Recent Advances in US Geothermal R&D: Implications for Global Development

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Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy
Geothermal Program: Key Goals and Objectives

Creating Impact

**Increased Focus**

**Identify New Geothermal Opportunities**
- Lowered risk and cost
- New prospecting workflow

**Enhanced Geothermal Systems (EGS) R&D, Demonstrations and Underground Field Observatory**
- New techniques and technologies

**Non-Technical Barriers**
- Regulatory
- Financial/Commercial

**Project Synergies**
- Co-Production and Distributed Power
- Strategic Materials
## Geothermal Program Balance

### Transition from Near to Long Term

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Timeline</th>
<th>Low Temp</th>
<th>Co-Production</th>
<th>Blind Hydrothermal</th>
<th>In-Field EGS</th>
<th>Greenfield EGS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utilize waste-heat / promote distributed energy</strong></td>
<td><strong>Near Term</strong></td>
<td><strong>Near Term</strong></td>
<td><strong>Near to Intermediate</strong></td>
<td><strong>Near to Intermediate</strong></td>
<td><strong>Long Term</strong></td>
<td><strong>Develop replicable model for commercial scale-up</strong></td>
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<td><strong>Leverage O&amp;G infrastructure</strong></td>
<td><strong>Near Term</strong></td>
<td><strong>10's-100's MW, aggregate to GW potential</strong></td>
<td><strong>10's GW additional potential</strong></td>
<td><strong>100's MW- GW's potential - low risk</strong></td>
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<td><strong>Growing Interest, New Potential Sector</strong></td>
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<td><strong>Majority of the Private Sector</strong></td>
<td><strong>Near to Intermediate</strong></td>
<td><strong>10's GW additional potential</strong></td>
<td><strong>100's MW- GW's potential - low risk</strong></td>
<td><strong>Private Sector, very few companies to date</strong></td>
<td><strong>High potential for growth and new entrants resulting from EGS Field Lab</strong></td>
<td></td>
</tr>
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<td><strong>Local or Rural, Direct Use</strong></td>
<td><strong>Near Term</strong></td>
<td><strong>10's-100's MW, aggregate to GW potential</strong></td>
<td><strong>10's GW additional potential</strong></td>
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### GTO Operational Space

*Energy Efficiency & Renewable Energy*
Geothermal power plants brought online/expanded in 2012-13 (154 MW)

- San Emidio Expansion
  U.S. Geothermal (12.75 MW)

- Florida Canyon Mine
  Electratherm (0.1 MW)

- Tuscarora Power Plant
  Ormat (18 MW)

- Beowawe Power Plant
  Terra-Gen (1.9 MW)

- Dixie Valley I Power Plant
  Terra-Gen (6.2 MW)

- Hudson Ranch Plant
  Energy Source (49.9 MW)

- McGinness Hills Power Plant
  Ormat (30 MW)

- Puna Plant Expansion
  Ormat (8 MW)

Nevada: 68.95 MW
California: 49.9 MW
Oregon: 28 MW
Geothermal Projects
Phase III and IV Development

Developers*

- CalEnergy
- Chena Hot Springs
- Cyrq Energy
- ElectraTherm
- Enel North America
- Gradient Resources
- Kodali, Inc.
- OIT
- Ormat Technologies
- Ram Power, Inc.
- Surprise Valley Electric
- Terra-Gen
- U.S. Geothermal

*Nevada Developers in bold.

SOURCE:

Phase III
~750 MW
(Planned Capacity Addition)

Phase IV
~200 MW
(Planned Capacity Addition)

Phase III: Permitting and Initial Development
Phase IV: Resource Production and Power Plant Construction
US Geothermal Potential by 2030
Pathway to Growth

