Coal To Geothermal:

Engineered Geothermal Systems

Susan Petty
SMU Power Plays
Coal and Geothermal Workshop
January 2018
Coal Plant Retirement

Figure 1. Net summer capacity of operating, already retired, and scheduled to be retired coal plants

Source: Brookings analysis of EIA monthly electric generator inventory, September 2016
# EPRI: Geothermal Management of Coal Plant Waste Water Case Studies

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Location</th>
<th>Operator</th>
<th>Gross Rating (MW)</th>
<th>Disposal Rate (MLD)</th>
<th>Waste Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountaineer Power Plant</td>
<td>New Haven, WV</td>
<td>AEP</td>
<td>1300</td>
<td>19</td>
<td>Surface Discharge</td>
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<tr>
<td>North Valmy Generating Station</td>
<td>Valmy, NV</td>
<td>NV Energy</td>
<td>522</td>
<td>2.2</td>
<td>Ponds</td>
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<tr>
<td>Colstrip PPL</td>
<td>Colstrip, MT</td>
<td>Colstrip PPL</td>
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<td>1.1</td>
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<td>Cayuga Generating Station</td>
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<td>Newburgh, NY</td>
<td>Dynegy</td>
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<td>34</td>
<td>Surface Discharge</td>
</tr>
</tbody>
</table>
Why Are Coal Plants Retiring?

Coal represents a declining share of electricity generation in the nation

Source: Brookings Analysis of EIA Annual Electricity Generation Data.
Some Factors in Coal Plant Retirement

- **Aging coal fleet**
  - The median generating station was built in 1966
  - Old plants have lower efficiency
  - Run less often and have poorer economics

- **New and proposed EPA regulations**
  - Clean Air Transport Rule
  - Proposed Coal Combustion Residuals rule,
  - The proposed Tailoring Rule (covering greenhouse gas emissions),
  - The Ozone NAAQS (National Ambient Air Quality Standards),
  - The forthcoming National Emission Standard for Hazardous Air Pollutants (NESHAPs),
  - Cooling water regulations under section 316(b) of the Clean Water Act. [2][3][4]

- **Low prices of power from natural gas plants**
- **Lower prices for renewables**
Aging Plants Are Less Efficient: Can’t Meet Standards Without Expensive Upgrades

Table 1: Age of U.S. Coal Plants

<table>
<thead>
<tr>
<th>Years Built</th>
<th># of Units</th>
<th>Total Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005-2009</td>
<td>21</td>
<td>6,785</td>
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<tr>
<td>2000-2004</td>
<td>13</td>
<td>1,382</td>
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<tr>
<td>1995-1999</td>
<td>24</td>
<td>4,372</td>
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<tr>
<td>1990-1994</td>
<td>67</td>
<td>8,638</td>
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<td>1985-1989</td>
<td>102</td>
<td>23,734</td>
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<tr>
<td>1980-1984</td>
<td>117</td>
<td>56,105</td>
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<tr>
<td>1975-1979</td>
<td>125</td>
<td>55,879</td>
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<tr>
<td>1970-1974</td>
<td>137</td>
<td>66,466</td>
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<tr>
<td>1965-1969</td>
<td>158</td>
<td>41,656</td>
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<tr>
<td>1960-1964</td>
<td>157</td>
<td>25,310</td>
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<tr>
<td>1955-1959</td>
<td>209</td>
<td>28,883</td>
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<td>1950-1954</td>
<td>213</td>
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<td>1940-1949</td>
<td>93</td>
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<td>1930-1939</td>
<td>20</td>
<td>132</td>
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<tr>
<td>1920-1929</td>
<td>10</td>
<td>69</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>1,466</strong></td>
<td><strong>339,509</strong></td>
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</tbody>
</table>

Figure 5. Carbon Dioxide Emissions vs. Net Plant Efficiency

Source: Booras, G. and N. Holt, Pulverized Coal and IGCC plant Cost and Performance Estimates, Gasification

https://www.sourcewatch.org/index.php/Coal_plant_retirements
Renewable Prices are Dropping

Renewables are becoming competitive with coal on price

Unsubsidized levelized cost of energy comparison ($/MWh)

Source: Lazard’s Levelized Cost of Energy Analysis Version 9.0
Price Volatility with Increasing Intermittent Renewables: ERCOT
Price Volatility with Increasing Intermittent Renewables: CAISO
Price Volatility with Increasing Intermittent Renewables: NYISO
How Can Geothermal Be Part of the Solution?

