et. al.** presented a discussion on overcoming drilling challenges with rotary steerable systems in deep geothermal wells in the Molasse Basin of southern Germany. These wells have been between drilled to between 8,200 to 14,700 feet, with horizontal displacement of up to 9,800 feet. The wells are drilled into karstified dolomites and limestones of the upper Jurassic that form the most productive thermal aquifer of the basin. Depending on temperature and production rates, the thermal energy is used for power generation coupled with heating, or for heating alone in the case of lower temperatures. Temperatures between 176 to 284^{o}F and water production rates over 44,000 BPD are common.

The third presentation, by **Olga Borozdina et. al.**, focused on thermochemical modeling of cooled brine injection into low enthalpy sedimentary reservoirs for district heating projects. The concept discussed is that of a doublet well system – an injector - producer combination – and the chemistry consequences that can result and which must be managed. Two case studies were modeled for this study, the Dogger limestones of the Paris Basin and the Rijswijk sandstones in the southern Netherlands (below). The practical outcomes of the studies were that although porosity changes caused by temperature-induced precipitation or dissolution of mineral species (carbonated, anhydrite, silicates) do occur, their magnitude does not significantly alter porosity, permeability, nor subsequent reservoir performance.

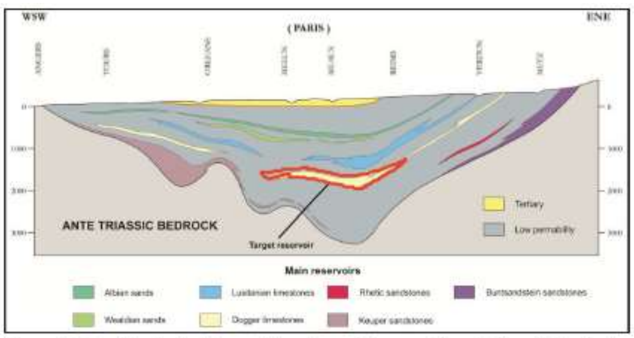


Figure 3. Case Study 1 - Dogger limestones. Cross sectional view of the Paris Basin and target reservoir (modified from Ph Maget 1983).

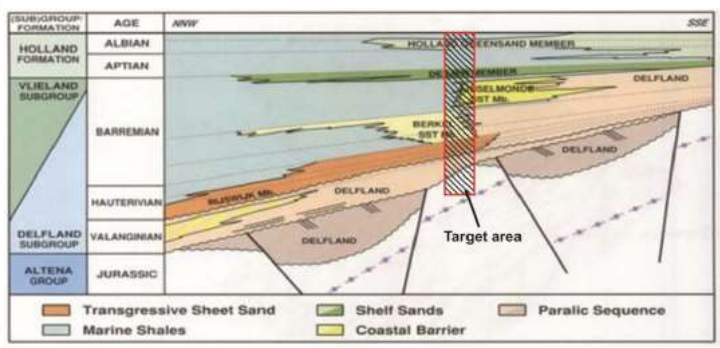


Figure 4. Case Study 2 - Rijswijk sandstones. Location of target area and geological background (Netherlands Organization for Applied Scientific Research, TNO).

<u>Coproduction – 5 papers</u>

Not to be outdone by coproduced geothermal demonstration projects in the U.S., the LB reservoir in the Huabei oil field has been studied and used in China for geothermal power production. **Shouliang Xin et. al.** reported that pilot tests were conducted in oil wells with produced water temperatures in the 230 to 250^{o}F range. The field is 93 miles south of Beijing with an oil reservoir area of around 11,000 acres, with the oil layer located in Mesoproterozoic Jixian System Dolomite at a depth of over 10,500 feet. Rock porosity was reported at 6.0% with permeability around 158 md. There is a dense micro fracture network at 1 to 2 fractures/cm^2. The rock is dominated by small vugs and the fractures are the main channel for fluid flow. Prior to this project there are 6 producing wells out of a field total of 27, with a 97.8% water cut. The project appeared to be an attempt to not only increase the amount of oil being produced but with the increase in hot water production to also capture the heat and generate electrical power. To test this concept a 400 kW screw expander manufacture by Jiujiang Power was used with a water flow of over 18,000 BPD from 8 producing wells. Gross output was 360 kW with net at 310 kW, for a total energy generated of 310,000 kWh of electricity over a several month period. When fully operational, the power plant (below) can generate 2,700,000 kWh of electricity per year, with an increase in oil production.

Figure 3. Oil-water tank and cooling tower.

Figure 4. Heat exchanger and geothermal power generation plant.

Figure 5. Geothermal power generation system: binary expander.

Returning to the U.S., **Chad Augustine** and **David Falkenstern** of NREL provided an estimate of the near-term electricity generation potential from coproduced water from active oil and gas wells. Previous studies have estimated that 15-25 billion barrels of water are coproduced annually. These studies suggested that total electricity generation potential could be in the tens of gigawatts. Augustine and Falkenstern focused on the near-term market potential of the coproduced resource by developing a 2.5 million well database from information derived from 24 state oil and gas commissions (below), of which 500,000 were identified as active wells. Cut-off temperature for electricity production was chosen to be 176^{o}F. As an electronic database for well temperatures was not readily available, the authors assumed a BHT from comparing the location and depth of the wells to previous U.S.-wide geothermal and temperature maps derived from the SMU Geothermal Laboratory and the older AAPG BHT database. With these assumptions in place, the authors concluded that a near-term electricity production potential of 300 Megawatts existed. Various practical operational factors such as minimum power plant size, available cooling water or transmission, project economics, etc. Interesting roughly two-thirds of the near-term potential was found to exist in Texas.

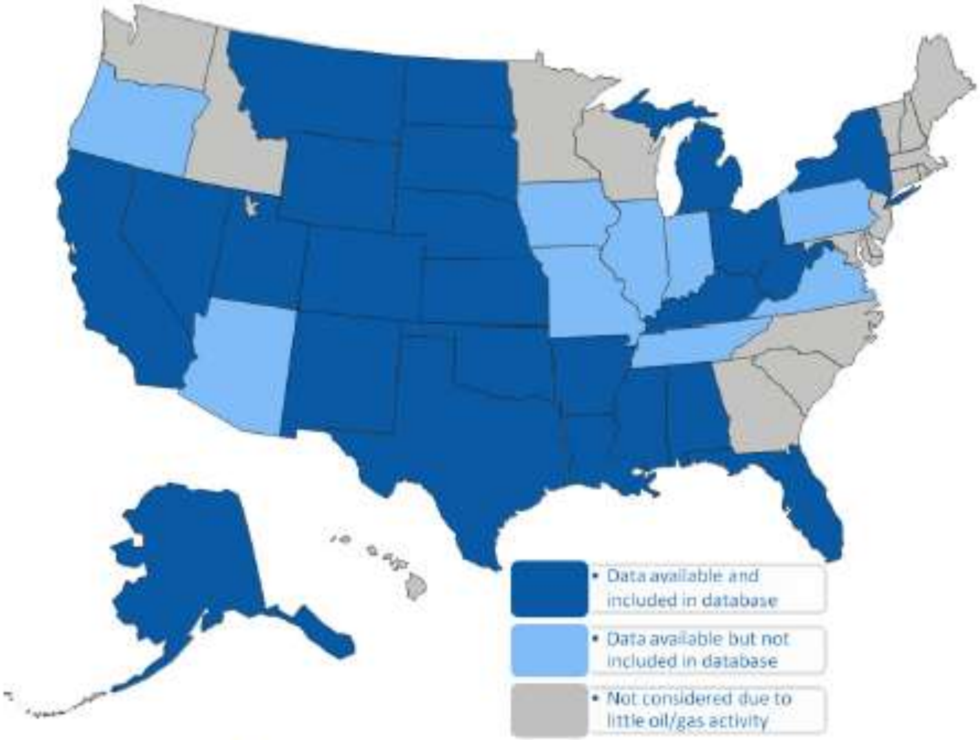


Figure 1. Map of United States showing states with oil and gas databases included in study.

Focusing in to specific basin level geothermal, **Anna Crowell et. al.** investigated various BHT correction methods within the Denver Basin of Colorado and Nebraska (below). When O&G wells are drilled the act of drilling alters the temperature profile of a well to some generally unknown depth into the surrounding rock. Since most wells are not allowed to sit to allow for a return to temperature equilibrium between the well bore and the formation, correction factors are the attempt calculate what the actual BHT in the well would be if equilibrium were reached. Crowell investigated three existing schemes: the Forster, the Harrison, and the Kehle corrections. Each of these correction equations were generated with a specific region or dataset in mind, making the application of these corrections to other basins inappropriate since different lithologies and thermal histories will be present in different areas. Several wells that were in the Nebraska part of the basin were in temperature equilibrium (below), and these wells were used to generate a correction factor specific to the Denver Basin.

