The Role of Geothermal in Enhancing Energy Diversity and Security in the Western US

[GEOTHERMAL LARGE AND SMALL]

Roger Hill
GeoPowering the West
Sandia Energy Programs

State Working Groups

1. Alaska, est. in 2002
2. Arizona, est. in 2002
3. California, est. in 2003
4. Hawaii, est. in 2003
5. Idaho, est. in 2002
6. Oregon, est. in 2003
7. Nevada, est. in 2000
8. New Mexico, est. in 2000
9. Texas, est. in 2005
10. Utah, est. in 2002
11. Washington, est. in 2002
Western US: Load Growth

Source: Renewable Energy Atlas
Electricity Generation

Total Megawatt Hours Generated

<table>
<thead>
<tr>
<th>State</th>
<th>Hours Generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>84,000,000</td>
</tr>
<tr>
<td>California</td>
<td>191,500,000</td>
</tr>
<tr>
<td>Colorado</td>
<td>39,500,000</td>
</tr>
<tr>
<td>Idaho</td>
<td>14,400,000</td>
</tr>
<tr>
<td>Montana</td>
<td>31,400,000</td>
</tr>
<tr>
<td>Nevada</td>
<td>32,800,000</td>
</tr>
<tr>
<td>New Mexico</td>
<td>32,600,000</td>
</tr>
<tr>
<td>Oregon</td>
<td>56,700,000</td>
</tr>
<tr>
<td>Utah</td>
<td>36,800,000</td>
</tr>
<tr>
<td>Washington</td>
<td>117,100,000</td>
</tr>
<tr>
<td>Wyoming</td>
<td>43,600,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>580,400,000</strong></td>
</tr>
</tbody>
</table>

Each pie chart is scaled to the total amount of energy produced.

Data source: Energy Information Administration 1999

Source:
Renewable Energy Atlas
Regional Power Plant Emissions

**Power Plant Emissions, 2000**
Each bar represents the location of a power plant regulated under the EPA's Acid Rain Program (Title IV). The height of the bars is scaled to reflect the emissions levels for each plant. Because CO₂ emissions are so much higher than either SO₂ or NOₓ, different scaling factors were used to determine the height of the bars.

**Total Emissions in Region from Title IV Plants, 2000**

<table>
<thead>
<tr>
<th>Emission</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur Dioxide (SO₂)</td>
<td>506,662</td>
</tr>
<tr>
<td>Nitrogen Oxide (NOₓ)</td>
<td>547,754</td>
</tr>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>316,774,136</td>
</tr>
</tbody>
</table>

*Data source: EPA Acid Rain Program (Title IV) Emissions Scorecard, 2000*

Source: Renewable Energy Atlas
US Natural Gas Prod. Will Grow 13% Imports Will Grow 157%

Source: DOE/EIA AEO2005
EIA has consistently underestimated gas prices

Wellhead Natural Gas Prices (2002$/Mcf)

Source: Union of Concerned Scientists
The Role of Geothermal in Enhancing Energy Diversity and Security in the Western US

A Mean-Variance Portfolio Optimization of the Region’s Generating Mix to 2013

Prepared for Sandia National Labs

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Hobart College and Sandia National Labs

February 28, 2005
Optimization Defines Four Bands for New Geothermal Based on Resource Accessibility

<table>
<thead>
<tr>
<th>Band</th>
<th>Resource Availability</th>
<th>Generating Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MW</td>
<td>2003</td>
</tr>
<tr>
<td>Existing</td>
<td>2,543</td>
<td>$.062</td>
</tr>
<tr>
<td>Geothermal-1</td>
<td>2,457</td>
<td>$.047</td>
</tr>
<tr>
<td>Geothermal-2</td>
<td>2,500</td>
<td>$.052</td>
</tr>
<tr>
<td>Geothermal-3</td>
<td>2,500</td>
<td>$.057</td>
</tr>
<tr>
<td>Geothermal-4</td>
<td>20,000</td>
<td>$.071</td>
</tr>
<tr>
<td>Total</td>
<td>30,000</td>
<td>-</td>
</tr>
</tbody>
</table>
EIA 2003 and 2013 Generating Mixes