- Geothermal has no fuel cost
- Operational costs very low
- Baseload power but can provide grid support and load following
- For utility scale projects, capital costs lower than coal
- With EGS technology technically feasible most places.
- We can manage waste water from the coal plant while it continues to operate

*Geothermal: The only renewable that can replace coal.*
Heat Stored in Rock

200°C
ΔT=10°C

1 km³ Granite

3,490,000 BBL of Oil Equivalent or 1,360,000 MWh as electricity (155 MWe)
Enhanced Geothermal Systems
What is EGS and how does it differ from conventional geothermal

Hydrothermal Systems
- Natural permeability
- High flow rates
- Few big systems
- Located in Western US
- Exploration expensive
  - Must find temperature with permeability
  - Drilling is needed for exploration
  - Dry hole rate remains over 30%
- Economic even for low temperatures
  - 3500 MWe on-line in the US.
  - >11,500 MWe worldwide
- ~98% average availability

Enhanced Geothermal Systems (EGS)
- Low or no natural permeability
- Reservoir must be engineered to:
  - Obtain high flow rates
  - Develop good heat exchange area
- Exploration risk reduced
- Only Temperature needed
- Drill deeper to get greater temperature for improved efficiency
- Large systems can be developed
- Uses proven state of the art drilling technology
- Fracturing technology developing
- AltaRock technology for multizone stimulation can reduce cost
- Potential for CO2 sequestration
Potential: Coal to Geothermal

• 50,000 MW of aging coal fired generation in the US alone needs to be repowered or shut down because it can’t meet current emissions standards

• World wide efforts to reduce coal fired generation. China closing oldest plants. EU closing 10,000 MW over next 5 years. More planned for future.

• Clean Power Plan (if implemented), state RPS, and COP21 commitments will increase this.

• Repowering with natural gas doesn’t solve the problem of greenhouse gas emissions and many of these plants need expensive gas pipelines to provide enough supply to repower with gas

• Need a Smart Retirement Strategy that maintains jobs, community value and infrastructure to generate new power

• Repowering with EGS takes advantage of existing infrastructure, means zero emissions with very low cost to operate and keeps jobs.
The Southwest
Southwest Coal Plants

- Planned for Retirement in Texas
  - Big Brown – 2018
  - Sandown – 2018
  - Monticello - 2018
  - Deely-2018

"Sustained low wholesale power prices, an oversupplied renewable generation market, and low natural gas prices, along with other factors."

- Four Corners, NM – 3 Units closed
- San Juan Generating Station - 2022
- Navajo Generating Station, AZ - 2019
The Pacific Northwest
Pacific Northwest Coal Plants

- Planned for Retirement
  - Centralia – 2025
  - Boardman – 2020
  - Colstrip Units 1 & 2 - 2020
Coal to Geothermal: Boardman

- Area near Boardman plant has elevated temperature gradient - 200°C at 5 km.
- Stress regime is favorable for reservoir creation.
- Water for cooling, existing transmission intertie and water for reservoir fill up available on site.
- Natural gas production probable. Could be used to boost water temperature
- Plant scheduled for shut-down 2025. Must be replaced with renewables.
- MOU with PGE in discussion
The Northeast
Northeast Coal Plants

- Planned for Retirement
  - Cayuga, NY – 2019
  - Albright, WV – 2020
  - Kammer, WV - 2020

Natural gas will replace coal plants in PA
- Armstrong – 2017
- Hunlock – 2020
- Mitchell- 2020
How Would EGS Work at a Typical Site?