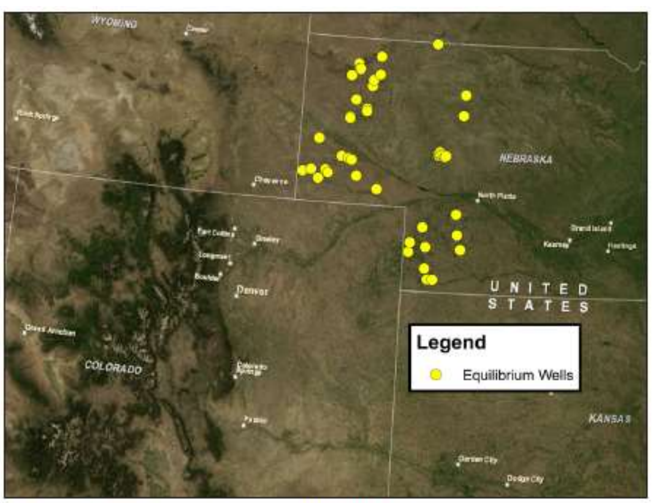


Figure 1. Locations of wells logged at equilibrium.

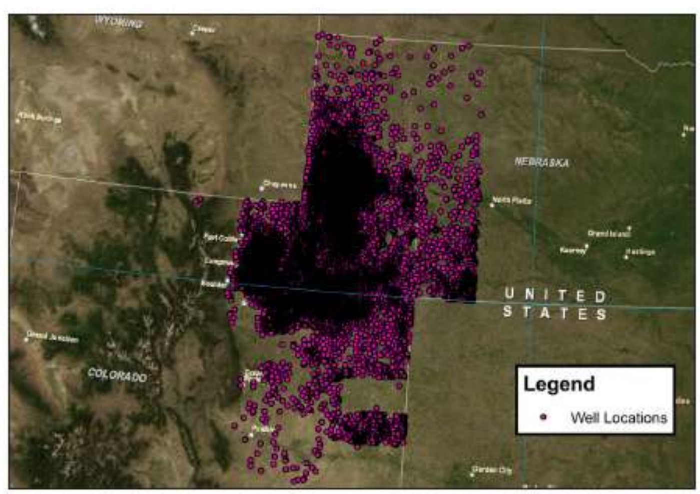


Figure 2. Spatial extent of the Denver Basin BHT data.

Moving into Wyoming, **Joshua Nordquist** and **Lyle Johnson** presented a discussion of data collected on a 3.5 year operation of an Ormat 250 kW power generation plant operating on the RMOTC facility at the Teapot Dome oil field north of Casper. During this time the power plant has produced over 2,120,000 kWh (enough for 120 homes each year) and utilized over 11,140,000 barrels of water, at a temperature between 195 to 210^{o}F. Production is from the Tensleep Battery that has up to 60,000 BWPD available from multiple wells. This project was started as a demonstration to determine the feasibility of coproduced geothermal energy and has been successful in showing the potential for future development. Further information can be found at www.rmotc.doe.gov.

Figure 1. The RMOTC OEC, commissioned in September 2008.

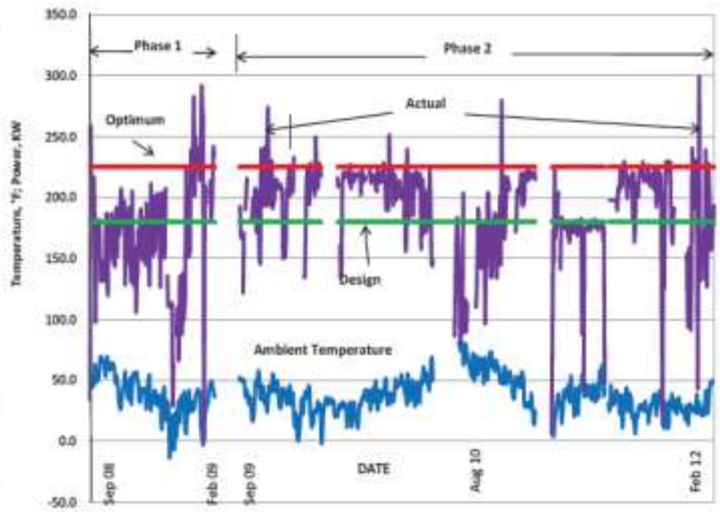


Figure 5. The RMOTC OEC has been operating for over 3.5 years.

Knowing and determining the reliability of data is important when using that data to make decisions regarding energy production, be it geothermal or O&G operations. Various standards of quality codes have been used since the 1970's for conventional geothermal analysis that include equilibrium temperature logs, thermal conductivity measurements, and appropriate data corrections. However the increased use of BHT data from O&G wells has required a reevaluation and new standards that cover this preponderance of new data being made available through the National Geothermal Data System**. Maria Richards et. al.** from SMU have proposed a revised reliability code that incorporated the past systems with increased parameter definition to cover both the traditional and BHT sites. A method encompassing weighted values for each primary parameter used to determine heat flow is linked in a series to rank the site reliability. Thus heat flows from different data types and calculation methods can be compared to determine data reliability.

Enhanced Geothermal Systems (EGS) – 2 papers

EGS represents an approach whereby a geothermal potential exists at a location but that the deliverable water/heat from that formation will occur only if the formation or rock units are enhance through some induced process – i.e. fracking. In the first of these two papers **M.S. Bruno et. al.** from Terralog USA stated that the recent advance in drilling, completion, and production technology within the O&G industry have the potential to be applied in the geothermal industry to unlock geothermal resources in areas where geothermal has not been produced. Working in conjunction with the University of California, Irvine, this group is investigating advance design concepts for paired horizontal well recirculation systems that would be optimally configured for geothermal energy recovery in permeable sedimentary and crystalline formations. In this example horizontal well pairs would exist as an injector and producer (below) to establish a relatively closed loop recirculation system, thus allowing more efficient and controlled flow and heat transfer, and reduced wastewater management requirements.

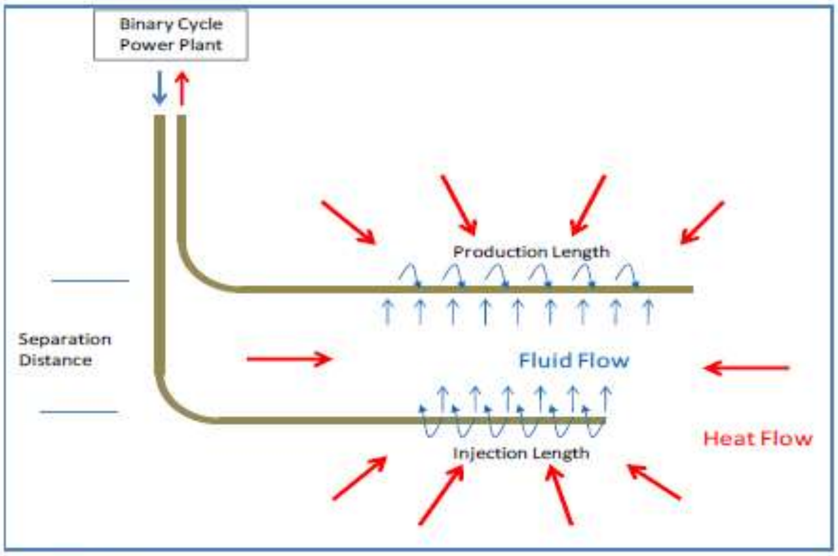


Figure 1. Horizontal well pairs for closed loop geothermal recovery system.

The second paper of this session by **Rick Allis et. al.** looked at stratigraphic reservoirs in the Great Basin. They indicate that deep basins in this high heat flow region of the western U.S. may have stratigraphic reservoirs deeper than 9,800 feet with temperatures over 300^{o}F. These reseervoirs are sub-horizontal and may be larger in area and geothermal power potential than the traditional fault-hosted hydrothermal reservoirs that have been previously developed. They looked in some detail at two such basins, the Black Rock Desert in Utah and the north Steptoe Valley in Nevada, identifying high temperatures and sufficient signs of stratigraphic permeability to warrant more intensive investigation of their geothermal power potential.

Exploration – 4 papers

Exploration is the first step in any subsurface energy (or mineral) production; you got to know where the resource is located. **M. Lee Allison et. al.** at the Arizona Geological Survey have been the portal of data collection for the National Geothermal Data System (below) was begun with financial support through the DOE for the purpose of fostering geothermal energy exploration and development. The data is being provided by all 50 states (www.stategeothermaldata.org), federal agencies, national labs, and academic centers. An increasing set of over 30 geoscience data content models is in use or under development to define standardized interchange formats for aqueous chemistry, borehole temperature data, DSTs, seismic event hypocenter, geologic unit features, well header features, heat flow/temperature gradients, and permeability to name just a few of the data assets being made available. As of May 2012 there were nealry 37,000 records registered in the system catalog, and 550,075 data resources online, along with hundreds of Web services to deliver integrated data to the desktop from free downloading or online use. The GDS is under simultaneous design, population, and deployment with completion of the initial phases due mid-to-late 2013.