Geothermal Shares
2003: 2%  2013: 4%
## Generating Cost Inputs: Nominal $/kWh

### US Western Region Portfolio analysis
Nominal Technology Cost Inputs Assuming 3% Inflation
(Nominal $/kWh)

<table>
<thead>
<tr>
<th>Technology</th>
<th>2003 Existing</th>
<th>2003 New</th>
<th>2013 Existing</th>
<th>2013 New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>$0.037</td>
<td>$0.049</td>
<td>$0.049</td>
<td>$0.068</td>
</tr>
<tr>
<td>Gas</td>
<td>$0.048</td>
<td>$0.037</td>
<td>$0.075</td>
<td>$0.067</td>
</tr>
<tr>
<td>Nuclear</td>
<td>$0.014</td>
<td>$0.062</td>
<td>$0.018</td>
<td>$0.081</td>
</tr>
<tr>
<td>Wind</td>
<td>$0.043</td>
<td>$0.047</td>
<td>$0.056</td>
<td>$0.062</td>
</tr>
<tr>
<td>Hydro</td>
<td>$0.046</td>
<td>$0.046</td>
<td>$0.060</td>
<td>$0.060</td>
</tr>
<tr>
<td>Geothermal</td>
<td>$0.064</td>
<td></td>
<td>$0.083</td>
<td></td>
</tr>
<tr>
<td>New Geo 1</td>
<td>$0.049</td>
<td></td>
<td>$0.060</td>
<td></td>
</tr>
<tr>
<td>New Geo 2</td>
<td>$0.053</td>
<td></td>
<td>$0.066</td>
<td></td>
</tr>
<tr>
<td>New Geo 3</td>
<td>$0.058</td>
<td></td>
<td>$0.072</td>
<td></td>
</tr>
<tr>
<td>New Geo 4</td>
<td>$0.073</td>
<td></td>
<td>$0.090</td>
<td></td>
</tr>
</tbody>
</table>

Based on US-EIA and Sandia National Laboratories cost estimates, adjusted for 3% inflation.
Understanding Risk

• Portfolio optimization locates generating mixes with minimum expected cost and risk

• For each technology, risk is the year-to-year variability (standard deviation) of the three generating cost inputs: fuel, O&M and capital (construction period risk)
  – Fossil fuel standard deviations are estimated from historic US data
    • e.g. standard deviation for natural gas over the last 10 years is 0.30
  – Standard deviations for capital and O&M are estimated using proxy procedures (see Awerbuch and Berger, IEA, 2003)

• The construction period risk for embedded technologies is 0.0

• ‘New’ technologies are therefore riskier than embedded ones
  – e.g. new coal is riskier than ‘old’ coal
## Technology Risk Estimates
(Standard Deviation) \(^a/\)

<table>
<thead>
<tr>
<th></th>
<th>Construction Period (^b/)</th>
<th>Fuel (^c/)</th>
<th>Variable O&amp;M</th>
<th>Fixed O&amp;M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.20</td>
<td>0.020</td>
<td>0.2</td>
<td>0.087</td>
</tr>
<tr>
<td>Gas</td>
<td>0.15</td>
<td>0.300</td>
<td>0.2</td>
<td>0.087</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.20</td>
<td>0.194</td>
<td>0.2</td>
<td>0.087</td>
</tr>
<tr>
<td>Wind</td>
<td>0.05</td>
<td>-</td>
<td>0.2</td>
<td>0.087</td>
</tr>
<tr>
<td>Hydro</td>
<td>0.20</td>
<td>-</td>
<td>0.2</td>
<td>0.087</td>
</tr>
<tr>
<td>Geothermal (^d/)</td>
<td>0.15</td>
<td>-</td>
<td>0.2</td>
<td>0.087</td>
</tr>
</tbody>
</table>

\(^a/\) Estimation procedures developed in Awerbuch and Berger (Paris, IEA, 2003)

\(^b/\) Construction period costs for existing (embedded) technologies is 0.0

\(^c/\) Empirical estimate based on 1994-2003 data

\(^d/\) Four geothermal categories are used in the analysis. While exploration and other costs increase, construction period risk is assumed to remain constant.

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Total Risk for each generating technology is a weighted statistical summation of the component risks
2013 Baseline Portfolio Optimization

Portfolio Risk-Cost and Technology Shares

<table>
<thead>
<tr>
<th>Technology</th>
<th>Mix P</th>
<th>Mix N</th>
<th>EIA Mix 2013</th>
<th>Mix S</th>
<th>Mix Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>Cost</td>
<td>$49.21</td>
<td>$46.28</td>
<td>$46.28</td>
<td>$44.03</td>
<td>$44.02</td>
</tr>
</tbody>
</table>

- **Mix P:** Costs $.003/KWh more than EIA Mix: 9x as much Geo
- **Mix N:** costs the same as EIA Mix: 5x as much Geo
- **Mix S:** costs less than EIA Mix: 75% more Geo

