Northwest **Power** and
Conservation Council

June 7, 2016

MEMORANDUM

TO: **Power Committee**

FROM: **Gillian Charles, Energy Policy Analyst**

SUBJECT: **Geothermal energy potential and the Newberry Geothermal Energy research facility**

BACKGROUND:

Presenter: Alain Bonneville, Pacific Northwest National Laboratory (PNNL)
Laura Nofziger, AltaRock Energy
Rebecca O'Neil, PNNL

Summary: Mr. Bonneville, Ms. Nofziger, and Ms. O'Neil will be presenting an overview of geothermal energy as a baseload renewable resource. In particular, they will be discussing what the potential is in the region, the costs and barriers to development, and the advantages and differences between conventional geothermal and enhanced geothermal systems (EGS).

On Monday, June 13 (the day before the Power Committee meeting), several Council members and staff will be taking a tour of the Newberry Geothermal Energy (NEWGEN) research facility near the Newberry Volcano. This site is one of five finalists for the Department of Energy's Frontier Observatory for Research in Geothermal Energy (FORGE). If selected, it will become the dedicated national research facility for scientists and engineers to develop and test new EGS technologies and help further the deployment and commercialization of EGS.

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Relevance: The Seventh Power Plan identified conventional geothermal as a potential renewable resource for compliance with state Renewable Portfolio Standards. One advantage geothermal has is that it produces a consistent output similar to a baseload resource like natural gas and coal. Variable energy resources like wind and solar produce energy intermittently, solely dependent on when the wind blows and the sun shines (except when combined with energy storage). To date, development of conventional geothermal resources in the region has been limited due to its high development risk, but the technical potential, particularly in Central/Southern Oregon and Idaho, is significant.

The Seventh Plan identified EGS as an emerging technology that has significant potential in the future Northwest power system. Action item ANLYS-14 directs Council staff to monitor and track development, costs, potential, significant milestones, and early demonstration projects and commercial deployments.

Workplan: Power Division A.4.3 – Implement Seventh Power Plan and related Council priorities – Generation Resources – Track emerging technologies and development trends related to generating resources and utility scale storage.

Background: Conventional geothermal energy requires the simultaneous occurrence of high temperature, permeable rock below the Earth's surface and the natural presence of a fluid source or hydrothermal reservoir. EGS only requires hot rock – the rest is engineered through fracturing to create permeability and the injection of fluid from an often, but not always, man-made source. While conventional geothermal requires expensive drilling for the right combination of natural occurrences – and often results in "dry" hole wells – EGS manufactures those occurrences and thereby minimizes the risk of high cost exploratory drilling. However, additional risks come with EGS, including issues caused by fracturing the rock ("fracking") that can sometimes lead to seismic activity or fluid seepage tampering natural bodies of water nearby.

The NEWGEN project is led by PNNL, in partnership with Oregon State University, AltaRock Energy, GE Global Research, and Statoil.

More Info: http://www.newberrygeothermal.com/
There is a short video if you scroll down the page – it describes EGS and the proposed research facility at the Newberry volcano. There is also additional information regarding the facility and the process.

Alain Bonneville, Ph.D, PNNL. Dr. Bonneville is a Laboratory Fellow and geophysicist who joined the Pacific Northwest National Laboratory in 2009. He is the principal investigator of a diverse range of projects involving basic and applied research in geological storage of CO2, geophysical monitoring techniques and geothermal energy. Between 2009 and 2013, he led the PNNL Carbon Sequestration Initiative. Prior to this role, he was a full professor of Geophysics and vice director of the Institut de Physique du Globe de Paris (IPGP). He has made contributions to various domains of Earth sciences, from the study of intra-plate volcanism to marine heat flow and geodesy. During the 1990s, as a professor at the University of French Polynesia, he became a recognized specialist of the geodynamics of the South Pacific and founded the Geodetic Observatory of Tahiti with support from NASA and CNES.

Laura Nofziger, Senior Vice President and Managing Director, AltaRock Energy. Ms. Nofziger has 15 years of energy industry experience in production, reservoir and fracture stimulation engineering and management. Laura previously served as eni Petroleum's Production Manager over their Nikaitchuq asset on the North Slope of Alaska where she was responsible for overall management of Production & Operations activities. As production manager, she managed a team of more than 200 people, a 40,000 BOPD processing facility, over 40 extended-reach horizontal wells, and the asset's operating budget. Prior to her position at eni, Laura was the lead engineer for AltaRock Energy (ARE), where she developed the Stimulation and Well Testing Best Practices for the Geysers demonstration project while being responsible for all production, stimulation, well testing and logging cost estimates, procedures and field execution. Prior to AltaRock Energy, Laura worked as a production engineer for several independent oil and gas companies, overseeing onshore Southern US assets.
Laura holds a BS in Petroleum Engineering from The University of Texas.

Rebecca O'Neil, PNNL. Ms. O'Neil is a program manager for Pacific Northwest National Laboratory, serving as the lab relationship manager for the US DOE EERE Wind and Water Technologies portfolio as well as lab initiatives related to regulatory development for energy storage. She joined PNNL in 2015 from the Oregon Department of Energy, where she spent five years representing the agency on water power development; administering the renewable portfolio standard and environmental commodities; emerging technology such as energy storage and regional integration issues; and managing a multi-million dollar portfolio of federal grants ranging from agricultural efficiency to wood stove replacement in air quality limited regions of the state. Before her state service, she managed the multifamily energy efficiency program for a contractor of Energy Trust of Oregon and represented a coalition of river conservation and recreation organizations in federal hydropower dam licensing. She serves on multiple organizational boards and advisory groups related to renewable energy.