- Create EGS reservoirs through cold water stimulation using AltaRock TZIM technology to fill reservoir with stored waste water
- Once EGS reservoir is operating, water loss to rock managed to dispose of all waste water from coal plant
- Reduce coal fired generation as geothermal project expands
- Two options:
  - 2-5 km (8000-16,000 ft) deep wells in Sedimentary Basin
    - Temperature known – 302ºF (150ºC)
    - Binary power plant with wet cooling
    - Water losses to rock higher due to natural permeability in sediments
    - 3-5 MW per well so for 100 MW plant 24 production wells, 18 injection wells
  - 3-7.5 km (10,000-25,000 ft) deep wells in crystalline basement rocks
    - Temperature (>225ºC, 440ºF) projected from shallower wells
    - Better conversion efficiency means more power per well even with lower flow rates
    - Flash plant with evaporative cooling or hybrid flash/binary plant with air cooling
    - Water losses: evaporation in cooling tower and loss to reservoir rock
    - 5-9 MW per well for 100 MW plant need 12 producers, 7 injectors
EGS Project: Moderate Temperature

Water use during EGS Reservoir Creation

<table>
<thead>
<tr>
<th>Year</th>
<th>New Wells</th>
<th>Annual Water Loss from Operations (Mgal)</th>
<th>Annual Water Loss from Stimulation (Mgal)</th>
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<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>344</td>
<td>518</td>
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<tr>
<td>2</td>
<td>12</td>
<td>661</td>
<td>478</td>
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<tr>
<td>3</td>
<td>10</td>
<td>926</td>
<td>398</td>
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<tr>
<td>4</td>
<td>8</td>
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<td>5</td>
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<td>1,508</td>
<td>239</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>1,667</td>
<td>239</td>
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</tbody>
</table>

- 15,000 ft wells
- 320°F resource temperature
- Average 3.5-5 MW per producer using TZIM stimulation
- 740 acres can yield 50 MW with little surface disturbance
EGS project – High Temperature

- 11,150-16,000 ft wells in basement
- 480ºF resource temperature
- Average 6-8 MW per producer using TZIM stimulation
- 740 acres can yield 80 MW

<table>
<thead>
<tr>
<th>Year</th>
<th>New Wells</th>
<th>Annual Water Loss from Operations (Mgal)</th>
<th>Annual Water Loss from Stimulation (Mgal)</th>
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<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>741</td>
<td>418</td>
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<tr>
<td>2</td>
<td>8</td>
<td>1235</td>
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<tr>
<td>3</td>
<td>8</td>
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<tr>
<td>4</td>
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</tr>
<tr>
<td>7</td>
<td>0</td>
<td>2592</td>
<td></td>
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</tbody>
</table>

- Water use during EGS Reservoir Creation
- Year 1 Wellfield layout ~3 km (2 sections)
- 11,150-16,000 ft wells in basement
- 480ºF resource temperature
- Average 6-8 MW per producer using TZIM stimulation
- 740 acres can yield 80 MW
Surface Facilities:

How Do We Generate Electricity with Coal?
How Much of the Coal Plant Can I Use for My Geothermal Project?

Plant Scherer, Georgia

Credit: Georgia Power
Cycle Efficiency

\[ h_1 = 3375 \text{ kJ/kg} \]

\[ P_1 = 10 \text{ MPa} \]

\[ T_1 = 500^\circ\text{C} \]

\[ q - w = \Delta h + \Delta k_e + \Delta k_p \]

\[ w = h_1 - h_2 = 3375 - 2373 = 1002 \text{ kJ/kg} \]

\[ \dot{W}_{turbine} = \dot{m} w = 8 \text{[kg/s]} \times 1002 \text{[kJ/kg]} = 8 \text{ MW} \]

\[ h_2 = h_f + X h_{fg} = 251.4 + 0.9 (2357.5) = 2373 \text{ kJ/kg} \]

Graphs showing cycle efficiency and ORC cycle efficiency.
How Do We Generate Power With Geothermal?