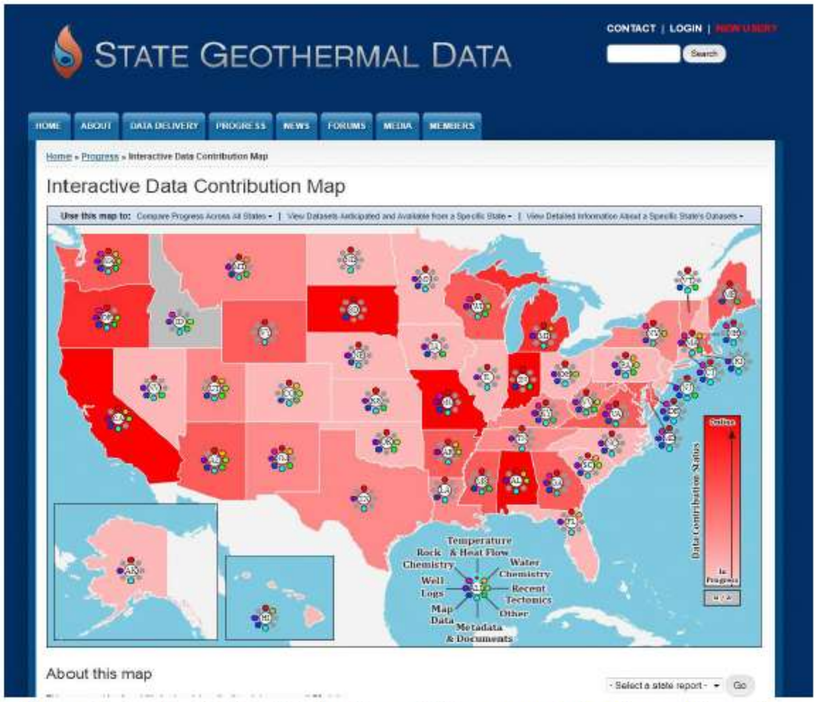


Figure 1. Interactive Data Contribution Map available on www.stategeothermaldata.org for tracking the progress of state's data collection.

Other groups actively involved in establishing this database are the DOE-EERE Geothermal Technologies Program, Boise State University, and NREL. **Arlene Anderson et. al.** presented information on the basic structure of the NGDS as envisioned by the DOE. They discussed the planned functionality of the site for data retrieval, usage, and submission of information. DOE foresees a NGDS that will allow users to search, analyze, and download high quality geothermal data sets and relevant geothermal information. Once the system is fully operational, the future of the NGDS lies in basic activites of data capture, data curation, and data analysis. An example of data analytical integration would be the use of an ESRI ArcGIS application used to pull in Google temperature and depth maps as well as SMU 2004 heatflow maps (below). The success of the program depends upon geothermal scientists and data scientists working to answer key questions pertinent to putting clean, base-load geothermal energy on-line.

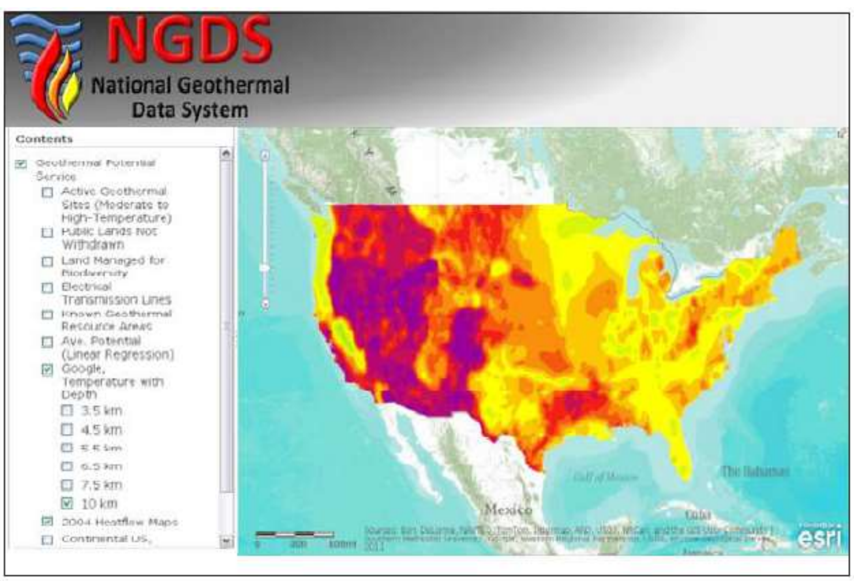


Figure 4. Example of NGDS Analytical Integration.

While the U.S. is actively placing geothermal related data in a format for anyone to use, Canada is also moving forward in ways for developing its geothermal resources. **Alexander Richter et. al.** provided a 2012 update on development within Canada involving resource potential, geothermal projects currently being developed, and a description of the current geothermal energy market and its players, along with the activities of the Canadian Geothermal Energy Association (CanGEA) that works to foster geothermal development in Canada. Various studies have indicated that a significant resource potential exists, but that the market for geothermal power and direct use of heat has remained stagnant. CanGEA has been working to create a favorable legal framework and support scheme on both the federal and provincial/territorial level. Additionally, CanGEA is developing a National Geothermal Database, provincial/territorial geothermal favorability maps, commencing work on a Geothermal Power and Direct Use of Heat Technology Roadmap and Implementation Framework, and continuing its efforts to bring geothermal to the oil and gas sector of Canada.

Power generation projects

Project	Developer	Province/ Territory	Status
Swan Hills	Borealis GeoPower	Alberta	Co-produced fluids project of 2MW
Canoe Reach	Borealis GeoPower	British Columbia	Feasibility phase
Lillooet	Alterra Power/ 2149749 Ontario Inc.	British Columbia	3 permits
South Meager	Ram Power	British Columbia	Under development
Ft. Liard	Borealis GeoPower	Northwest Territories	Feasibility for 1MW pilot project
Rafferty	Deep Earth Energy Production Corp.	Saskatchewan	Feasibility

Direct use projects

Project	Developer	Province/ Territory	Status
Ft. Liard	Acho Dene Koe First Nation, Borealis GeoPower	Northwest Territories	Feasibility stage
Con Mine	City of Yellowknife	Yellowknife, NWT	unknown

Figure 2. Overview of current projects in Canada.[2]

Return to the U.S., **William Gosnold et. al.** have been investigating the thermostratigraphy of the Williston Basin (below), important not only for geothermal energy but also for better understanding the history of oil and gas generation. They developed an approach for determining temperatures of strata in a sedimentary basin using heat flow, formation lithology, thickness, and thermal conductivity of rock. They calibrated the method on five sites in the basin where temperature versus depth profiles allowed an iterative analysis of temperature gradient, thermal conductivity, and heat flow. Comparison of the temperature projections to BHT provided insight on determining a reliable correction for BHT data. Large scale application of the method using stacked structure contours can provide a complet and accurate assessment of geothermal resources in a basin.

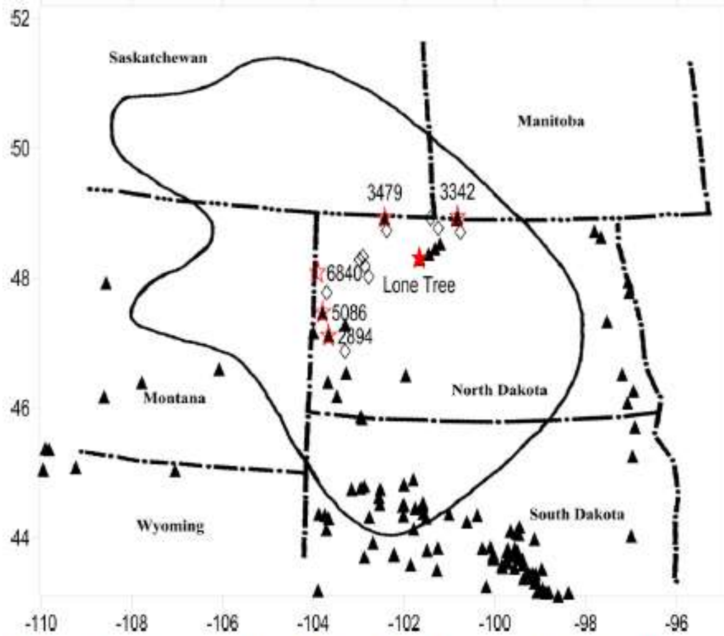


Figure 1. Locations of Williston Basin heat flow sites (black triangles and solid red star), deep wells with equilibrium temperatures (open red stars) and cored well sites with thermal conductivity measurements (open diamonds). Numbers identify wells in Figures 3-7 and Tables 2-6. Solid red star designated "Lone Tree" is an oil field site where the first heat flow measurement in the basin was made (Blackwell, 1969).

Geophysics – 1 paper

Reflection seismic data has generally not been used extensively in the geothermal industry while magnetic surveys have been more important in industry development. **E.P. Ardakani** and **D.R. Schmitt** presented a discussion on the integration of both survey types for geothermal exploration in NE Alberta, Canada. The "Athabasca region" holds a significant amount of Alberta's bitumen resources contained in both oil sands and carbonates. The area has not been developed due to is relative isolation from existing infrastructure and uncertainties associated with in-situ production from the carbonates. More recent interest in the region has opened possibilities for either EGS or conventional geothermal system development. Over 50 2D seismic lines and high resolution aeromagnetic data, along with well log data from 511 wells, were obtained for integration and interpretation in construction a regional geological/geophysical model for this area of relatively thin layers of sediments overlying the Precambrian metamorphic rocks of the Canadian Shield. Motivation for the study is the need to find sustainable and lower greenhouse gas emission solution for production of bitumen from these oil sands, using the geothermal heat as part of the production process.