**Technology Energy Share**

- Coal: 23% 31% 31% 29% 23%
- Gas: 9% 10% 20% 25% 30%
- Nuclear: 4% 4% 9% 4% 4%
- Wind: 3% 3% 2% 3% 3%
- Hydro: 27% 33% 34% 34% 34%
- Geothermal: 35% 20% 4% 7% 7%
Western Region Generating Cost-Risk Trends

- 2013 EIA Mix has higher cost and risk relative to 2003
  - Driven by 32% demand increase, decommissioning existing plant, resource shortages and limitations on available options
- Move to larger gas/coal shares adds to portfolio cost and risk
  - Increases year-to-year expected generating cost volatility
- Reduces Energy Diversity/ Security
- Geothermal and wind are ideally positioned to diversify the generating mix and reduce cost/risk
A Mean-Variance Portfolio Optimization of the Western Region’s Generating Mix to 2013

• Portfolio optimization locates generating mixes with lowest-expected cost at every level of risk
  – Risk is the year-to-year variability of technology generating costs
• EIA (NEMS) projected generating mixes serve as a benchmark or starting point;
  – Detailed decommissioning date assumptions using World Electricity Power Plant Database age of existing plants
• The optimal results generally indicate that compared to EIA target mixes, there exist generating mixes with larger geothermal shares at no greater expected cost or risk
  – There exist mixes with larger geothermal shares that exhibit lower expected cost and risk
National R&D helps to expand the geothermal resource base:

- Geophysics and geoscience to locate and define reservoirs
- Drilling research to reduce costs
- Improving capabilities and efficiencies of power plants.

The McKelvey Diagram

- **Reserves**
  - Proven
  - Probable
  - Possible

- **Undiscovered Resources**

- **Sub-Economic Resources**

“The McKelvey Diagram”
Low-Temp Resources are More Common

- 83% of the sites require binary plants (also, EGS/HDR will most likely need binary plants)

- And 50% of the available energy is below temperatures requiring binary plants (170C)

Frequency of occurrence and energy of hydrothermal convection systems identified by the USGS in 1978

Source: NREL
Geothermal Resource Prospecting

The Early Years!
Geothermal Applications in Summary

Geothermal Energy Uses

Typical uses of geothermal energy at different temperatures

*Geothermal electricity can be used to produce renewable hydrogen.
**Cool water is added to make the temperature just right for fish.
# Attributes of Geothermal Power

## Advantages
- Enormous potential
- High, reliable plant capacity factor
- Greenhouse gas reduction
- Low environmental impact
- Much mature technology

## Disadvantages
- Expensive drilling
- Regional resource
- Resource uncharacterized
- Threshold plant size
- Plant prefers constant load
- Environmental perception
Expected Trends in Future Energy System Evolution

Energy safety, security, reliability, and sustainability have become important energy system design parameters.

This will change how energy systems are optimized and upgraded.

This will impact future decisions on energy policy, supply, and use.

How do we efficiently and cost-effectively transition to this new future infrastructure?
The primary role of PIER Renewables is to help the State meet aggressive renewable energy policy goals by investing in high priority RD&D issues.

### Projected Renewables to Meet California Policy Goals

**Total: 29,000 GWh**  
(~11% Renewables)

**Target: 54,000 GWh**  
(20% RPS)

**Target: 98,000 GWh**  
(33% RPS w/ 3 GW Solar and 1.5 GW Biomass)

Data Sources: 2004, CEC Electricity Report which includes all renewables in the State, not just IOUs; 2010 and 2020, PIER Renewables Projections.

Source: CEC
Prince Piero Ginori Conti invented the first geothermal power plant in 1904, at the Larderello dry steam field in Italy.
This binary power plant, at Wendell-Amadee, California, runs by itself. If it detects a problem, it automatically radios the operator to come to the site.

Source: GEO
This small binary power plant is in Fang, Thailand.
Small Geothermal Power Plants in the Oil Patch

Advantages for O&G industry
• Helps to service pumping
• O&G industry has similar technology and infrastructure
• Potentially supplements resources exploitation

Economic advantages
• Distributed power at full retail cost
• Enhanced or extended operations uneconomical
• Exploration already is largely characterized
• Modular and can start small

Advantages for the Nation
• Offers addition energy choice
Utility Systems

Oil and Gas

Gas

Transmission

Substation

Distribution

Load

Generator

Wind

Coal

Geothermal in utility portfolio or at the load
You’ve Heard of Combined Heat and Power?

Geothermal offers combined:

Heat...........Power........... and Pleasure!

Sources: Geothermal Education Office
Geothermal Energy

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