Binary Plant

Flash Plant
Equipment Used in Geothermal Power Generations

- Single flash plants are simple but inefficient
- Multi-stage, HP/IP/LP much better efficiency
- Binary power generation favored in arid areas due to ability to use air cooling
- Most new binary plants used at moderate temperatures from 125C-170C.
- Efficient power generation needed, particularly important for deep, expensive wells used for EGS
- Plants need to adapt easily to changing temperature/pressure conditions
How Do We Produce Geothermal Wells

Moderate Temperature: 125C-170C

- We need REALLY high flow rates
- Wells pumped to binary power plant
- Pumps are general lineshaft, but some ESP
- Net thermal efficiency between 8%-15%
- Very high flow rates needed: 60-120 kg/s
How Do We Produce Geothermal Wells

Well flowed by boiling

High Temperature: >170°C

- Wells pumped between 170°C-200°C
- Above 200°C, no pumps available.
  - Too hot for ESP
  - Deep set depth needed to provide sufficient head over pump, so usually too deep for line shaft pumps
- Wells self flow by density gradient through boiling
- Water and steam reaches surface at saturation temperature for controlled wellhead pressure
Thermal energy storage with HP steam discharge - use refurbished used HP/LP steam turbine for both geothermal generation and thermal storage steam generator

Steam from Thermal Storage

Geothermal wells-200 kph at ~45 psig

Energy from grid and from geothermal charged thermal storage

Steam from Thermal Storage

55 kva generator

Condenser

Stored condensate for steam generation from Thermal Storage

Water wells make-up water lost from cooling tower

Geothermal
10 MWg
9 MWn

LP side
HP side
Western States Coal Plants

Example: NV Energy North Valmy Generating station.

- Valmy plant slated to close between 2019-2025
- High geothermal gradient with ample data.
- Potential for conventional geothermal project as first phase
- Holding residual waste water in holding/evaporation ponds.
Eastern States Coal Plants

Example: Cayuga Power Plant near Lansing, New York.
- Plant is located in one of the best areas for geothermal energy in the east.
- Slated to close in Feb., 2015 but governor stopped closure to preserve jobs/property taxes
- Gas repower would need expensive pipeline the public doesn’t want
- Utility wants to build new T-line, shut down the plant and buy power from the market
- Looking for a solution that makes sense.
Reservoir stimulation/make-up water

- Water use is one of the most important environmental issues for EGS
- Need about 215-370 acre-feet (70-120 million gallons) of water for initial hydroshearing stimulation per 5-18 MW
- Lose 1-10% of water to rock during operation of field. Pressure controls magnitude of losses
- Can be managed to lose more or less water with production and injection pressures.
- Water can be minimally treated to remove particulates, but dissolved solids are not usually an issue.
- Closed loop operation prevents escape of contaminants into environment

Cooling water make-up

- Need ~400 gpm circulating water per MW
- Lose ~10% to evaporation in evaporative cooling tower
- Binary plants can use dry cooling, but efficiency is reduced
- Overall conversion efficiency has impact on EGS costs
- Hybrid systems possible
- Innovative cooling systems under development
- Water quality for cooling needs is higher than for circulating in the EGS reservoir
Proposed Work:

- **Coal Transition Funding from TransAlta for Centralia coal plant**
  - Feasibility study with detailed engineering design. Not funded
  - Re-propose as combined biomass/geothermal project with TSI?
  - Washington State Clean Energy Fund supplement to Coal Transition Funding for Centralia
    - Total $1.8M for lead up to pilot project. Request $1.3M from Centralia fund
    - $500k to supplement drilling on ARE lands leased from Weyerhauser

- **Pilot project at Centralia, Boardman or Colstrip**
  - Total $30M pilot plant - $10M-$15M from Transalta.
  - Need $15M from HERO through foundation funding or impact investment

- **Cornell University: Deep Earth Resource EGS project**
  - HERO performs feasibility study
  - AltaRock provides EGS technology

- **R&D**
  - Flow test at Newberry
  - Drilling at Mt. St. Helens through Play Fairway/WA Clean
  - Seismic calibration and passive seismic monitoring
Centralia Biomass/Geothermal Hybrid

- Proposal to Coal Transition Grant Fund not accepted
- Reapply with Emphasis on maintaining jobs favors biomass and natural gas
- TSI, Inc. in Lynnwood - Torrefaction method that can produce wood waste biomass that can be directly used in coal plant
- Combined with geothermal could reduce energy requirements for biomass drying
- Produce power from geothermal and dry biomass from wood waste
- Need to understand:
  - Biomass supply
  - Geothermal project costs
  - Worker training for biomass operation
  - Schedule for transition
  - Demand for baseload power
Colstrip in Central Montana: High Temperature Gradients