Regulatory Environmental Issues – 2 papers

Energy and environmental analyses have been important in working to develop a robust set of geothermal technologies that meet future demand. Previous work summarized what is currently known about the life-cycle freshwater requirements of hydrothermal and EGS-generating systems. **Corrie Clark** and **Chris Harto** of Argonne Nationa Laboratory presented an assessment of the use of freshwater in low-temperature geopressured geothermal power (GPP) generation systems as part of a larger effort to compare the life-cycle impacts of geothermal electricity generation with other power generation technologies. Argonne carried out this life-cycle analysis (LCA) to quantify energy, water, and environmental impacts of GPP plants to understand the potential environmental impacts of future geothermal industry growth. The LCA boundaries include all on-site activities for the construction and operation of a geothermal facility over a 30 year operational lifetime. The LCA focused on a GPP scenario that produced 3.6 MW of electric power from the geothermal contribution and 17.3 MW of thermal power from the natural gas contribution. Parameters (below) used were based on industry expers and well field characteristics at Pleasant Bayou (Texas) and other geopressured geothermal test wells. Clark and Harto found that on a per-well basis and a per-kWh lifetime energy output basis, geopressured geothermal systems appear to consume less water than other geothermal technologies. Overall water requirements across the lifetime are low because maintaining reservoir pressure is not a long-term goal of geopressured systems. The spent geofluid is typically sent to a disposal well, alsothe opportunities for reuse of the geofluid could be explored.

Table 1. Parameters Evaluated in Geopressured Geothermal Scenario.

Parameter	Assumed Value
Producer/injector ratio	2:1
Number of turbines	1
Generator type	Binary
Cooling	Air-cooled
Temperature, °C	130–150
Thermal drawdown, % per year	0
Well replacement	None
Production well depth, km	4–6
Injection well depth, km	2–3
Gas/brine ratio (SCF/STB*)	25–35
Flow rate, kg/s	35–55
Distance between wells, m	1,000
Location of plant relative to wells	Central

* SCF/STB = standard cubic feet per stock tank barrel.

Turning from freshwater usage in geothermal production, **Paul Morgan** presented information on geothermal regulations in Colorado, with land ownership being a key issue. Colorado geothermal resources are separately classified as water on private land and as mineral on state and federally-administered lands. Additionally, where classified as mineral, only the heat is classified as mineral, regardless of the land administration. Any water used to extract the heat is administered by the Colorado State Engineer through the Division of Water Resources. Rules and regulation for permitting geothermal exploration and development are better understood if considered separately for private, state-administered, and federally-administered lands. Many geothermal resources cover more than one of these types of land, but the permitting processes are not synchronized. Sovereign Native American lands were not included in his discussion as they represent a special category of land. As a result multiple agencies may be involved at any given time with geothermal activities (below), with each agency or group operating on different time schedules.

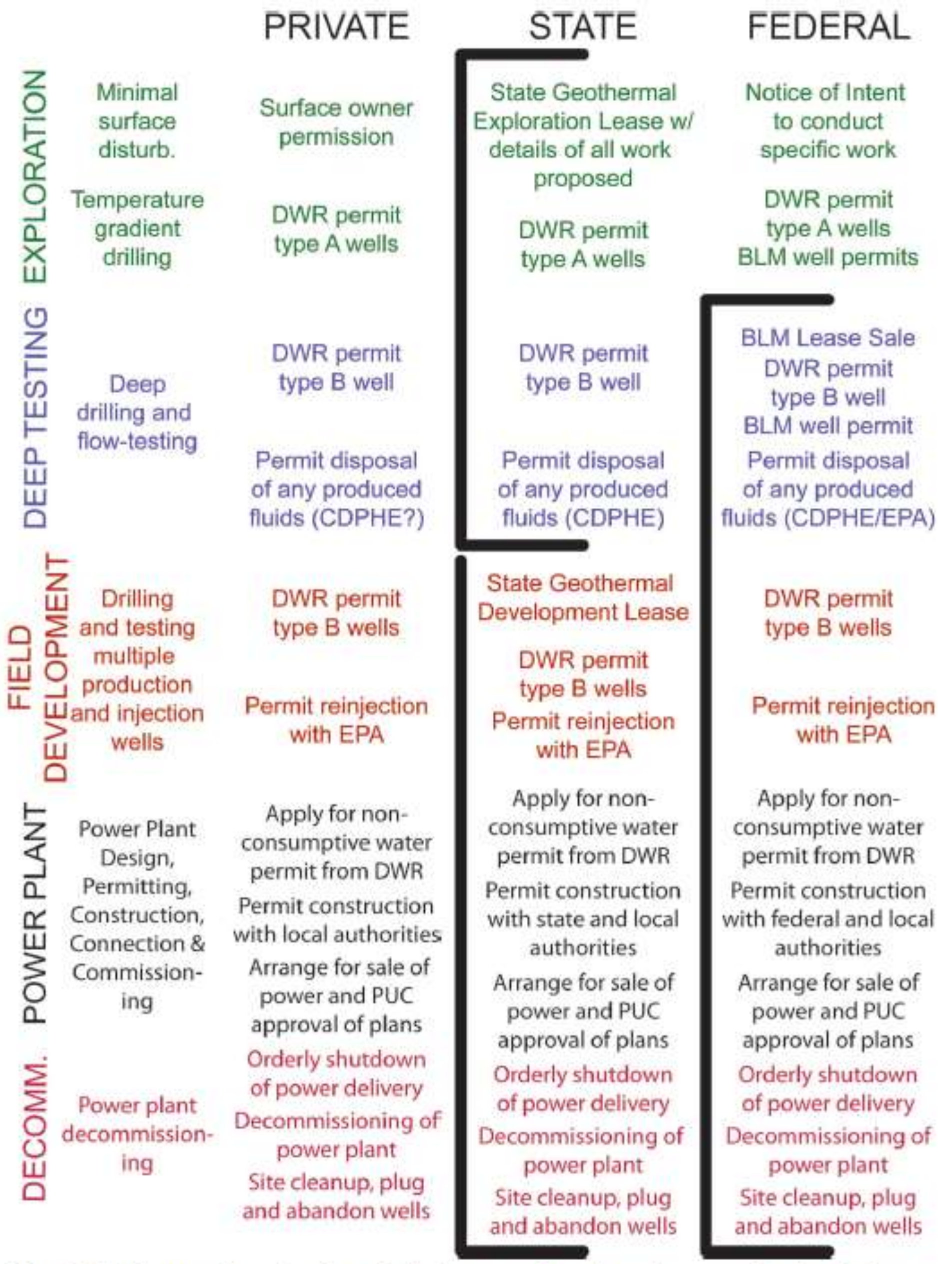


Figure 2. Basic stages in exploration and development of geothermal resources for electrical power generation in Colorado and corresponding major permit processes on different land types, as described in text. The heavy black brackets under "State" indicate the duration of the State Geothermal Exploration Lease and the State Geothermal Development Lease if all activities indicated are applied for and approved in the respective lease applications. The heavy square brackets under "Federal" indicate the duration of activities for which a Federal Geothermal Lease can last (also time limited), but each activity requires a separate application and approval. Abbreviations: DWR - Colorado Division of Water Resources; BLM - Bureau of Land Management; CDPHE - Colorado Department of Public Health and the Environment; EPA - Environmental Protection Agency; PUC - Colorado Public Utilities Commission.

<u>Reservoir Management – 1 paper</u>

Every geologist knows that geothermal energy is a vast resource, based solely on the makeup of our planet. The difficulty is in retrieving it for use and support of our technical infrastructure. Much of the geothermal production has historically occurred in the western states, with EGS technology opening areas where low-temperature geothermal reservoirs can be used for various purposes. **Madhur Bedre** and

Brian Anderson from West Virginia University presented a paper discussing sensitivity analysis of low-T reservoirs and the direct use of geothermal energy. While they indicate that the eastern U.S. has lower temperature gradients than many of the western states, Wet Virginia has higher gradient compared to other eastern states. Of course knowledge of this fact has been the direct result of much greater drilling in places such as the Appalachian Basin for O&G reservoirs. For example, this data has resulted in identifying a hot spot in the eastern part of West Virginia with temperatures reach 300^{o}F at a depth of around 14,700 to 16,400 feet. Bedre and Anderson performed a sensitivity analysis of a reservoir at this temperature and at a depth of 16,400 feet using seven natural and human controlled parameters within a geothermal reservoir: reservoir temperature, injection fluid temperature, injection flow rate, porosity, rock thermal conductivity, water loss (%), and well spacing. A 30 year timeframe of operation was used to run the reservoir simulation. There results indicated that reservoir temperature was the most important parameter affecting production. Variations in porosity and rock thermal conductivity did not affect the reservoir performance significantly. Other factors had varying levels of impact, with reservoir temperature or injection flow rate having the greatest impact.