- **EGS**
  - 
P95 7.9 GWe
  - mean 9 GWe
  - P5 3.7 GWe

- **Hydrothermal**
  - 
P95 16 GWe
  - mean 10 GWe
  - P5 7.9 GWe

- **Coproduced**
  - 
P95 30 GWe
  - mean 30 GWe
  - P5 7.9 GWe

- **Existing Capacity**

<table>
<thead>
<tr>
<th>Year</th>
<th>Installed Capacity (GWe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>1.0</td>
</tr>
<tr>
<td>2009</td>
<td>1.5</td>
</tr>
<tr>
<td>2012</td>
<td>2.0</td>
</tr>
<tr>
<td>2015</td>
<td>2.5</td>
</tr>
<tr>
<td>2018</td>
<td>3.0</td>
</tr>
<tr>
<td>2021</td>
<td>3.5</td>
</tr>
<tr>
<td>2024</td>
<td>4.0</td>
</tr>
<tr>
<td>2027</td>
<td>4.5</td>
</tr>
<tr>
<td>2030</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Program Focus**
- **In the pipeline**
  - Discovery Phase (GEA)
  - Confirmation Phase (GEA)
  - Power Plant Construction Phase (GEA)

**Pathway to Growth**
- **Existing Capacity**
  - **EGS**
  - **Blind Hydrothermal**
  - **Coproduced**

**Installed Capacity (GWe)**
- 0 to 35

**Resource Potential (GW)**
- 0 to 1000

**Technology Headroom**
- P95 7.9 GWe
- mean 9 GWe
- P5 3.7 GWe

**Undiscovered Hydrothermal**
- P95 16 GWe
- mean 10 GWe
- P5 7.9 GWe

**Identified Resources**
- P95 30 GWe
- mean 30 GWe
- P5 7.9 GWe

**From USGS, 2008**
EERE’s 5 Core Questions
Where and How Does The R&D Fit?

1. **High Impact**

2. **Additionality**

3. **Openness**

4. **Enduring Economic Benefit**

5. **Proper Role of Government**
Geothermal Office Investment Synergies

R&D Successes in One Area Multiply to Other Programs

Systems Analysis

- Tracers and interpretation
- Well completions
- High temperature tools and sensors
- Remote sensing
- Performance monitoring
- Geochemistry
- Efficient cooling
- Power plant demonstrations
- Imaging and modeling fluid flow
- Bit design
- Microseismic analysis
- Stress measurement and characterization
- Regulatory streamlining

Hydrothermal

- Coproduction demos

Low Temp

- Working fluids

EGS

- Rock stimulation technologies
- EGS demos

NGDS

- Workforce and education
- Levelized cost of electricity
- International
Economic Analysis Drives R&D Priorities

Drilling, Project Size – Risk and Costs

Need combined improvements and efficiencies
### Low-Temperature:
- **Beowawe Power**: Beowawe, NV – 2.5 MW added
- **TerraGen Sierra Holdings**: Dixie Valley, NV – 6 MW online

### Co-Production:
- **Simbol Materials**: Lithium extraction plant groundbreaking expected 2013
- Deploying two binary systems in operating O&G fields.

### Hydrothermal:
- ~150+ MW of new hydrothermal capacity
- 26 wells drilled to date

### EGS Demonstrations:
- **IN-FIELD**: Ormat: Desert Peak, NV – 1.7 MW
- **NEAR-FIELD**: Calpine: The Geysers, CA - 5 MW
- **GREENFIELD**: AltaRock: Newberry, OR

### Cross-Cutting Research & Development:
- **CSI Technologies /AltaRock** - Diverters
- **Baker Hughes** – Ultrasonic Fracture Imager
- **Sandia National Lab** – PDC Bits
Recent Project Successes
Low Temperature Portfolio

Beowawe Power, LLC

- Funding Source: ARRA
  - DOE Funds: $2M
  - Awardee Cost Share: $2.4M
- Completed construction in 2011 of a binary power plant
- Plant came online in the Spring of 2011 producing 2.5 MW gross

Terra-Gen Sierra Holdings, LLC (Dixie Valley)

- Funding Source: ARRA
  - DOE Funds: $2M
  - Awardee Cost Share: $13.4M
- Binary Power Plant online and producing 6 MW gross since September 2012
- Unit has operated over 500 hours as of November 2012