- Deep sedimentary basins with ample data from oil wells
- Williston Basin oil wells have demonstrated elevated temperatures with depth
- Best sites for deep hot water
- Coal fired power plants across the area
- Temperature gradients above 45°C/km
- Deep disposal well drilled for Colstrip plant found good temperatures for EGS geothermal
- Waste water disposal an issue
Steps To Transition of Coal to Geothermal:
Phased approach reduces risk. Transitions jobs

- Phase 1 – Detailed engineering feasibility study
  - Site assessment – geologic, geophysical, seismic temperature and project data evaluation using existing data.
  - Gap analysis with plan for collecting additional data including core hole and additional geophysics
  - Environmental and regulatory compliance assessment
  - Public outreach – webinars, public meetings and conference to educate stakeholders
  - Drill deep core-hole to acquire data on temperature with depth, rock stresses, rock type and drilling conditions
  - Detailed engineering study including well design, stimulation design and cost analysis.
  - Economic analysis including power markets and financing potential

- Phase 2 – Demonstration project
  - Obtain project financing
  - Permitting and regulatory compliance
  - Modify temporary seismic array as indicated from Phase 1 studies.
  - Modify project plan using data.
  - Drill 1 injector and up to three producers and create a stimulated reservoir for small scale power project as demonstration.
  - Construct demonstration power plant
  - Operate facility while designing expansion project
  - Go/No-go decision on Full Scale Expansion

- Phase 3 – Expansion to utility scale project
  - Obtain project financing
  - Permitting and regulatory compliance
  - Determine from Phase 2 project data the potential for total development of project site
  - Adjust plan using Phase 1 data to optimize project economics
  - Run multiple rigs to drill project wells
  - Stimulate wells
  - Construct full scale power plant
Pilot Project Proposal

Goal: Develop a pilot project at Boardman using EGS technology at Boardman

<table>
<thead>
<tr>
<th>Phase I</th>
<th>Preparatory Phase</th>
<th>Pre</th>
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<tbody>
<tr>
<td>Task 1.1</td>
<td>Project management</td>
<td>$ 97,120</td>
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<td>Task 1.2</td>
<td>Public outreach</td>
<td>$ 31,536</td>
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<td>Task 1.3</td>
<td>Data collection, review and assessment (e.g., PNNL BWIP data)(Gap analysis)</td>
<td>$ 52,480</td>
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<td>Task 1.4</td>
<td>Geophysical analysis and conceptual modeling: gravity, MT, and/or passive seismic (basement depth??)</td>
<td>$ 181,200</td>
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<tr>
<td>Task 1.5</td>
<td>Permitting, regulatory and compliance matrix</td>
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<td>Task 1.6</td>
<td>Permit fees and well drilling bonds</td>
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<td>Induced seismicity risk assessment - assuming stimulation</td>
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<td>Exploration plan design and drilling plan</td>
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<td>Initial economic analysis (including natural gas potential)</td>
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<td>Fundraising/financing for demo project</td>
<td>$ 50,528</td>
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<tr>
<td>Task 1.11</td>
<td>Reporting and presentations , include recommendations and Phase II budget</td>
<td>$ 25,636</td>
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Go/No-Go decision point - Proceed to Phase II

Deliverable: Cost & Risk Analysis Report with preliminary engineering design

- Go/No-Go Decision: Is development at Boardman feasible?

If Go, continue to Phase 2: Drill and Stimulate First Well
Decisions From Phase 1

- Target depth
- Likely lithology at target (sediments or basement?)
- Fluid pressure - overpressures >5000 psi possible
- Porosity & permeability at target
- Well design (bit & casing sizes)
- Drilling cost
- Preliminary pilot plant design and cost
- Preliminary economic analysis
- Resource potential of Boardman site
- Natural gas production possible?
- Permitting and regulatory compliance matrix and permitting for first well

*Reducing the natural gas risk with geothermal (and geopressure)*
*Reducing the geothermal risk with natural gas.*
## Phase 2 - Drill/Stimulate 1st Well