Resource Assessment – 2 papers

There has been a renewed interest in recovering the geothermal energy stored in sedimentary basins (below) for electricity production. With exploration for O&G resources, well logs, temperatures at depth, and reservoir properties such as depth to basement and formation thickness are better known than in many conventional geothermal areas. The availability of this data reduces exploration risk and allows development of exploration models for each basin. **Collen Porro et. al.** of NREL presented estimates in the magnitude of recoverable geothermal energy from 15 major U.S. sedimentary basins (below) and ranked these basin relative to their potential. Total available thermal resource per basin was estimated using the volumetric heat-in-place method, and a qualitative recovery factor was determined for each basin based on data on flow volume, hydrothermal recharge, and vertical and horizontal permeability. Some of the findings of this study are shown below in the following figures. A more in depth study is necessary to better determine recovery factors for each basin. [*Of interest is that onshore Gulf of Mexico was not included in this study, where past efforts produced viable geothermal energy – Erdlac comment.*]

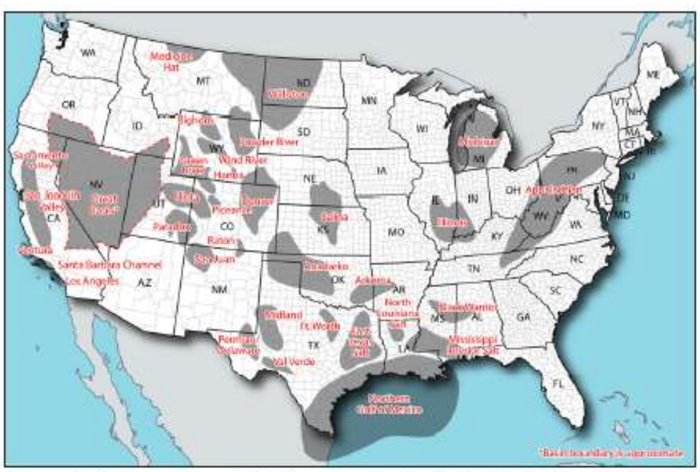


Figure 1. Surface extent of sedimentary basins in the United States (adapted from Davis, 1984; Faulds et al., 2004).

Table 1. Sedimentary Basins Included in Analysis.

1	Anadarko	9	Powder River
2	Bighorn	10	Raton
3	Denver	11	Sacramento
4	Ft. Worth	12	San Joaquin
5	Great Basin	13	Uinta
6	Green River	14	Williston
7	Hanna	15	Wind River
8	Permian/Delaware		

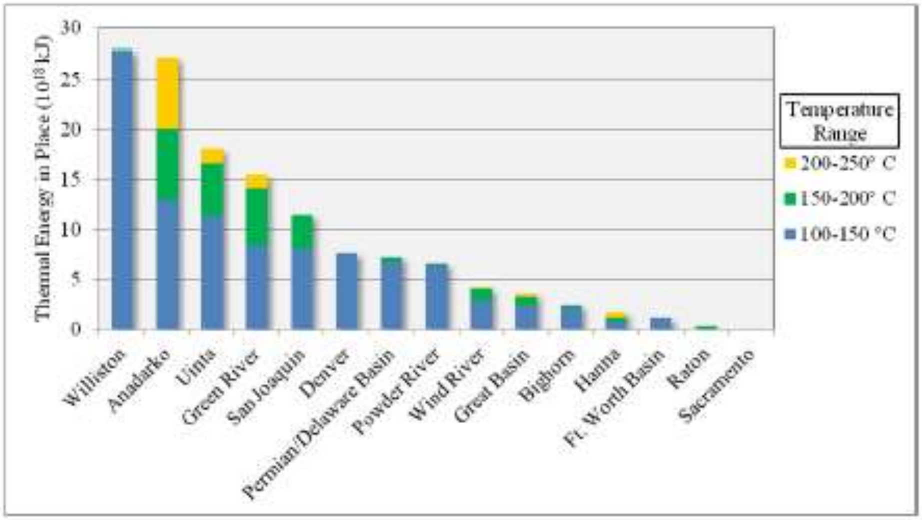


Figure 8. Total heat in place for all 15 basins from highest to lowest.

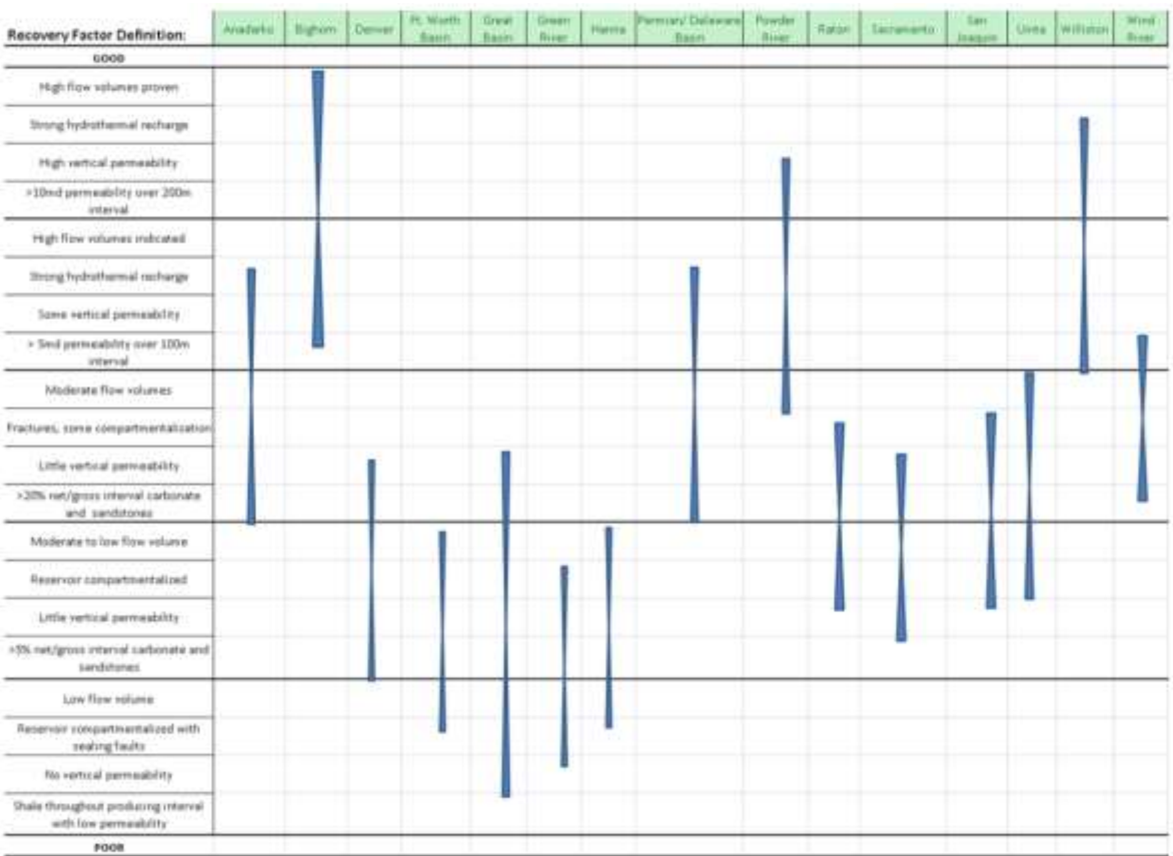


Figure 9. Qualitative plot of basin recovery factors.

Turning from the regional U.S. basin study to a specific basin, **Karoline Bohlen** presented a preliminary geothermal resource assessment for the Raton Basin in Colorado. While Colorado has substantial thermal resources, slow geothermal progress has generally been due to geological complexities, rugged terrains, and NIMBT attitudes that have prevented serious development. A number of rock samples have been taken from the outcrop of Basin rocks to determine thermal conductivity in the laboratory. Surface and BHT data was available from 1,172 active gas [*probably coal-bed methane – Erdlac comment*] in the

Raton Basin from an operating producer. Total depths ranged from just over 650 to over 7,200 feet. The majority (999 wells) are less than 3,200 feet and go no deeper than the Pierre Shales. Using the well data and conductivity values thermal gradients and heat flow were calculated for 3,200, 6,500, and 9,800 foot depths, indicating higher temperatures at depth than previously thought. All of the analyses resulted in a picture of the Raton Basin being a far better candidate for geothermal power production than previously thought. [*This is interesting due to the fact that Pioneer Natural Resources through the efforts of Hal Macartney has worked with the Colorado Geological Survey to conduct a small investigation of the geothermal potential for power generation for possible on site usage, as reported in the past – Erdlac comment.*]

SMU Geothermal Conference – March 13-14, 2013

No geothermal conference was held at SMU in 2012 as there was conflict with other geothermal meetings around the country and the fact that the SMU personnel were busy in participation is these conferences, such as at the AAPG Annual meeting. However an SMU Geothermal Laboratory Conference on Geothermal Energy and Waste Heat to Power: Utilizing Oil and Gas Plays was held in March, 2013 with 171 attendees, 24 oral presentations, and 10 poster presentations. The AAPG EMD geothermal committee was represented by David Blackwell and Paul Morgan. I had planned to attend but an illness that my wife had precluded my attendance. Notes recorded about the conference taken by Denise Gatlin and Maria Richards, along with a student Stefano Benato, assisted me in writing this article.

