DOE Updated U.S. Geothermal Supply Curve

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
U.S. Geothermal Supply Curve Project

Purpose: To provide input to annual reporting by the U.S. DOE under the Government Performance and Results Act of 1993, the DOE portfolio development support processes, and market penetration models in support of other DOE analyses.

Outline

Geothermal Resource

• Hydrothermal resource
  – Identified
  – Undiscovered

• Enhanced Geothermal Systems (EGS) resource
  – Near-Hydrothermal Field EGS
  – Deep EGS

Supply Curve

• Based on expert input
• Two cases: Base and target

Results, Conclusions, and Recommendations
General Approach

**Risk Assessment**
- Expert input
- Present and future costs
- Different budget scenarios

**Cases**
- GTP R&D goals
- Budget levels
- Time frames
- Reference scenarios

**Geothermal Resource**
- Define resource
- Identify information sources
- Develop database

**GIS Data Mapping**
- Spatial coordinates of resources

**Input for Market Penetration Models**
- NEMS
- MARKAL
- ReEDS
- SEDS

**Supply Curve**

**Estimate LCOE in GETEM**
- Resource characteristics
- Component costs
- Time/budget scenario

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**Supply Curve**
GEOTHERMAL TECHNOLOGIES

Hydrothermal
- Conventional technology – Steam, dual flash, flash, binary
- Shallow (1-3 km), hot (150+ °C), naturally occurring, localized
- Examples – The Geysers, Salton Sea, Hatch (NV) Plant

Enhanced Geothermal Systems (EGS)
- Near-Hydrothermal Field EGS
  - “Almost” hydrothermal fields – lack permeability and/or in-situ fluids
  - Near-term, lowest cost EGS – likely to be developed first
  - Examples – Geysers (Calpine), Newberry (AltaRock), Raft River (U. Utah)
- Deep EGS
  - Deployable “anywhere” – drill until high temperatures found
  - 3+ km deep, no natural permeability and/or in-situ fluid – fracture + flow
  - Long term, higher costs – likely to follow successful near-field tests
  - Examples – Fenton Hills, Soultz, Cooper Basin

Oil and Gas Co-Produced Fluids
- Geopressure Fluid

Direct Use
- Ground Source Heat Pumps
Resource Characterization

Hydrothermal Resource: Identified

Installed Capacity

- Geothermal Energy Association: 3,153 MWₑ (Sept. 2009)
- Energy Information Administration: 2,480 MWₑ (summer capacity, 12/31/07)

Potential Capacity

- USGS Circular 790 (1979): 23,000 ± 3,400 MWₑ
- USGS 2008 Geothermal Resource Assessment:
  - Mean: 9,057 MWₑ
  - 95%ile: 3,675 MWₑ
  - 5%ile: 16,457 MWₑ

For NREL study…

6,394 MWₑ remaining capacity

Hydrothermal Resource: Undiscovered

USGS 2008 Geothermal Assessment
- Based on GIS mapping tools and statistical model of spatial correlation of geological factors
- Estimated undiscovered hydrothermal resource potential:
  - Mean: 30,030 MW<sub>e</sub>
  - 95%ile: 7,917 MW<sub>e</sub>
  - 5%ile: 73,286 MW<sub>e</sub>

For NREL Study…
30,030 MW<sub>e</sub> potential capacity
Geothermal Resource

Near-Hydrothermal Field EGS

Near-hydrothermal field EGS resource is “halo” around hydrothermal fields.

Formal assessment not performed yet

- Use current identified hydrothermal sites
- Assume resource is difference between USGS hydrothermal high (5% probability) and mean values for each site represents near-hydrothermal field EGS opportunity

For NREL Study…

7,031 MWₑ potential capacity

Caveats

- First-order estimate of resource
- Does not consider near-hydrothermal field EGS resource associated with undiscovered hydrothermal sites
Geothermal Resource

Deep EGS Resource

Previous Assessments


- USGS 2008 Geothermal Resource Assessment estimated mean value of 517,800 MWₑ deep EGS potential
  - Limited to 11 Western states
  - Only considers 3-6 km depth range
  - Federally-protected and DOD lands excluded
Geothermal Resource

Deep EGS Resource - NREL

- Same method used in MIT report (2006)
- Thermal resource based on SMU maps of temp vs. depth (3-10 km) used in previous assessment
  - Exclude federally-protected lands (e.g. DOD, federal parks)
- Potential electric capacity calculation methodology:
  - Calculate heat in place for 1-km thick slices of rock
  - Apply recovery factor (20%), heat recovery rate (30 years), and assumed plant efficiency (DiPippo 2004) for resource temperature
  - Multiply potential electric capacity of each resource temperature range by area covered on map

For NREL Study…

15,908 GWₑ potential capacity
### Geothermal Resource

#### Deep EGS Resource - NREL

<table>
<thead>
<tr>
<th>Reservoir Depth (km)</th>
<th>Potential Electric Capacity (MWₑ)</th>
<th>Resource Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>150-200</td>
<td>200-250</td>
</tr>
<tr>
<td>4</td>
<td>91,516</td>
<td>117</td>
</tr>
<tr>
<td>5</td>
<td>590,763</td>
<td>26,526</td>
</tr>
<tr>
<td>6</td>
<td>1,139,749</td>
<td>227,969</td>
</tr>
<tr>
<td>7</td>
<td>1,337,049</td>
<td>723,692</td>
</tr>
<tr>
<td>8</td>
<td>1,539,597</td>
<td>1,129,434</td>
</tr>
<tr>
<td>9</td>
<td>1,881,116</td>
<td>1,159,750</td>
</tr>
<tr>
<td>10</td>
<td>1,907,066</td>
<td>1,251,474</td>
</tr>
</tbody>
</table>