Completed Beowawe Power Plant (Photo credit: TG)

Image by Google Maps
What’s next for Hydrothermal?
Tools, Maps, Analysis, “Plays”

- Continue to advance Innovative Exploration Technologies (IET) and demonstrations

- New drilling and measurement technologies

- Play fairway analysis (borrowed from oil and gas); observational, analytical integration, interpretation, basin and systems evolution

Favorable structural settings and setting types for geothermal systems (Faulds et al., 2011)

Source: CNSOPB, Nova Scotia
Oil and gas uses “facies” routinely to describe geologic settings in the subsurface – *standard practice*

Not yet done routinely in geothermal; critical path towards describing “flow units” and like-kind reservoir units.

Will allow large scale reservoir and resource characterization and upside definition.
## Core Program Focus
### EGS Demonstration Projects

<table>
<thead>
<tr>
<th>Performer</th>
<th>Project Site</th>
<th>Site Information</th>
<th>Stimulation Timeline</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ormat Technologies Inc.</td>
<td>Desert Peak, NV</td>
<td>Adjacent to existing hydrothermal sites</td>
<td><strong>Successful stimulation – commercial, grid-connected, 1.7 MWe</strong></td>
<td>$ 4.3 M</td>
</tr>
<tr>
<td>Geysers Power Company, LLC</td>
<td>The Geysers, CA</td>
<td>Reopen two existing wells to deepen for injection and stimulation</td>
<td><strong>Successful stimulation, 5 MWe scale</strong></td>
<td>$ 6.2 M</td>
</tr>
<tr>
<td>University of Utah</td>
<td>Raft River, ID</td>
<td>Improve the performance of the existing Raft River geothermal field</td>
<td>FY13 stimulation</td>
<td>$ 8.9 M</td>
</tr>
<tr>
<td>Ormat Technologies Inc.</td>
<td>Bradys Hot Springs, NV</td>
<td>Improve the performance of the existing Brady’s geothermal field</td>
<td>FY13 stimulation</td>
<td>$ 3.4 M</td>
</tr>
<tr>
<td>AltaRock Energy Inc.</td>
<td>Newberry Volcano, OR</td>
<td>High potential in an area without existing geothermal development</td>
<td><strong>Successful stimulation</strong></td>
<td>$ 21.4 M</td>
</tr>
<tr>
<td>NakNek Electric Association</td>
<td>NakNek, AK</td>
<td>Located in remote location in Alaska without existing geothermal development</td>
<td>Project closeout</td>
<td>$ 12.4 M</td>
</tr>
</tbody>
</table>
What is EGS?

EGS technologies will allow us to tap geothermal resources – 100+ GWe, or enough to power 100 million homes – that would be otherwise inaccessible.

EGS can capture power from anywhere there is sufficiently hot rock, exponentially increasing the reach of geothermal development in the U.S.
Ormat Technologies’ Desert Peak-2 EGS project successfully supplied 1.7 MW electricity to the grid – a first-in-the-nation achievement.

DOE invested $5.4 million, with a private costshare of $2.6 million.

Desert Peak represents a near-term opportunity to develop EGS at lower cost and risk; potential for reserve additions at highly competitive costs.

Pathway to larger, more complex and more challenging R&D efforts.

“DOE’s Geothermal Technologies Office is changing geothermal development in the U.S.”

Lucien Bronicki, Ormat Founder and Chief Technology Officer (4/2013)

– Yahoo: Stockwatch

“'If we can go to all the hundred or thousands of wells that are unproductive and tinker with them to make them productive, this is a game changer.’”