Enhanced Geothermal Systems

The Energy Under Our Feet

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Geothermal Energy

The deeper you go the hotter it gets.

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Using the Earth's Heat

Conventional or Hydrothermal Energy

- Drill wells into fractured or porous rock
- Pump or self-flow water to surface
- Direct use of heat
  - Heating and cooling
  - Industrial processes – food drying, washing
  - Aquaculture
- Power Generation
  - Flashed Steam
  - Binary
  - Dry Steam

Combined heat and power at Chena Hot Springs, Alaska

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Where is it?

Geothermal Power Generation Worldwide

As of 2006, geothermal energy produces 9402.1 MWe from ~250 geothermal power plants in 22 countries.

Producing Country	*Megawatts*	*Producing Country*	*Megawatts*
United States	2900	Kenya	127
Philippines	1900	China	32
Italy	790	Turkey	21
Mexico	953	Russia	79
Indonesia	797	Portugal (Azores)	16
Japan	535	Guatemala	33
New Zealand	345	France (Guadeloupe)	15
Costa Rica	163	Taiwan	3
Iceland	322	Papua New Guinea	60
El Salvador	151	Germany	7
Nicaragua	**77**	**Total**	**9,402.1 MW**

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Where Do We Find It?

- Volcanic areas
- Thin crust
- Deep sedimentary basins
- Deep faulting

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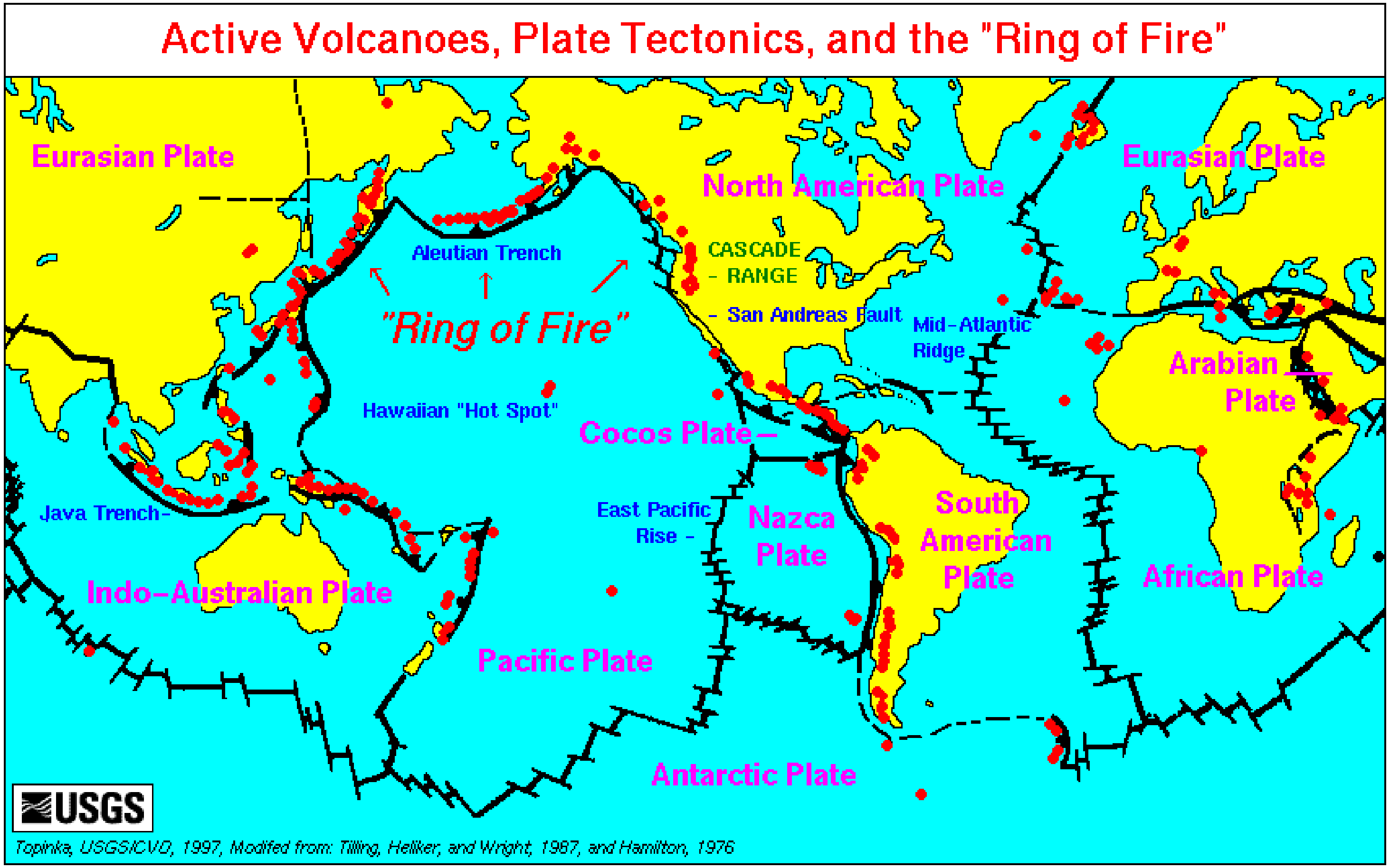
Volcanic Areas - Ring of Fire



