Large-Scale Geothermal Power Prospects await Exploration and Development in the Eastern Great Basin

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After the boom years of ~ 3 GWe of geothermal development in the U.S. (1970s-1990s), capacity additions have barely exceeded plant rundown.

<table>
<thead>
<tr>
<th>Proposed New Generation (EIA, 8/2015; up to 2022, but mostly 2015 - 2019)</th>
<th>Summer Capacity (MWe)</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal *</td>
<td>476</td>
<td>0.5%</td>
</tr>
<tr>
<td>Coal</td>
<td>2,013</td>
<td>2.0%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>56,180</td>
<td>56.8%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>5,670</td>
<td>5.7%</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>1,067</td>
<td>1.1%</td>
</tr>
<tr>
<td>Wind</td>
<td>21,564</td>
<td>21.8%</td>
</tr>
<tr>
<td>Solar</td>
<td>11,120</td>
<td>11.2%</td>
</tr>
<tr>
<td>Other</td>
<td>829</td>
<td>0.8%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>98,919</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

* 10 plants: 7 in CA (Geysers, Salton Sea); 1 in each of NV, UT and OR
In the next 7 years, EIA show only 60 MWe of additions planned for the Great Basin

Planned new power plant additions show geothermal is barely a player in the changing power generation scene here.

What can change this?
What is needed to get the geothermal industry reinvesting in exploration?

1. Adaption of recent technology developments in the oil patch that will substantially reduce drilling costs (and LCOE) for moderate temperature (~180°C) stratigraphic reservoirs at 3-4 km depth.

2. Recognition of the viability of stratigraphic reservoirs; developments can be ~100 MWe in size; many opportunities exist in the high heat flow parts of the Great Basin; five highlighted in this talk.
Examples of types of geothermal reservoir targets. No vertical exaggeration. **Engineered geothermal systems (EGS)** create the permeability by hydrofracturing. **Stratigraphic Reservoirs** have **natural permeability** within geologic units, hosted beneath a rock succession with a conductive thermal gradient. In contrast to hydrothermal systems, the reservoir target is **laterally extensive** (100’s of MWe potential per reservoir target), but will be deeper (3 – 4 km).
Stratigraphic Reservoirs are NOT a new concept (read McNitt, 1995; Aussie, Euro projects)

But there are two critical questions for developing these reservoirs:

• Are reservoirs at 3 – 4 km economic to develop?
• Will we find the required well productivity (permeability)?

Two drilled examples from the Great Basin

A shallow example

A deeper example

Cove Fort reservoir (UT)  
(Rowley et al., 2013)
Economic modeling with GETEM suggests if reservoir temperatures exceed 150°C at 2 km or 200°C at 4 km, then large scale developments possible at 10c/kWh (unsubsidized power price; Mines et al., 2014).

• Great Basin heat flow is often about 90 – 100 mW/m² so reservoir targets are 3 – 4 km depth

10 C/kWh LCOE threshold for stratigraphic reservoirs (~ 100 MWe; Mines et al., 2014)
When will advances in oil and gas drilling technology improve geothermal reservoir development? Stratigraphic reservoir targets should have similar drilling conditions to tight oil targets, but a bit hotter (180°C vs. 120°C); we need larger diameter wells to support the flow rates.

At Bakken, wells drill 3 km vertically and 3 km horizontally in about 20 days; horizontal legs are now being spaced 100 m apart, wellheads ~ 10 m apart, with skid-mounted rig minimizing rig set-up, tear-down times.

Modern water floods – vertical injectors, producers with horizontal legs.

Geothermal wellfield costs including confirmation wells and make-up wells represent about half the LCOE (~ 10c/kWh) for 3+ km depth wells with horizontal legs in stratigraphic reservoir; ~ 100 MWe scale power plant; good permeability (Mines et al., 2014; GETEM)

Geothermal wells drilled radially out to 2 km from one pad could potentially access > 10 km² of a stratigraphic reservoir, which could be a 30 MWe modular geothermal development.
Permeability data from oil and gas database (GASIS) and groundwater databases (Kirby, 2012); evidence that carbonate and clean siliciclastic stratigraphic units at 3 – 5 km could sustain good geothermal production wells. Igneous reservoirs look like a poor choice (unless active faulting?)
High heat flow areas of the Great Basin combined with reservoirs in the deep carbonate system of the eastern Great Basin are an obvious target.
N. Steptoe Valley (NV)  
(permeability and temperature proven by oil exploration wells; transmission line nearby)

Pavant Butte (UT)  
(temperature proven by oil exploration well; permeability indicated by faulting and volcanic feeder dikes; transmission lines nearby)

Idaho Thrust Belt (ID)  
(permeability and temperature proven by oil exploration wells; transmission line nearby)
Elko Basins, NV

Pine Valley to Beowawe, and Mary’s River Valley have a similar regional thermal regime

Layman, 1984

Hulen et al., 1990
Over $2.5 billion is being invested west of Salt Lake City during next 5 years (expanded airport; state prison relocation); why is geothermal not being considered? Gravel at ~ 2 km could be a hot aquifer target.
Concluding Comments

• Stratigraphic reservoirs offer deep permeable targets suitable for large-scale power development (~ 100 MWe+). This is the path to GWe-scale growth for geothermal power.

• In contrast to hydrothermal targets, the thermal regime is predominantly conductive (and predictable). Many prospects exist at 180°C, 3.5 km depth, > 90 mW/m² heat flow.

• Technologies developed for tight oil and gas are applicable to stratigraphic reservoirs. We need to significantly reduce the drilling cost curve. Adaptation rather than Innovation is what is required.

• The Eastern Great Basin has numerous sites where there are good prospects for large-scale power development (Lower Paleozoic carbonates being the primary reservoir target). Traditional exploration techniques – heat flow holes (> 300 m deep), more gravity measurements, and seismic reflection profiling are priority methods.

• What’s next? – Play Fairways Phase 2 would be a good mechanism to reduce development risk. Unfortunately three of the five prospects discussed here are not inside the present play fairways funded by DOE.

The vision: GWE-scale growth in U.S. geothermal power generation resumes with development of stratigraphic reservoirs.