Excluded areas: DOD land, federally-protected land (e.g. - Yellowstone)
### Geothermal Resource

#### Results – NREL study

<table>
<thead>
<tr>
<th>Resource</th>
<th>Resource Potential Capacity</th>
<th>Source(s) and Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydrothermal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identified Hydrothermal Sites</td>
<td>6.39</td>
<td>USGS 2008 Geothermal Resource Assessment(^1)</td>
</tr>
</tbody>
</table>
| - Identified hydrothermal sites  
- Sites \(\geq 110 \, ^\circ C\) included  
- Currently installed capacity excluded | |
| Undiscovered Hydrothermal | 30.03 | USGS 2008 Geothermal Resource Assessment\(^1\) |
| **Enhanced Geothermal Systems (EGS)** | | |
| Near-Hydrothermal Field EGS | 7.03 | Assumptions based on USGS 2008 assessment\(^1\) |
| - Regions near identified hydrothermal sites  
- Sites \(\geq 110 \, ^\circ C\) included  
- Difference between mean and 95\(^{th}\)\%ile hydrothermal resource estimate | |
| Deep EGS | 15,908 | NREL 2006 Assessment\(^2\), MIT Report\(^3\), SMU Data\(^4\) |
| - Based on volume method of thermal energy in rock  
3-10 km depth and \(\geq 150 \, ^\circ C\)  
- Did not consider economic or technical feasibility | |

\(^1\) (Williams, Reed et al. 2008b)  
\(^2\) (Petty and Porro 2007)  
\(^3\) (Tester et al. 2006)  
\(^4\) (SMU 2009)

*Technologies such as co-produced fluids, geopressured not assessed*
General Approach

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**Resource Characterization**
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**Supply Curve**

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12 | 2009 DOE GEOTHERMAL SUPPLY CURVE UPDATE: Prepared by the National Renewable Energy Laboratory (NREL) eere.energy.gov
Technology Component Cost and Performance Data

- Apply expert input distributions from 2009 risk assessment to GETEM
- Use @Risk risk analysis software to run Monte Carlo simulations
- Drilling Costs updated to value 30\% lower than 2008 BLS PPI index value based on conversations with leading geothermal drilling contractors

Hydrothermal

- Estimate LCOE for each identified site using GETEM
- Undiscovered hydrothermal resource characteristics based on average of existing identified hydrothermal sites in each state

EGS

- Estimate LCOE for each temperature/depth combination using GETEM
- Two cases considered:

<table>
<thead>
<tr>
<th>Enabling Technology</th>
<th>Base Case Value</th>
<th>Target Case Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Well Flow Rate</td>
<td>30 kg/s</td>
<td>60 kg/s</td>
</tr>
<tr>
<td>Thermal Drawdown Rate</td>
<td>3.0 %/year</td>
<td>0.3 %/year</td>
</tr>
<tr>
<td>Production/Injection Well Ratio</td>
<td>2:1</td>
<td>2:1</td>
</tr>
</tbody>
</table>
Hydrothermal Supply Curve (Identified & Undiscovered)

Grey lines show 10th%ile and 90th%ile values for supply curve.
Near-Hydrothermal EGS Supply Curve

- Base Case: 3%/year thermal drawdown rate, 30 kg/s producer well flow rate
- Target Case: 0.3%/year thermal drawdown rate, 60 kg/s producer well flow rate
- Grey lines show 10th%ile and 90th%ile values for supply curve.
Deep EGS Supply Curve

- Base Case: 3%/year thermal drawdown rate, 30 kg/s producer well flow rate
- Target Case: 0.3%/year thermal drawdown rate, 60 kg/s producer well flow rate
- Grey lines show 10th%ile and 90th%ile values for supply curve.
Aggregated Supply Curve

- **Base Case**: 3%/year thermal drawdown rate, 30 kg/s producer well flow rate
- **Target Case**: 0.3%/year thermal drawdown rate, 60 kg/s producer well flow rate
Deep EGS: Optimum Reservoir Temperature-Depth

![Diagram showing the relationship between reservoir temperature and depth, with a power plant as a reference.](image)
Updated U.S. Geothermal Supply Curve
Conclusions/Recommendations

Geothermal Resource and Supply Curve

1. 36.4 GW undeveloped hydrothermal available (majority undiscovered)
2. Near-hydrothermal field EGS resource has potential to be low-cost method of expanding capacity around existing fields
3. Deep EGS is huge resource, but deployment controlled by economics
4. Meeting GTP reservoir engineering goals (target case) could significantly lower EGS costs and deployment levels

Caveats and Limitations

1. Results dependent on assumptions in base/target cases
2. Supply curve results assumed relatively high drilling costs compared to current drilling cost trends
3. Geothermal similar to oil & gas – as exploration and recovery techniques improve, amount of recoverable reserves should increase

More Resource Assessment Needed

1. Undiscovered hydrothermal and near-hydrothermal field EGS need more thorough assessment
2. Deep EGS – better resolution data need for temperature vs. depth maps
3. Co-produced fluids assessment needed