<table>
<thead>
<tr>
<th>Phase II</th>
<th>Drill and Stimulate Exploration/Production Well</th>
<th>$ 11,846,431</th>
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<tbody>
<tr>
<td>Task 2.1</td>
<td>Project management</td>
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<td>Public outreach</td>
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<td>Task 2.3</td>
<td>Permitting, installation, and monitoring of MSA</td>
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<td>Task 2.4</td>
<td>Wellfield and reservoir creation design and engineering and planning</td>
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<td>Task 2.5</td>
<td>Drill 15,000 - 17,000 deep exploration/production well</td>
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<td>Well logging and completion</td>
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<td>Task 2.7</td>
<td>Well stimulation including microseismic fracture mapping</td>
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<td>Task 2.8</td>
<td>Well testing</td>
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<td>Task 2.9</td>
<td>Second (injection) well design based on results</td>
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<tr>
<td>Task 2.10</td>
<td>Pilot plant preliminary design and permitting</td>
<td>$ 473,200</td>
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<tr>
<td>Task 2.11</td>
<td>Updated economic analysis of Boardman</td>
<td>$ 52,788</td>
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**Go/No-Go decision point - Proceed to Phase III**

**Deliverable:** First EGS well with testing. Costing update. Final plan for second well.

- **Go/No-Go Decision:** Drill second well?

If Go, continue to Phase 3: Drill and Stimulate Second Well
Decisions From Phase 2

- Design of second well
- Preliminary power plant design
- Updated economics
- Permitting and regulatory compliance update

Reducing the natural gas risk with geothermal (and geopressure)
Reducing the geothermal risk with natural gas.
Phase 3 - Drill/Stimulate 2nd Well

<table>
<thead>
<tr>
<th>Phase III</th>
<th>Drill and Stimulate Second (Injection) Well</th>
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<td>Stimulation plan design based on results</td>
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<td>Task 3.6</td>
<td>Drill second well (added for high scenario)</td>
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<td>Stimulate second well</td>
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<td>Post stimulation well testing</td>
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<td>Task 3.9</td>
<td>Preliminary power plant design and engineering, transmission and interconnection design</td>
<td>$ 1,161,600</td>
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<td>Task 3.10</td>
<td>Update project economics and risk analysis</td>
<td>$ 39,737</td>
</tr>
<tr>
<td>Task 3.11</td>
<td>Reporting and presentations</td>
<td>$ 48,704</td>
</tr>
</tbody>
</table>

Go/No-Go decision point - Proceed to Phase IV


➢ Go/No-Go Decision: Construct pilot plant?

If Go, continue to Phase 4: Construct pilot plant
Decisions From Phase 3

- Final pilot plant design with engineering and risk analysis update
- Updated economics
- Permitting and regulatory compliance update
- Final resource assessment for utility scale power potential

*Reducing the natural gas risk with geothermal (and geopressure)*
*Reducing the geothermal risk with natural gas.*
# Phase 4 - Construct Pilot Plant

## Deliverable:
Operating pilot plant. Plan for utility scale project. Operating report.

- Go/No-Go Decision: Plan for utility scale project?
Boardman Summary and Questions

What Will We Find

- Underlain by thick layer of Columbia River Basalt
- Geothermal resource is most likely sandstone, with stored hot water
- Natural gas may be by-product of water production

What Do We Need to Find

- Would well stimulation be able to develop sufficient production/injection?
- Is the land position at Boardman large enough to expand to utility scale using EGS technology?
- Could the Boardman site be developed along with another site such as Newberry to provide the demand supplied now by the coal plant?
How Do We Work Together?

- HERO, AltaRock Energy, GE Global Research, Blade Energy Partners, Portland General Electric
- Joint Venture
- Build/Operate/Transfer
- HERO can assist with pilot plant financing
- AltaRock can provide project development experience
- Blade Energy can provide drilling technology and large scale resource project experience
- GE Global Research can provide power plant innovative design for pilot plant
Questions for PGE

- How much baseload power at Boardman needs to be replaced?

- What is the value of load-following?
  - Geothermal plants can load follow but can’t be turned on and off
  - Blue Mountain ramps at about 6 MW/min
  - Summer decrease in output can be mitigated with solar thermal.
  - Thermal storage is possible in EGS projects

- What is the timeline for power replacement?

