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PARAMETRIC ANALYSIS OF THE FACTORS CONTROLLING THE COSTS OF SEDIMENTARY GEOTHERMAL SYSTEMS – PRELIMINARY RESULTS

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Objective

The goal of this study is to estimate the capital costs of developing sedimentary systems for electricity generation and to identify the main factors controlling their costs. Of special interest is the impact that reservoir productivity, modeled using the well productivity index (PI), has on sedimentary geothermal system costs. The results of this study will be used during detailed sedimentary reservoir modeling to estimate the overall performance characteristics of the sedimentary reservoir required for commercially-competitive power generation systems.

Methodology

Parametric analysis of the main factors controlling the costs of sedimentary geothermal systems was carried out using a modified version of the Geothermal Electricity Technology Evaluation Model (GETEM). The sedimentary system modeled assumed production from and injection into a single sedimentary formation, so that all produced water is re-injected back into the same sedimentary formation. During model runs, **the production well flow rate was optimized to minimize electricity generation costs.** The table below shows the parameters and values chosen for parametric analysis:

Parameter Matrix

Productivity Index (PI)	Reservoir Depth	Reservoir Temperature	Production/ Injection Well Ratio
(L/s/bar)/ (lb/h/psi)	**(m)/**(ft)	**(°C)/**(°F)	(-)
• **2**/1,100 • **3.3**/1,800 • **5**/2,700 • **10**/5,500 • **30**/16,400	• **3,000**/10,000 • **4,000**/13,000 • **5,000**/16,500	• **190**/375 • **175**/350 • **160**/320	• **1:1** • **2:1**

Assumptions

The analysis was carried out using a version of GETEM modified to model sedimentary geothermal systems. The following assumptions were used for all model runs:

- Production from and injection into a single sedimentary formation, so that all produced water is re-injected back into the same sedimentary formation.
- Hydrostatic pressure gradient for reservoir.
- Both injection and production wells are pumped. Injection pump is on surface, while production well uses a down hole pump.
- 30 MW_e-net air-cooled binary geothermal power plant, with plant performance (modeled as brine effectiveness) optimized to minimize total project costs.

Drilling costs have a significant impact on overall project costs. The default drilling cost curves in GETEM were used to estimate well costs. The table below shows the casing designs and costs used in GETEM:

Well Designs and Cost Estimates

	3,000 m		4,000 m		5,000 m	
	(m)	(ft)	(m)	(ft)	(m)	(ft)
Upper Interval	0 - 1,500	0 - 4,920	0 - 2,000	0 - 6,500	0 - 2,500	0 - 8,200
Intermediate Interval	1,500 - 2,550	4,920 - 8,350	2,000 - 3,400	6,500 - 11,150	2,500 - 4,250	8,200 - 13,950
10.63" Open Hole Production Zone	2,550 - 3,000	8,350 - 10,000	3,400 - 4,000	11,150 - 13100	4,250 - 5,000	13,950 16,500
Well Completion Cost ($)	$7.8M		$11.9M		$16.8M	

Results

Results of the GETEM runs for the parametric study are shown in the figure below.

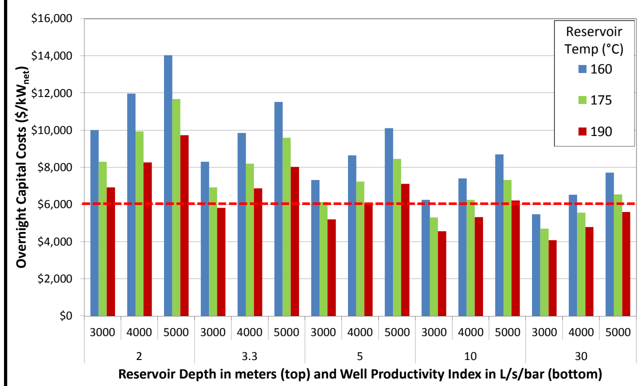

Figure 1. *Sedimentary geothermal system overnight capital costs for base case model runs. Only results for the 1:1 production/injection well ratio are shown.*