Paul Thomsen, Director of Policy and Business Development at Ormat – MIT Technology Review, 4/2013
Enhanced Geothermal Systems (EGS)

Facies Concept – A Continuum

**Greenfield:**
No existing geothermal development or infrastructure

**In-Field**
Located within an unproductive portion of an operational hydrothermal field

**Near Field/Field Extension**
On the margins of existing hydrothermal fields
OUR VISION:

Increased success at Demo projects

Near-term use at existing fields as reservoir enhancement tool

1. Widespread deployment to ensure resource and reserve growth
2. Recognition by investment community of low risk and large opportunity

Preparedness - strategy, funding, oversight
Snapshot of U.S. Efforts in EGS

**EERE-funded demonstration projects showing excellent results**

**AltaRock - Newberry Volcano**
Stimulation completed Winter 2013
Analysis in progress

**Raft River**
Stimulation scheduled for early summer

**Bradys**
Stimulation in progress

**The Geysers**
- Volume
- Flow rate
- Power Gen.

**Desert Peak**
- Volume
- Flow rate
- Power Gen.

Successful demonstrations on the pathway to broader commercial adoption
Current Global EGS Landscape

- **Newberry Volcano**
  - Bend, Oregon
  - AltaRock Energy/DOE

- **1.5 MW KiGam**
  - Pohang Field
  - South Korea

- **1 MW Habanero Pilot EGS**
  - Cooper Basin, Australia

- **4 MW Insheim**
  - Insheim, Germany

- **5 MW The Geysers**
  - Middletown, California
  - Calpine Corporation/DOE

- **1.5 MW Soultz**
  - Kutzenhausen, France

- **1.7 MW Desert Peak**
  - Churchill County, Nevada
  - Ormat/DOE

- **RAFT RIVER**
  - Raft River, Idaho
  - University of Utah/DOE

- **2.9 MWe/3 MWt Landau**
  - Landau in der Pfalz
  - Germany

- **24 MWt ECOGI**
  - Buntsandstein
  - Germany

- **1 MW Habanero**
  - Cooper Basin
  - Australia

**United States**

**France**

**S Korea**

**Australia**

**Commercial**

**Demonstration**

**Under Development**

**Announced**
Key Barriers to EGS Development
Technology and Engineering Needs

<table>
<thead>
<tr>
<th>Technology Barriers</th>
<th>Potential Solution Set</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Access</td>
<td>Hard/Hot-rock drilling, completion technologies</td>
<td>EGS Success</td>
</tr>
<tr>
<td>New well geometries and concepts, optimized drilling</td>
<td></td>
<td>Game-changers</td>
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<td>Reservoir Creation</td>
<td>Horizontal wells – a first for geothermal</td>
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<tr>
<td>Characterize local stress, zonal isolation, novel fracturing methods, increase fractured volume per well</td>
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<td>Productivity</td>
<td>Rotary steering</td>
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<td>Increase flow rates without excessive pressure needs or flow localization</td>
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<tr>
<td>Sustainability</td>
<td>Smart tracers</td>
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<tr>
<td>Maintain productivity with minimal thermal drawdown and water losses</td>
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<tr>
<td>Stress-field diagnostics</td>
<td></td>
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<tr>
<td>Zonal Isolation</td>
<td>High-T sensors</td>
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<td>Cross-well monitoring</td>
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<td>Diverter technologies</td>
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Hard/Hot-rock drilling, completion technologies
Horizontal wells – a first for geothermal
Rotary steering
Smart tracers
High-T sensors
Cross-well monitoring
Diverter technologies
Game-changers
## R&D Pathway

### EGS R&D Pathway

#### Needs and Opportunities

<table>
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<tr>
<th>R&amp;D Needs and Opportunities</th>
<th>In- to Near-Field EGS</th>
<th>EGS Field Lab</th>
<th>Industry Uptake</th>
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<td><strong>Timeline</strong></td>
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<td>Near to Intermediate</td>
<td>Intermediate to Long Term</td>
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<td><strong>R&amp;D Needs and Opportunities</strong></td>
<td>Thermal Stimulations</td>
<td>First Horizontal Geothermal Wells</td>
<td>Reduced Risk from EGS Field Lab Methodology</td>
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<td>High-Temperature Thermally-Degradable Packers</td>
<td>Advanced Stimulation Methods</td>
<td>New Partnerships</td>
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<td>Multi-Stage Vertical-Well Stimulations</td>
<td>Multi-Stage Lateral Stimulations</td>
<td>Streamline Permitting and Fundability</td>
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<td></td>
<td>New Subsurface Imaging Tech</td>
<td>Optimize Productivity and Operational Controls</td>
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<td></td>
<td></td>
<td>New International, Inter-Agency, and O&amp;G Collaborations</td>
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</table>
Low Risk: Testing of downhole tools, monitoring systems, etc.