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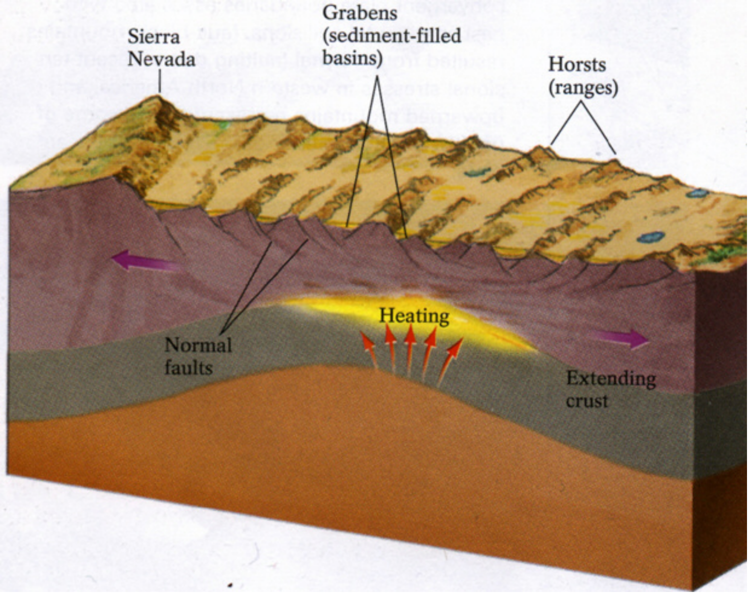
Thin Crust – Basin and Range

Crustal thinning brings heat close to the surface in the Basin and Range, the Rhinegraben in Europe and the East African Rift Valley as well as other places..



Geothermal well test in the Basin and Range of Nevada

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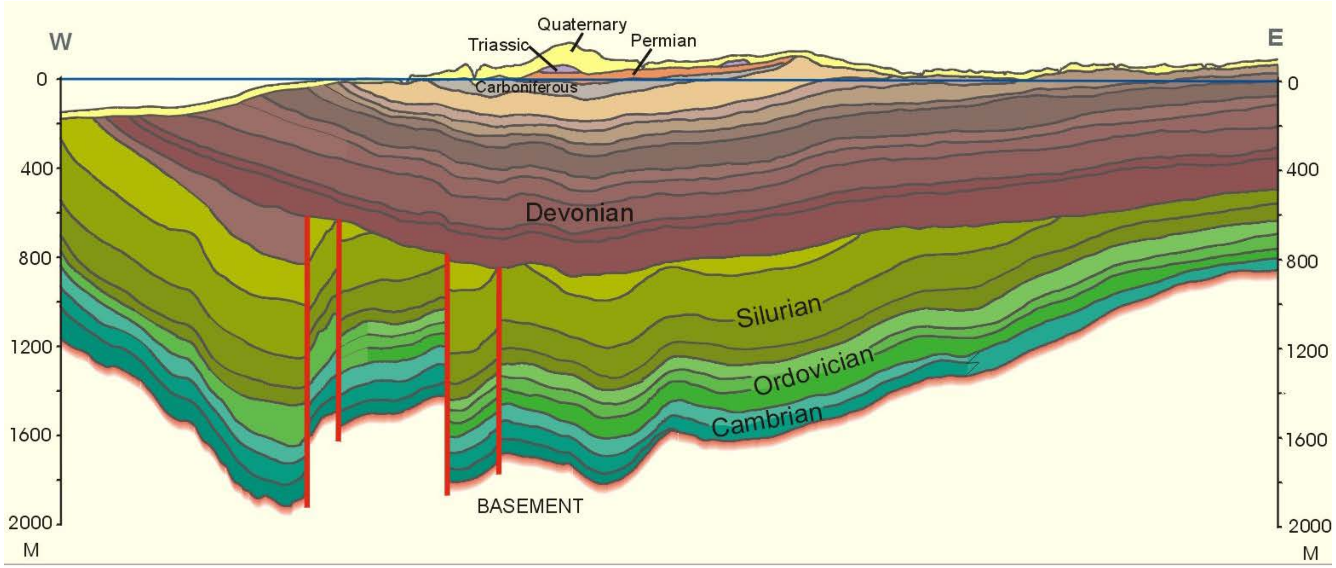
Deep Sedimentary Basins



Radioactive decay of isotopes in granitic basement rocks is trapped by insulating sediments.

Geopressured geothermal power plant test at Pleasant Bayou, LA

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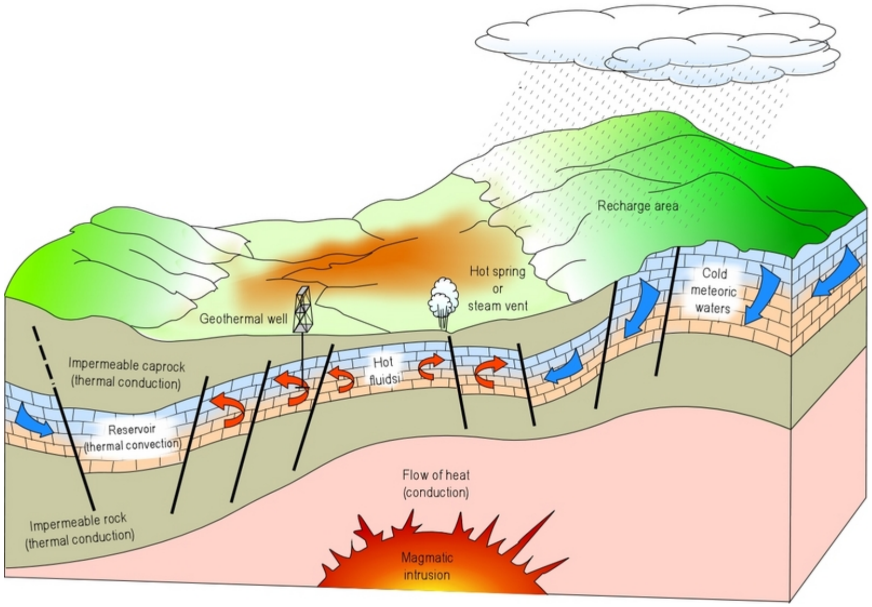
Deep Faulting



Faults extending deep in the earth bring high temperature fluids near the surface.