For the past seven years there has been a new focus for the geothermal industry to use the data from oil and gas fields to develop coproduction of all fluids and in turn extract the heat to generate power. Since the first SMU Geothermal Energy Utilization Conference in 2006 numerous improvements in technology, resource evaluation, and associated economics have occurred. The paradigm shift from high temperature, hydrothermal system geothermal development in the western US, to today's focus including low temperature, coproduction sedimentary basins, represents the broader interest in pushing the envelope for producing electricity. The expectation of early adoption by the oil and gas community has fallen short, yet interest and expectation that someday it will happen is generally accepted. For the first time, this event combined the surface waste heat to power (WHP) equipment with geothermal energy projects, realizing the need for the oil and gas industry to be able to "kick the tires" on equipment and in the process immediately be able to take advantage of the heat and pressure currently created by their surface equipment. This is of special interest as indicated by Texas Railroad Commissioner David Porter hosting a workshop on using excess natural gas for power on drilling leases, along with discussion of other options for on-site power generation such as waste heat energy capture in December of 2012.

<u>Oral Presentations</u>

Opening remarks by the Maguire Energy Institute's **Bud Weinstein** stating "Heat is a terrible thing to waste!" grabbed the attention of the attendees and set the ground work for covering all aspects of electrical production from heat sources in oil and gas fields. The source could be from surface equipment, referred to as "waste-heat", or geothermal heat brought to the surface with oil/gas/water from the reservoir.

Federal Energy Regulatory Commission (FERC) Chairman **Jon Wellinghoff** impressed the attendees during his keynote address with his in-depth knowledge of the geothermal and waste heat resources and applicable technologies. Wellinghoff emphasized FERC's focus to open the generation market to small, independent producers as a method to improve US electrical security, consistency and ability to deal with natural hazards. Use of geothermal resources, in all forms from home loop systems to direct use to electrical production along with the vast applications for waste heat power are seen by Wellinghoff as part of the necessary energy mix for the US to meet the projected electricity generation needs for the future.

The conference structure took attendees through all aspects of oil and gas field development, representing the vast applications for both geothermal and waste heat to apply to improved field operations. The Environmentally Friendly Drilling Systems Program (EFD) presenter, **David Burnett**, explained how society's acceptance of environmental issues either slows or speeds up changes from innovative technology improvements. Texas A & M University has been the coordinator of the EDF program working with US DOE, HARC, RPSEA, oil/gas companies, universities, national labs, and environmental organizations to develop and implement improved hydraulic fracturing use of water, and air emissions from drilling. An EDF scorecard was developed and is available to see how any site ranks within the defined criteria. Although geothermal is a smaller industry, as developers move into sedimentary basins for coproduced geothermal or larger scale projects using enhanced geothermal systems, Burnett emphasized the need to engage all stakeholders, public and private, for successful project completion. [*Just as hydraulic fracturing has resulted in public and private push-back in the O&G industry, the geothermal is not immune to similar events, such as push-back occurring in Hawaii regarding geothermal development – Erdlac comment from GEA news announcement.*]

Maceij Lukawski, a PhD candidate at Cornell University, compared geothermal drilling to oil and gas drilling costs. Flow rates in geothermal wells can only be dreamt about in most oil and gas environments as they start for geothermal typically in the 10,000 BPD range. Well drilling and completion contribute 20 – 75% of the capital investment in geothermal power plants, with enhanced geothermal systems the most costly upfront expenditures because of the deeper depths. One difference from oil and gas completions is the cementing of the full annulus because of the pressure and flow rates. Yet the study showed that while the cost of drilling has increased for oil and gas wells, geothermal well costs have leveled off because of improvements in drilling techniques for deeper depths, and at shallow depths (<6,000 ft) geothermal is similar to slightly less in cost. Lukawski concluded that the geothermal community should not use the oil and gas cost indices to normalize the cost of geothermal wells.

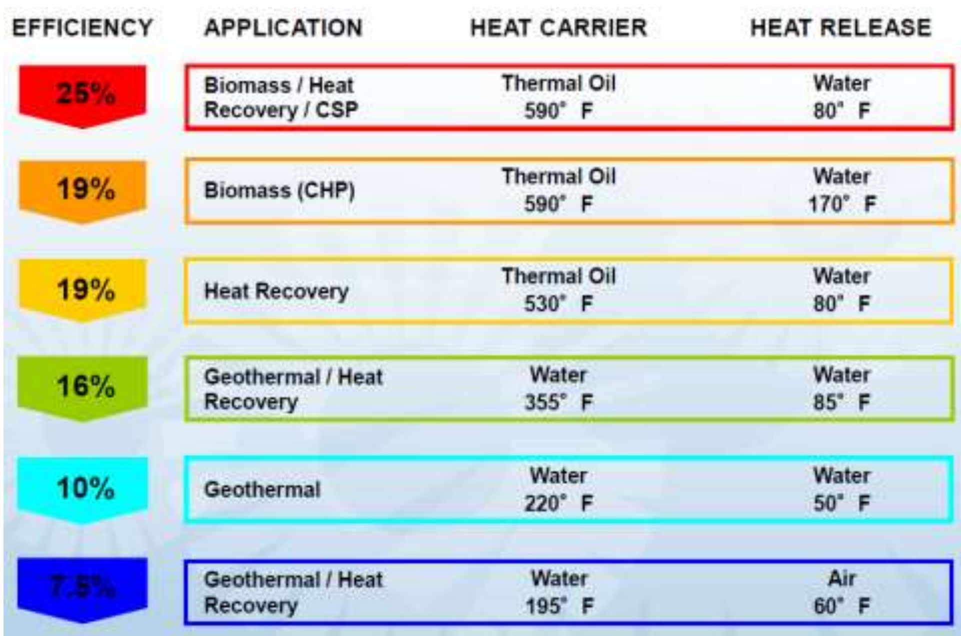
Once the reservoir is drilled, testing is needed; **Randy Normann** of Perma Works discussed how the Hydro-Fracturing Monitoring Tool is able to 'run barefoot' (no heat shield) up to 570°F under high pressure and stay in the reservoir for weeks to years without removing the logging tool. This allows for long term monitoring of changes in the well and reservoir such as testing changes in injection or production, well connectivity, shut-in testing, reservoir pull down test, and power plant maintenance. This capability will change our understanding of the life of a reservoir system, pressure fluxes, and how to improve stimulation. Tools capable of these harsh conditions make high temperature EGS projects more viable.

300C, 7/32 Cable

Here the tool NEVER leaves the well for ~24 hrs. Using it's high-speed pressure or standard logging mode, this tool can support hydraulic fracturing up to 25,000 psi/275C. In permanent well monitoring, PW electronics have demonstrated 2 years at ~200C.

A key factor driving the rapid improvement in equipment is the ability for manufacturers to meet the needs of both the geothermal and waste-heat to power communities with the same technology. Highlighting the small-scale (<100 kW) environments, **John Fox** of ElectraTherm discussed improvements in their Green Machine after a demo at an oil well in Mississippi (below) and how the same technology is being deployed rapidly into the European market to meet the demand for waste-heat applications. With fluid temperatures in the 190-240oF temperature range, a number of O&G operations become viable for waste heat energy capture including coproduced hot fluids, compressor stations, natural gas well head flaring, and amine sweetening plants.

Mike Ronzello of Pratt and Whitney Power Systems discussed the expected outcome from the acquisition by Mitsubishi Heavy Industries of the PWPS/Turboden ORC equipment line, which ranges from small to medium sized (1 – 10 MW). Ronzello's graphic on efficiency as a function of resource and surface temperature clearly explained the benefit of utilizing the highest heat sources. In his example, similar equipment efficiency can range between 7.5% and 25%, depending upon the source temperature variations, i.e., 195°F and 590°F respectively. This emphasized the importance of the temperature rather than industry or source of the temperature: biomass, geothermal, waste-heat, CHP etc.



Trying to contain excitement, **Halley Dickey** of TAS Energy (Turbine Air Systems), showed pictures of their first project on “un-separated mixed hydrocarbons” in California (below) at a mid-stream oil production facility. This project had fluid temperature of 300^{o}F from the ground at 38,000 lbs/hr and is from a steam flood. The expander was designed for a 1.2 MW output with actual gross output of 750 kW and a net of 500 kW. It was expected that this site has a potential of 1 MW gross output. The second part of Halley’s talk was on a “geopressured integrated hybrid system” that TAS is working on in the Gulf Coast region. Geopressured hybrid systems were proven at Pleasant Bayou in Brazoria County, Texas in the late 1980s with a nominal 1.0+ MW output from heat in the produced water and natural gas burned on site. This project would expand this work by incorporating a binary system with the un-separated mixed hydrocarbon approach along with waste heat recovery from engine exhaust and jacket water, and other efficiency improvements, for an integrated hybrid system producing 3.5 MW from some 25,000 BPD of produced fluid. Filters would be used for particulate capture should this be necessary.