Medium Risk: Testing of new drilling systems, chemical diverters, etc.

High Risk: Testing of potentially "destructive" well stimulation techniques

Examples: energetic well stimulation, testing which could lose part of the wellbore, stimulation which could alter a significant volume of the subsurface reservoir

Innovative Solutions

1. Faster, More Efficient Drilling Technologies

2. Advanced Downhole R&D

3. Measurement / Assessment Tools

4. Seismic Modeling, Monitoring & Protocols
WHY?
Promote transformative science and engineering to:
- Address key barriers
- Validate and optimize EGS technology
- Ensure deep understanding and reproducibility for commercial scale-up

Federal Role:
- Test technologies/take technical risks not possible in private sector
- Aggressive timeframe
- Gather and disseminate comprehensive data sets

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TECHNICAL CHALLENGES
- **Reservoir Access**
  - New well geometries and concepts, optimized drilling
- **Reservoir Creation**
  - Characterize local stress, zonal isolation, increase fractured volume per well
- **Productivity**
  - Increase flow rates without excessive pressure needs or flow localization
- **Sustainability**
  - Maintain productivity with minimal thermal drawdown and water losses

---

**FY13**
- Pre-conceptual Planning

**FY14**
- Conceptual Design
- Preliminary Design
- Final Design
- Site Characterization

**FY15-19**
- RD&D/Operations
- Closeout
EGS Field Lab
What does success look like?

1. **Subsurface “Roadmap”**
   - Fundamental understanding of how to create large-scale subsurface heat exchange systems
   - Reproducible in different geologic settings
   - Sustainable

2. **Successfully test new technologies in controlled environment**
   - Demonstration of path to lower costs
   - Select highest performing/most reliable methods and tools

3. **Data Sharing**
   - Capture of high-fidelity information and measurements
   - Immediate distribution to both public and private sector stakeholders

4. **Increased private investor funding due to lower risk and costs**
   - Lower financing costs as well
   - Major opportunity for new entrants into the industry

5. **Global leadership in a new renewable energy sector – with expectation of accelerated domestic and international adoption of EGS**

*Commercial pathway to EGS well productivity and large-scale power and direct use – becoming more broadly distributed throughout the country, beyond the western US*
Future GTO Initiatives/Focus Areas

Enhanced Geothermal Systems
- EGS Field Observatory
- Advance down-hole R&D
- Characterization/Assessment tools

Hydrothermal
- Play Fairway Analysis/Mapping
- Advancing horizontal drilling technologies, high temperature tools
- Leverage oil and gas technologies

Low Temp/Coproduced
- Strategic materials
- Co-production and binary unit growth
- Direct Use and Distributed Energy
- Sedimentary systems

Systems Analysis
- Completion of Regulatory Roadmap, streamlining
- National Geothermal Data System (NGDS) deployment
• **EGS Demonstration Successes:**
  – Will accelerate industry adoption - will be seen as predictable, low risk and highly fundable
  – EGS Field Lab (FORGE) a major opportunity for multi-partner participation, R&D advances and sector transformation

• **Hydrothermal:**
  – New drilling technologies, new geophysical and exploration techniques and play fairway maps will lower risk and cost

• **Low Temperature:**
  – Co-Production success will drive adoption by oil and gas, and contribute to broader use of direct use and distributed energy

All highly transferable to international sites and opportunities

**Global partnerships, collaboration, data sharing**
Pathway to Transformative Change

US Shale Gas: Technology Innovations Spawned Sector Transformation

Potential for similar impact in Geothermal using broadly comparable technologies

Sources: Lippman Consulting, Inc. 2011. Technology advances from King, 2012 (SPE 152596)