Test of new well for district heating system, Boise, Idaho. Deep faulting brings hot water to shallow depths in Boise, other areas of Idaho.

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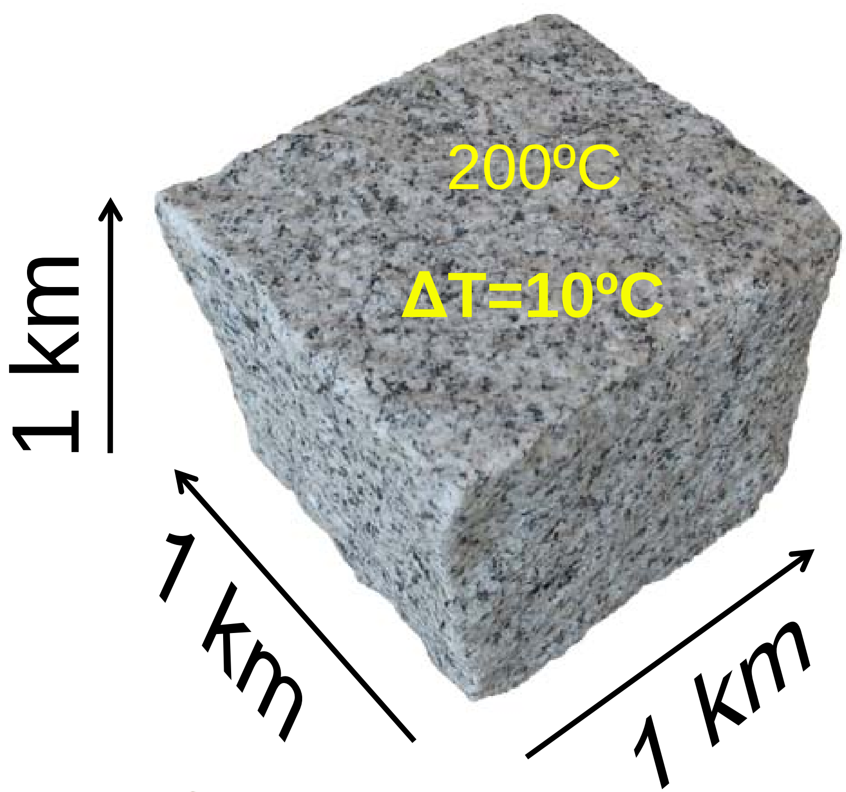
Heat Stored in Rock



1 km^3 Granite

29,300,000 BBL of Oil Equivalent

or

11,400,000 MWh

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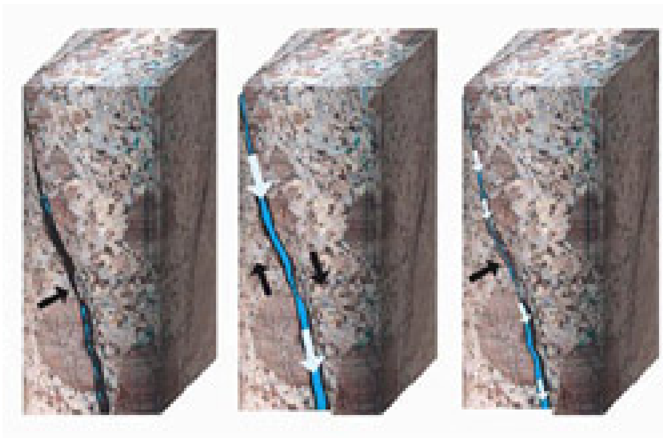
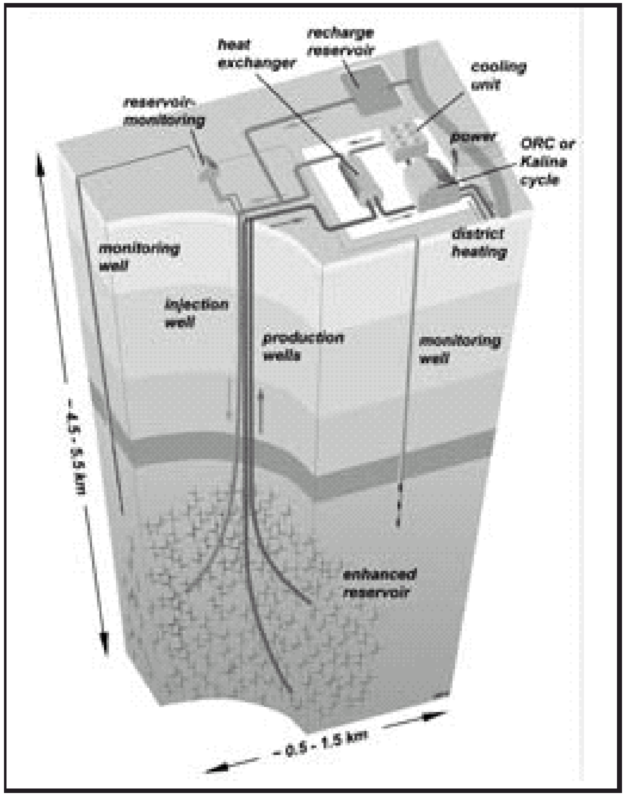
Enhanced Geothermal Systems