- How much replacement can come from conservation? Intermittent resources like wind and solar?
# Development Scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>Rigs</th>
<th>New Wells</th>
<th>Total Wells</th>
<th>MWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-17</td>
<td>1</td>
<td>2</td>
<td>1 / 1</td>
<td>3+ (Pilot plant)</td>
</tr>
<tr>
<td>2018</td>
<td>3</td>
<td>12</td>
<td>9 / 3</td>
<td>25 (1st unit)</td>
</tr>
<tr>
<td>2019</td>
<td>4</td>
<td>18</td>
<td>24 / 6</td>
<td>60 (units 2-3)</td>
</tr>
<tr>
<td>2020</td>
<td>3</td>
<td>12</td>
<td>33 / 9</td>
<td>100 (units 4-5)</td>
</tr>
</tbody>
</table>

**Assumptions**
- 4-5 wells per rig per year
- 3-4 producers per injector
- 3-5 MWnet per producer
Boardman Geothermal Potential

APPENDIX A
Past studies

- Columbia River Flood Basalt Province Special Paper (1989)
  - 5,000 – 10,000 ft of sediments (source and reservoir)
  - Overlain by 4,000 – 13,800 ft of Columbia River Basalt
  - Rattlesnake Hills gas field (1.3 BCFG, 1930-1941)
Regional Deep Wells
Temperatures at Depth

Based on exploration wells drilled below CRB

Target temp 175 C, 350 F
Temperature at 4.5 km (15,000ft) depth

Based on thermal modeling and SMU data base
<table>
<thead>
<tr>
<th>Formation</th>
<th>Rock Type / Age</th>
<th>Depth at Site (top)</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columbia River Basalts (CRB)</td>
<td>Basalts</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>Wenatchee, Ohanapecosh, John Day</td>
<td>Volcanics / Oligocene</td>
<td>2200 m</td>
<td>9 to 17%</td>
</tr>
<tr>
<td>Chumstick, Roslyn, Swauk, Clarno, Herren</td>
<td>Sand-stones / Eocene</td>
<td>&gt;3000 m</td>
<td>5 to 8%</td>
</tr>
<tr>
<td>Hudspeth</td>
<td>Marine Sediments / Cretaceous</td>
<td>??</td>
<td>?</td>
</tr>
<tr>
<td>Basement (exotic terrain)</td>
<td>Granite / Gneiss</td>
<td>&gt;4000 m</td>
<td>Fracture</td>
</tr>
</tbody>
</table>
13,000-13,600 ft, 570 MCFD gas, 160 gpm 314 °F water,
EGS in basement vs Hot sedimentary aquifers

**EGS**
- **Rock type** = crystalline (granite, gneiss)
- **Permeability** = enhanced fracture
- **Examples**
  - Newberry, Oregon
  - Cooper Basin (Australia)
  - Soultz, France
  - Landau, Germany
  - South Hungary EGS
  - Finland Deep Heat

**Hot Sediments**
- **Rock type** = sandstones, mudstones, shale
- **Permeability** = matrix, natural fracture permeability +/- fracture enhancement
- **Examples**
  - Bavarian region, Germany
  - limestone
  - Grosse Schoenbeck, Germany – sandstone and basalts
Other Geothermal Prospects in Oregon

APPENDIX B
Other geothermal prospects in OR

Weyerhaeuser Lands evaluated by AltaRock

Newberry Volcano

OR AltaRock Leases

WA AltaRock Leases
Other Possible EGS Resources

• Compare costs to alternative geothermal sites:
  – Newberry Volcano
  – Mt. Hood
  – Warm Springs
  – Mount St. Helens
  – Wind River, WA
  – Klamath and southern Oregon

• DOE risk reduction through Play Fairway studies in Oregon and Washington: Untapped Cascade resource.

• Basin and Range resources in OR
Conductive heat resource at Newberry

Accessible EGS Resource:
4-9 km from caldera center
Depth < 3.5 km,
> 2.4 GW for 30 years
40% of Oregon’s current average use!!

Newberry EGS reservoir Production Well Course and Target