Lessons Learned

1. ***When production well flow rate is unconstrained, the 2:1 production/ injection well ratio is marginally more expensive than the 1:1 ratio for all cases, so the figure above only shows the results for the 1:1 ratio.***
   - The 2:1 well ratio requires more wells to be drilled, raising costs.
   - The 2:1 well ratio also requires more parasitic pumping requirements (roughly twice as much).
2. ***The results show many scenarios with overnight capital costs comparable to those of conventional hydrothermal power plants*.***
   - 11 scenarios with overnight capital costs of <$6,000/kW.
     - Includes scenario with PI as low as 3.3 L/s/bar.
   - 4 scenarios with overnight capital costs of <$5,000/kW.
   - As expected, reservoirs that are shallow and have a relatively high temperature and PI are the most commercially feasible.
3. ***For PI of 10-30 L/s/bar, the following scenarios generally have overnight capital costs of approximately $6,000/kW or less:***
   - Depth <3,000m, Temperature >160°C
   - Depth <4,000m, Temperature >175°C
   - Depth <5,000m, Temperature >190°C
4. ***Down hole production well pump performance and operating limitations will be important to developing commercially-competitive systems.***
   - With no constraints on production pump flow rates, the optimized systems result in production well flow rates of 105 kg/s (1,800 gpm) for systems with low PI to 280 kg/s (5,100 gpm) for systems with high PI.
   - The higher flow rate results are at or beyond the operating limitations of existing production well pumps.

*EIA estimates overnight capital costs of $4,362/kW for binary geothermal power plants and $6,243/kW for dual flash geothermal power plants (EIA,. April 2013. "Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants." http://www.eia.gov/forecasts/capitalcost/pdf/updated_capcost.pdf, Table 1.

Sensitivity Studies

Several additional studies were conducted to explore the sensitivity of sedimentary geothermal system costs to key assumptions in the base case model.

1. Decreased Drilling Costs

Assumed that drilling costs were 75% of those in the base case.

- Total well field costs account for ~30%-50% of the total project costs in base case.
- ***Assuming a 25% reduction in drilling costs reduces overall project capital costs by 8%-14%.***
  - Impact increases with increasing reservoir depth (drilling costs increase non-linearly with depth) and decreases with increasing reservoir temperature (lower temperatures require more wells).
  - Impact decreases as PI increases (higher PI results in higher flow rates and requires fewer wells).

2. Limited Production Well Flow Rate

The base case study assumes no constraints on the production well flow rate. This results in flow rates that may be hard or impossible to obtain for some scenarios with currently available down hole production well pumps. For this case, **it was assumed that the production well flow rate was limited to 165 L/s (3,000 gpm)**.

- Results (***Figure 2)*** show that ***when production well flow rate is limited, the optimum production/injection well ratio depends on the reservoir (PI)***.
  - Low reservoir PI favors 1:1 production/injection well ratio. Flow limitation is more than or similar to optimum well flow rate in base case.
  - High reservoir PI requires 2:1 production/injection well ratio. The flow limitation requires drilling of additional production wells. This increases overall costs.

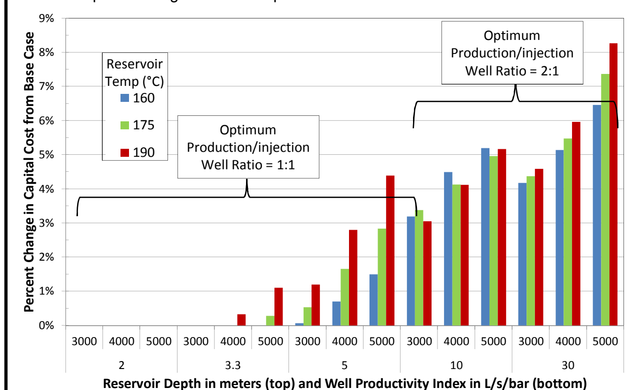

Figure 2. *Percent change from base case in sedimentary geothermal system overnight capital costs when 165 L/s (3,000 gpm) limit on production well flow rate is assumed.*

Conclusions

1. The study found many scenarios of sedimentary geothermal systems with overnight capital costs comparable to those of conventional hydrothermal power plants. Generally, these systems require a productivity index of 10-30+ L/s/bar.
2. The optimum production/injection well ratio for the sedimentary geothermal systems studied is 1:1, unless flow constraints limit well production.
3. Commercially competitive systems require production well flow rates that may be beyond the operating characteristics of currently available down hole production well pumps. Improving the performance and operating limits of down hole pumps will be important to developing sedimentary geothermal systems for electricity generation.

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