Enhancing the rock's permeability. The subsurface at Soultz-sous-Forêts consists of granite containing natural fractures. These fractures have been partially sealed over thousands of years (1). To be able to use these rocks as a heat exchanger, these fractures have to opened up again. This is achieved by injecting water at high pressure. The water expands the fractures, allowing the rocks to move slightly along the fracture planes (2). When the pressure is released, the fractures no longer fit together perfectly, and there is enough space to allow the circulation of water (3). (Courtesy of EEIG "Heat Mining", European Hot Dry Rock Project)



Cold water is circulated through created or enhanced fractures, heated by the rock and returned to the surface where it is used for heat or power.

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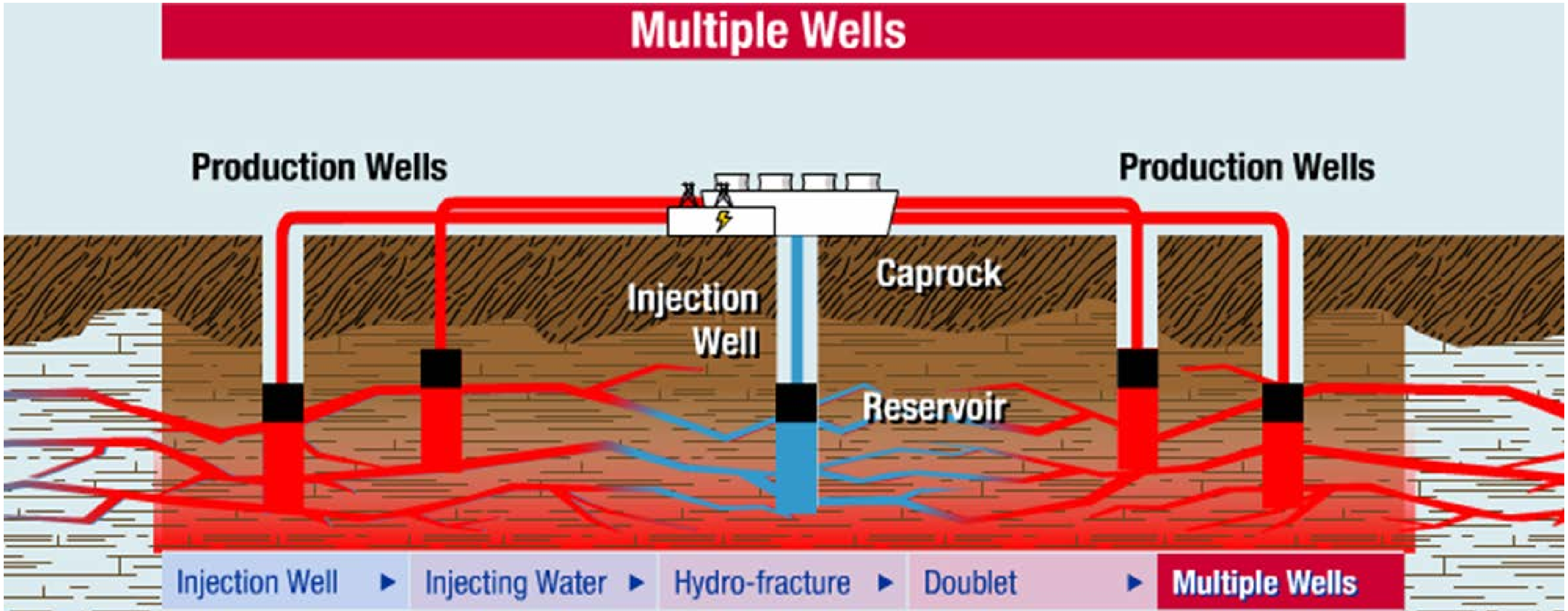
EGS Technology

How it works



Multiple Wells

Additional production wells are drilled to extract heat from large volumes of hot basement rock to meet power generation requirements. Now a previously unused but large energy source is available for clean, geothermal power generation.

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The Future of Geothermal Energy

- ***The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century***
  - http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf
  - 12 member panel lead by Dr. Jeff Tester through MIT

- **Conclusions:**
  - EGS power is technically feasible today
  - 50,000 MW of EGS power could be on line by 2050 with no federal investment
  - 100,000 MW by 2050 with federal investment of ~$350,000,000
  - Resource extends across US
  - Significant potential in areas with high temperature oil fields
  - Best resources economic today at high temperature, shallow sites
  - With incremental technology improvement, cost can be cut in half
  - With learning by doing and innovative technology improvement cost can be reduced for deep resources to ¼ cost with current technology

Enhanced Geothermal Systems

What is EGS and how does it 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
  - Dry hole rate remains 80%

-Economic even for low temperatures

->2800 MW on line

-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
  - Temperature only needed
  - Drill deeper to get greater temperature
- Large systems can be developed
- Uses proven state of the art drilling technology
- Fracturing technology developing
- Potential for CO2 sequestration