For the first time, two newly developed pressure related power systems were publicly viewable on the SMU Campus for the Geothermal Conference. **Kevin** and **Andy Kerlin** displayed their Helidyne planetary expander, named after the similarities to the sun/planets relationship for the machine’s extremely high precision rotating system with no belts or gears. This state-of-the art expander is designed to work with natural gas application such as J-T valves, wellhead chokes, gas processing plants, let-down stations and where possible, geothermal-geopressured wells.

The second system, the Langson Helical Screw Energy Converter, developed by **Richard Langson**, was installed in the SMU Campus boiler room to run the pressure equipment and show how it is capable of installation/removal in just hours. The machine greened-up campus electricity for a few hours during the day of its installation. Capable of using either water or steam it allows for fluctuating flow rates or pressure changes, making it applicable in numerous industry applications, such as geothermal-geopressure, petrochemical, power plants, biogas, and on equipment in the oil and gas field. The system is scalable with sizing variations between 1 to 50 MW. Langson indicated that installation costs could be ≤ $1,500/kW with return on investment in 1.85 years.

Instead of line shaft and submersible pumps for a high water cut well, the Gravity Head Pump is designed for installation without shafts, rods or electrical cables. **Michael Pierce** of Geotek Energy explained how with one additional string in a well the expander-pump is capable of lifting fluids from deeper depths and generates power from high temperature sites. The technology patent is pending and locations to demonstrate the technology are under consideration.

Setting the example in the gas compressor station business is the Canadian Gas Pipeline industry. **Tony Straquadine** of NRGreen Power gave examples of what the US could be accomplishing based on the already successful power generation in Canada. Using ORC technology the waste-heat to power facilities in Saskatchewan are producing over 20 MW currently, and in Alberta additional sites will bring the total generation to approximately 40 MW. Straquadine conveyed the frustration of the waste heat to power industry (WHP) not being included as a renewable energy equivalent since it's not defined in PURPA or the Energy Independence and Security Act of 2007. This sentiment was highlighted by **Kelsey Southerland** representing the WHP industry trade association, Heat is Power. This energy source is application based for generation capability, therefore the individual states have determined if it will be considered part of the renewable portfolio or considered separate. Being considered part of the renewable package option opens the door to improved financing, electrical purchase price, and tax credits. For the oil and gas industry, through inclusion of surface waste heat in their operations they have an opportunity improve their energy efficiency and in addition generate income through renewable energy credits and/or carbon offsets in those states with WHP incentives.

Presenter **Trevor Demayo**, Energy Management Coordinator for Chevron's San Joaquin Valley Operations detailed the competing uses for waste heat in a field before it can be used to generate electricity. The challenges are to find the locations where incremental power is needed, high power costs, and safety and security are improved with additional on-site electrical generation. Often the changes in the oil and gas industry are driven from regulations in other countries raising the bar to efficiency. Although the conference had generating electricity as a focus, it was noted by multiple presenters the need to off-set heating/cooling of buildings; how the use of wells for district heating or green commercial building sites is another substantial resource currently being under-utilized. Demayo included offsetting building loads for field operators as a first step to reducing known expenses, with little permitting/regulation concerns. District heating is underway in West Chester University in Pennsylvania and even Maine has geothermal potential with economically designed systems for buildings.

Through the increased ability to use bottom hole temperature data from oil and gas wells, the geothermal industry has studied how to correct the temperatures for drilling impact and then determined the geothermal resource. Discussed at this meeting were the reserves for Maine, New York, Pennsylvania, North Dakota, Oklahoma, Texas, Colorado, and Montana. The outcome of these studies shows that within sedimentary basins there are areas with temperature differentials between surface and current drilling depths possible of generating electricity. In states with high winter heat loads, there is also the ability to use the under 200°F fluids to heat buildings and thus reduce our nation's need for fossil fuel generated electricity. Texas Christian University has received an NSF grant to fund further research on stored energy within sedimentary basins. **John Holbrook**, lead of the SEDHEAT program, emphasized the importance of removing hurdles for the geothermal and oil and gas industries to work together on defining and developing the next generation of combined plays. Fluid flow pathways must be defined at a broader scale as well as more refined for greatest heat extraction. Inclusion in the SEDHEAT program is open to all researchers and companies.

The expectation by the geothermal industry is for low temperature coproduction projects within sedimentary basins will expand into the large-scale enhanced/engineered geothermal system (EGS). The US DOE is funding projects to move the "future of geothermal" forward. As results of experiments in

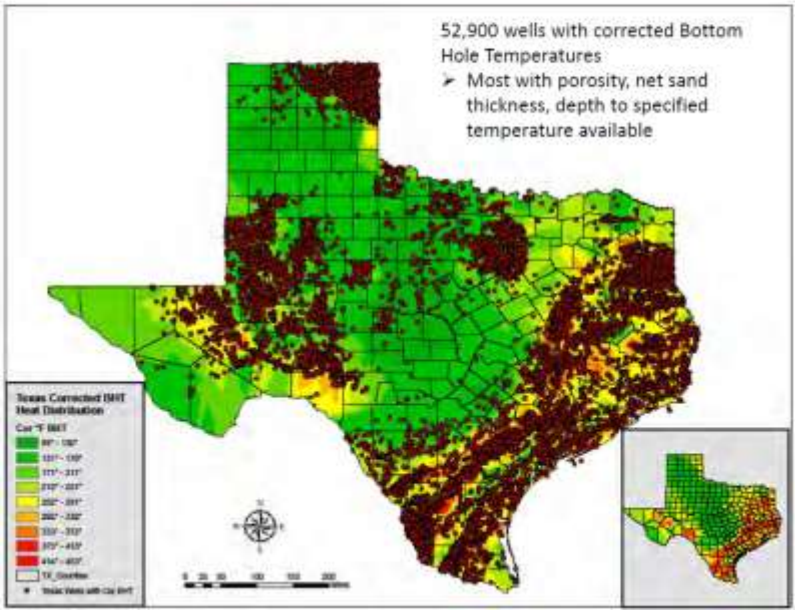
EGS during the past few months, that future is now today. **Matt Uddenberg** of AltaRock Energy highlighted how the project at Newberry Volcano in Oregon has successfully hydrosheared (created shear failure along existing fractures) the reservoir thereby increasing the reservoir capacity from approximately 10 l/s to 20 l/s over a one month cycling injection procedure.

High water volumes are rarely the talk of the oil and gas industry, but as **Will Gosnold** (University of North Dakota) showed, in the Williston Basin there is no way to avoid it. And, high water volumes are exactly what is needed for oil and gas wells to be economically viable for the geothermal energy production. By switching the focus and producing even higher water volumes, are possible geothermal sites using the Bakken, Red River, Madison and Cedar Hills formations. Finding companies to work with on demonstration of equipment is difficult. Denbury Resources is one company who has done so multiple times, allowing for comparison of various companies' equipment for the same field conditions both in the Williston Basin and central Mississippi. Gosnold's 2011/13 presentations compare output efficiency and cost for the power production equipment available. In the US with the 30% ITC and 10 cent power the payback is typically less than 5 years. As the MWs produced increases, the price/kilowatt hour needed drops to as low as 5 cents.

High water cut is also found to the west in Montana, where **Gary Carlson** reported on work underway on the Fort Peck Reservation. The area has a significant number of wells where coproduced geothermal energy has potential. Some 760 BHTs have been analyzed to date with the highest temperature recorded at 278^{o}F; nearly 90 BHTs are equal or greater than 200^{o}F. In addition to working with existing wells the project seeks to identify the geothermal potential in undrilled areas on the Reservation. Economic analysis toward power generation and greenhouse heating options are part of the project.

To the north yet into central Alaska, **Bernie Karl** of Chena Hot Springs gave a rousing presentation involving several new geothermal applications currently in use at the resort in Alaska. Beside approximately 400 kW power generation from two PWPS PureCycle units, Chena uses hot water for heating buildings, greenhouse support, and a 15 ton absorption chiller for temperature control inside their Ice Museum. A new 300 kW screw expander designed by Kerry and produced by Kaishan Compressor Co. is being installed to increase on-site production of additional electricity. Chena Power is also completing two mobile ORC demonstrations in Utah that can be used in oil and gas fields.