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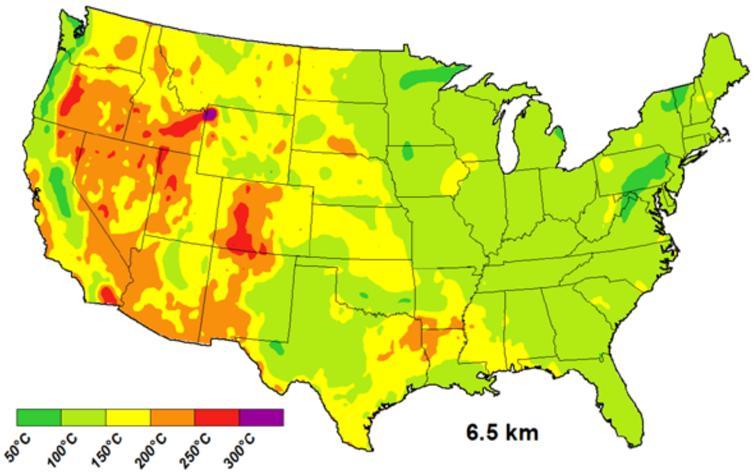
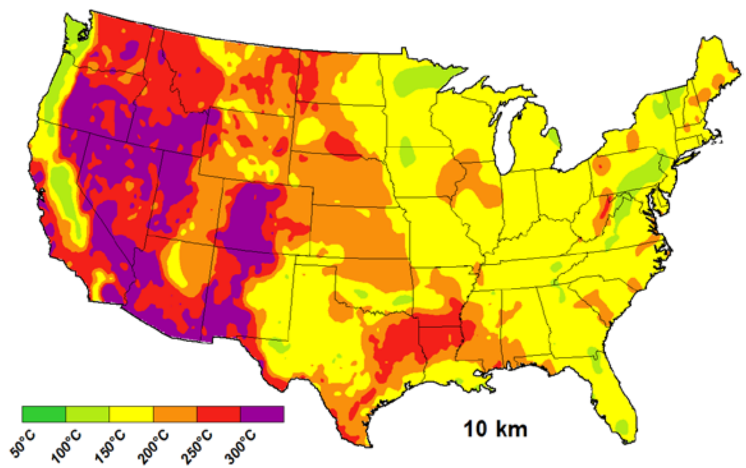
EGS Technology

How it works

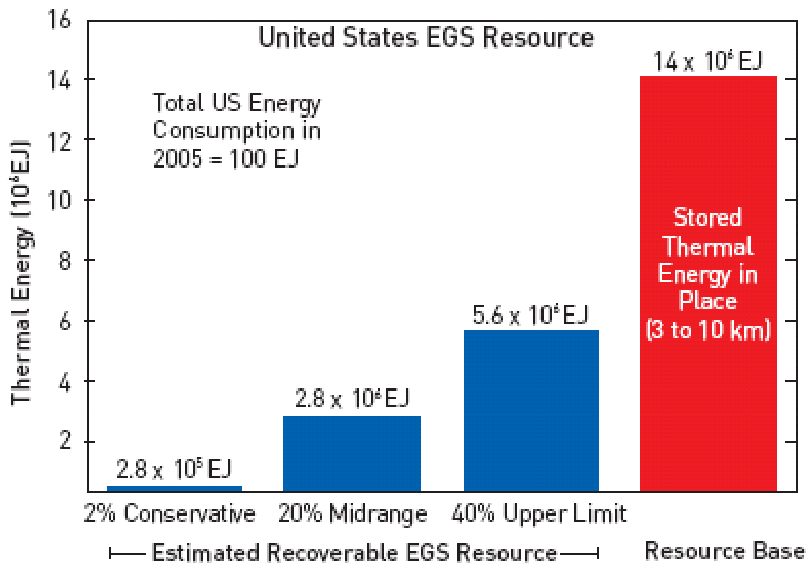
- Exploration
  - Existing data – water or oil wells, mining holes
  - Temperature gradient holes
  - Determine target depth based on economics
- Drill injector
- Create reservoir by stimulation
  - Evaluate borehole to identify natural fractures, stress field
  - Injection from surface
  - Stimulate natural fractures and map
- Drill producers into fractured volume
  - Restimulate if needed to improve connection
  - As many as 4 producers per injector





EGS Advantages

- Enormous un-tapped energy resource for baseload power generation
- Only known source of renewable energy with a capacity to carry large base loads.
- Significant U.S. reserves located in areas of power demand
- Zero emissions
- Low cost, renewable electricity
- Small plant footprint
- Widely distributed
- Much greater availability than wind and solar >95%
- Long project lifespan up to 30 or more years
- CO_2 sequestration
- Reduce cost and improve performance using CO_2 in the reservoir
- 1 km³ of rock cooled 20° C = 29,300,000 BBLs oil equivalent



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Cost Centers and Technology Improvement

- Exploration/Information gathering-Cost of Risk Reduction
  - 50% reduction in cost of risk
  - Better information – HT borehole televiewer, HT 3 component seismometer
  - Reduces drilling risk and resource risk as well as cost risk on depth to resource
- Cost of drilling
  - 20% reduction in cost of drilling
  - Eliminate one casing string – available from oil and gas technology
  - Improved rate of penetration through better bits – developed by Sandia – can be licensed
- Reservoir Stimulation
  - Double the flow per well from 40 l/s to 80 l/s without thermal breakthrough
  - Reduce the stimulation cost by better stimulation design (do it once, do it right)
  - Chemical stimulation methods
  - Improved instrumentation HT borehole televiewer, HT 3-component seismometer
  - Fracture design code
- Power Plant
  - 20% improvement in conversion efficiency
  - Improved turbine design
  - Best available binary technology
- Reservoir Management
  - Modeling software
  - Prevent or correct thermal breakthrough-chemical stimulation/ diversion
  - Reduce risk of scale or short circuit through rock/water, rock/CO2 interaction

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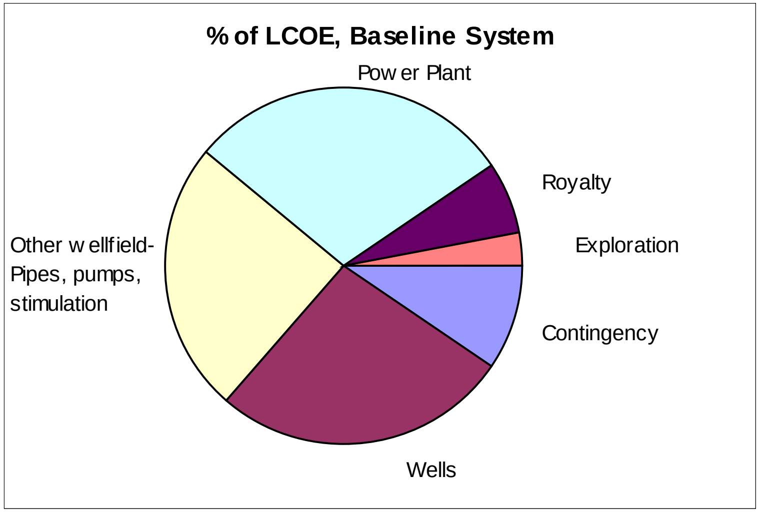
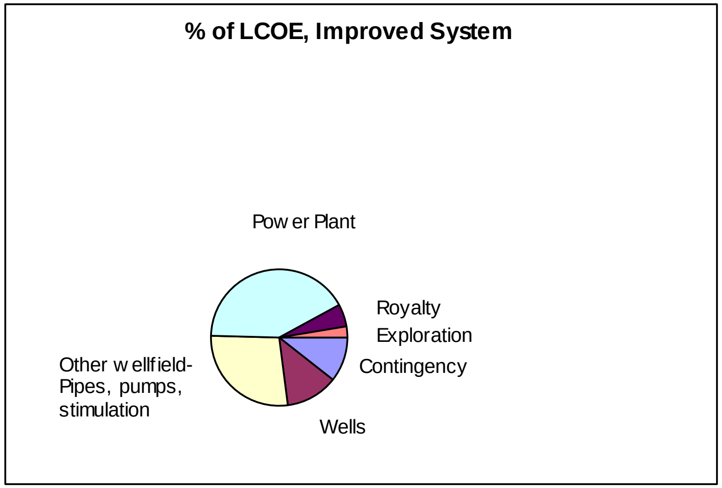
Economics

High Temperature System

300°C at 4 km

- With current technology ~7.8¢/kWh
- With improved technology 5.4¢/kWh
- Areas for technology improvement
  - Conversion cycle efficiency
  - Drilling cost reduction/risk reduction
    - Fewer casing strings
    - Higher hard rock ROP
    - Better measurement while drilling for HT (risk↓)
  - Improved stimulation technology
    - Better zone isolation
    - Better reservoir understanding
      - Stress measurement
      - Fracture ID
      - Higher flow per producer
      - Single well test methods





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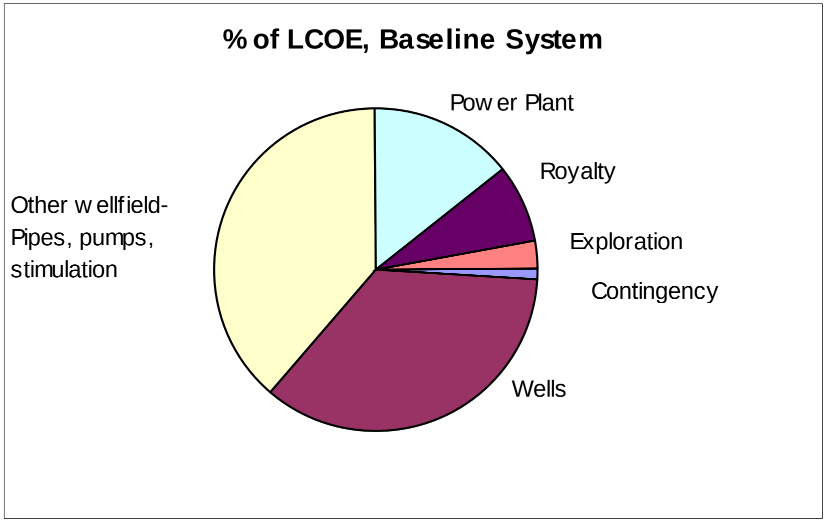
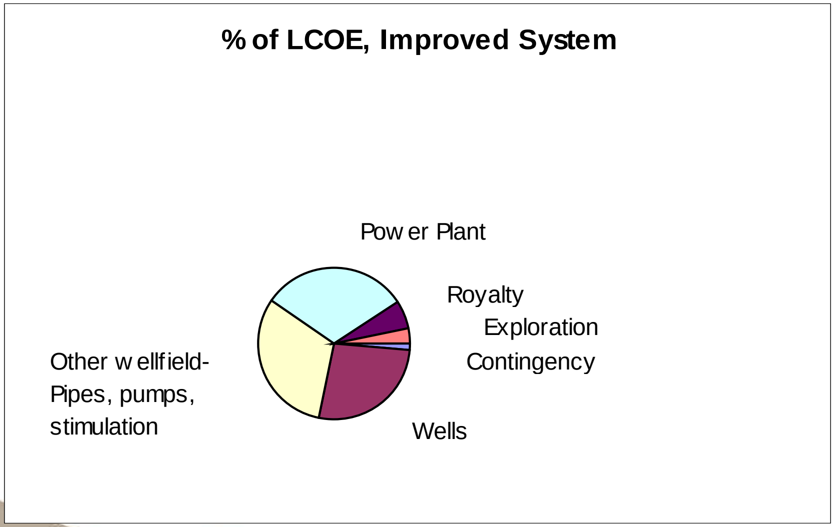
Economics