Heading south to a warmer climate **Bruce Cutright** of the BEG spoke on the state wide database of well temperature being compiled and that will be available in September, 2013. He discussed data analysis results, site identification, economics of geothermal and its competitiveness, and alternative heat extraction fluids such as CO2. The largest area of higher geothermal gradients was shown to be along the Balcones fault system and to the east and south. Other local areas of interest included the Crockett and Val Verde County area, the Trans-Pecos region along the border with Mexico, the deepest part of the Delaware Basin, a portion of the Texas Panhandle, and in the Fort Worth Basin.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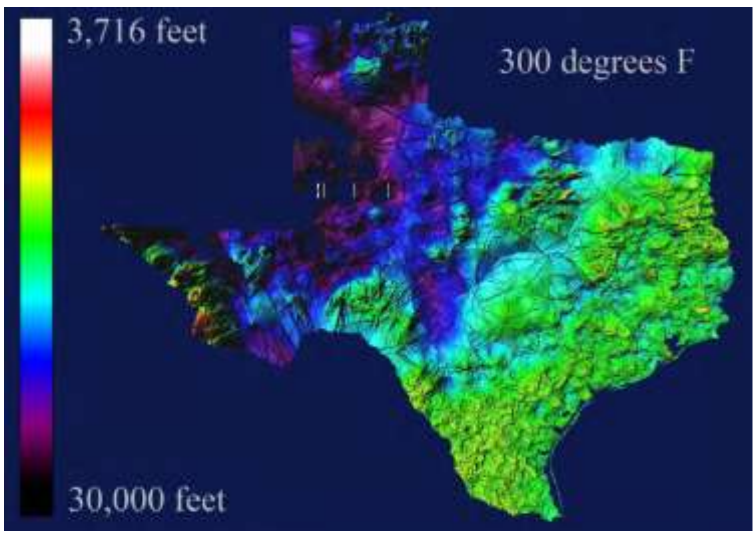
➢ Most with porosity, net sand thickness, depth to specified temperature available
Texas Corrected BHT Heat Distribution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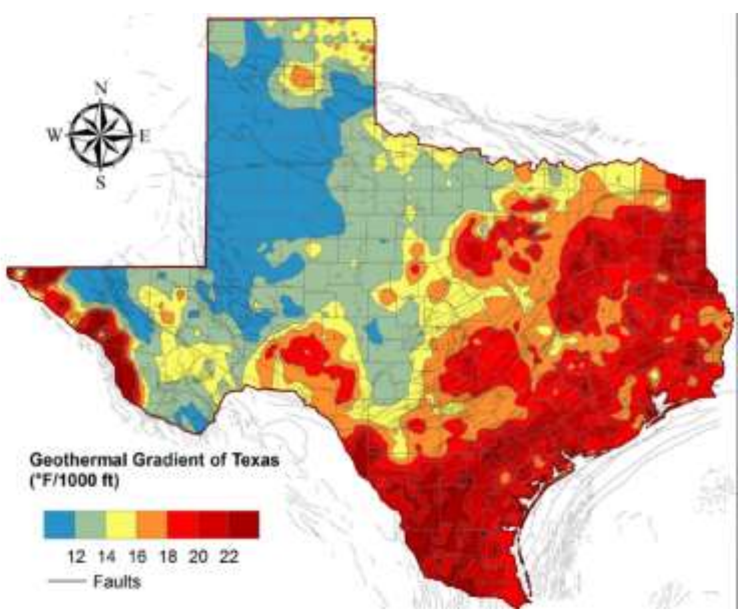
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The use of CO_2 for heat transport was continued by **Paul Dunn** (Enhanced Energy Group) as he spoke on its use in enhanced oil recovery and its potential use in engineered geothermal systems. He contrasted the use of CO_2 and water for heat transport. CO_2 has advantages over water in fields with reduced natural fluids. A current problem is the quantities of CO_2 required makes cost a major factor. New technology is reducing the cost to produce the CO_2 and designed for large scale production of 2 to 12 MW of electricity generated while consuming the CO_2 into the geothermal reservoir. It can also be used for enhanced oil recovery and beneficial for a combined geothermal/oil operation.

On the water side of things, **Steve Erdahl** presented information on re-using produced oilfield water, not just in geothermal development but also the impact of hydraulic fracturing. He reviewed aspects of macro market trends, economic analysis, and the growth of water usage in the oil and gas industry. He contrasted some of the differences such as cost of water usage between the geothermal and O&G industry.

Turning to other topics, energy financing for geothermal power was presented by **Daniel East** of The Carlyle Group. He spoke on the various types of energy related projects that the Group supports, with their focus on mezzanine financing. He discussed the typical geothermal project life cycle as it presently exists.

Electrical connectivity and various legal issues helped to round out the broad arena of topics. **James Schue** focused on Texas regulation of geothermal and the various agencies involved. This included past laws enacted by the state legislations that defines geothermal as a mineral. He also listed the tax codes that allow certain amounts of oil and gas to be “incidentally produced” from a geothermal well as being exempt from production taxes. He spoke on various legal issues of mineral ownership along with unknowns involving rule of capture with regards to heat. Schue also presented information on various legislative actions underway along with ERCOT and their concern on having reliable power generation, a plus for geothermal as a baseload energy resource.

Rounding out the federal involvement of oral speakers was **Douglas Hollett**, the Director of the Geothermal Technologies Office. He openly contributed to the discussion and answered related questions on the DOE program throughout the two days. Hollett gave the reception presentation, which was taped for a YouTube video, clearly informing the attendees on various short and long term goals and project activities related to all aspects of geothermal from identifying new geothermal plays to an “underground field observatory” for EGS R&D. Coproduction development, blind hydrothermal systems, and EGS are all in the DOE’s plan through 2030. The ability to add additional value with the inclusion of geothermal energy for projects using waste heat or storage technologies was a connector between the industries. Coming from the oil and gas industry, Hollett showed how current use of the word “Play” in the oil and gas industry is now being expanded to include geothermal energy as new drilling and hydroshearing techniques are changing the reservoir evolution.

PosterPresentations

A total of nine poster presentations were available for review during the first day of the two-day session. As with the oral presentations the posters covered the range from the potential for geothermal production in various areas of the country to equipment discussion. It was during the time of the poster session and the reception that the Helidyne planetary expander was available for first public viewing.

Areas in the northeast part of the U.S. were discussed with potential for geothermal development and usage. **James Hootsmans** of Colby College presented information on the geothermal potential of Maine. Unfortunately know pdf file nor write up discussing this presentation was available for review. However, a couple of states to the south and west **Andrea Aguirre et. al**. displayed information on BHT data from over 8,000 new wells drilled for unconventional natural gas in Pennsylvania and New York. Temperature reaching 300°F at 18,000 feet can be utilized for district heating in an economical manner. Another poster shown by **Denise Gatlin** of West Chester University in Pennsylvania discussed the performance of a 350-well district geoexchange system at WCU. No pdf file or notes were available for review.

Moving westward **Will Gosnold** also presented a poster on the status of the North Dakota oil field geothermal projects. Two posters were shown involving Colorado. The Lower Cretaceous formations in the Denver Basin were evaluated by **Anna Crowell et. al.** for recoverable thermal energy. Using a volumetric approach for assessing recoverable energy Crowell indicated that these formations, including the "D" and "J" oil producing sandstones, have high capacity for heat production with target temperature being around 280°F. **Paul Morgan** of the Colorado Geological Survey also presented on the Colorado geothermal gradients and opportunities within the Piceance Basin using BHT data from over 10,000 hydrocarbon wells. Morgan speculated on how geothermal energy could be used to preheat inplace oil shalet prior to hydrocarbon extraction. South of Colorado in Oklahoma, **Randy Keller** of the Oklahoma Geological Survey presented studies of thermal regimes and geothermal potential within Oklahoma. Discussion of the Meers fault, near the Wichita Mountains, brought to light the fact that even in the mid-continent, earthquakes naturally occur.

Falling into the more conventional arena for geothermal energy was a presentation of an EGS (Engineered Geothermal System) project at Desert Peak, Nevada. The poster offered a new, plausible explanation for the location of observed deep micro-earthquakes and for the potential mechanisms that controlled permeability changes during the main stimulation operations. The study defined key geological structures involved in the experiment and original permeability in the rock volume around the well. The continuum mechanics model ($FLAC^{3D}$) used in the study showed that fluid pressure diffusion generated during the low-flow rate injection phase is consistent with the activation of hydraulically-induced shear failure along the identified structures. The project was discussed by PhD Candidate, **Stefano Benato** of the Desert Research Institute (University of Nevada, Reno). This project is part of the US DOE funding for EGS and the Itasca Education Partnership program.

DOE Coproduction Technology Manager, **Timothy Reinhardt**, presented a poster on low-temperature and coproduced resources below 300°F and the various projects completed, ongoing, and being proposed for future activities. Proposed activities included an innovative rotating heat exchanger prototype and potential funding opportunities for FY 2014. Of interest to many was the new technique to extract strategic minerals from the geothermal brines. Lithium extraction is possible for incorporation into projects, where applicable. For the low temperature community, significant research is being completed by the Pacific Northwest National Lab to develop microporous metal-organic solids for heat-carrier and transfer mediums, expected to increase power generation by 15%.

The conference concluded with attendees re-energized to find ways to work with the oil and gas industry to develop geothermal and waste heat in existing fields. Waste heat applications already exist in almost every field across the nation. The Geothermal Industry was shown that financing larger projects may be easier, and if that is the case, producing the high fluid volumes shown to exist in the resource assessments can get projects to market with much needed clean energy for the local community. As Bud Weinstein stated, "Heat is a terrible thing to Waste"!