Low Temperature System

150°C at 5 km

- With current technology ~19.2¢/kWh
- With improved technology 7.4¢/kWh
- Areas for technology improvement
  - Conversion cycle efficiency
    - Improved HT pumping
    - More efficiency binary cycle
  - Drilling reduction/risk reduction
    - Fewer casing strings
    - Higher hard rock ROP
    - Better measurement while drilling for HT (risk↓)
  - Improved stimulation technology
    - Higher flow per producer!
    - Better zone isolation
    - Better reservoir understanding
      - Stress measurement
      - Fracture ID
      - Single well test methods





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Transmission Access

- *Projects can be located near transmission lines*
- *Projects can be located away from scenic areas*

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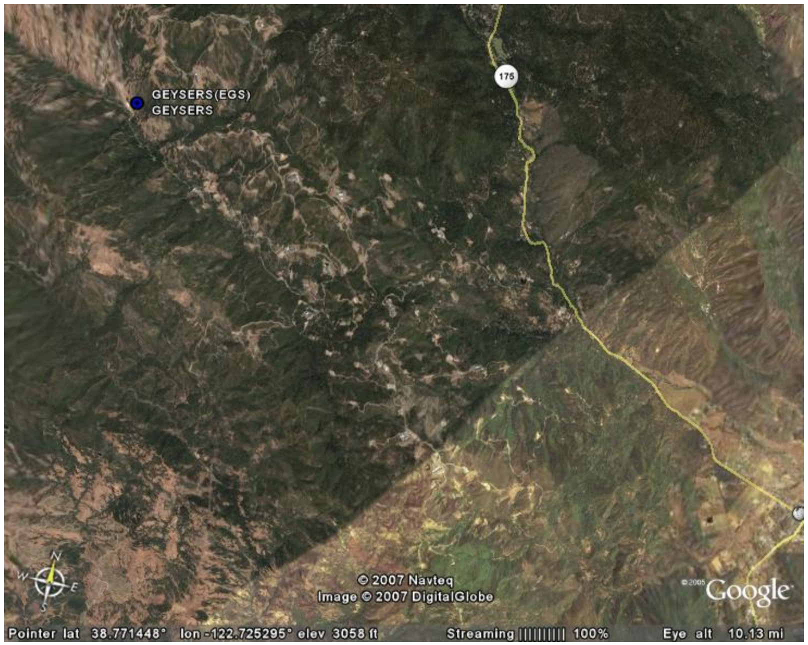
Environmental Impact of EGS

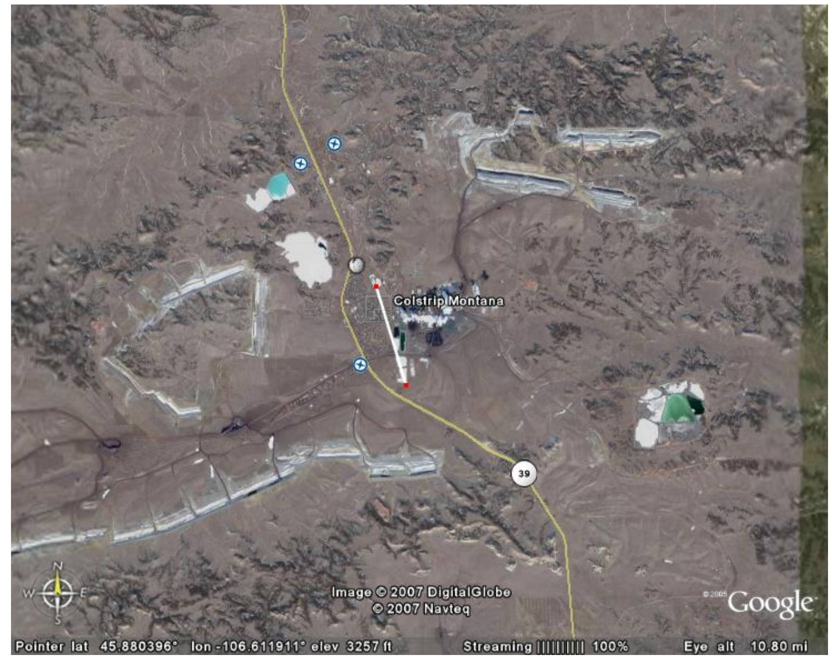
- Plant emissions
  - No plant emissions with binary plants
  - With flash plants, plant emissions extremely low, can be mitigated
- Drilling and site preparation
  - Relatively small land disturbance
  - Several wells drilled from one 100 ft x 300 ft pad
  - Plant is small, one story high
  - Rock cuttings and reservoir fluids benign with EGS resources

Scalable to big projects –
But with a small footprint

- 1000 MW Geothermal facility from 10 miles up



- 1000 MW Mine mouth coal project from 10 miles up



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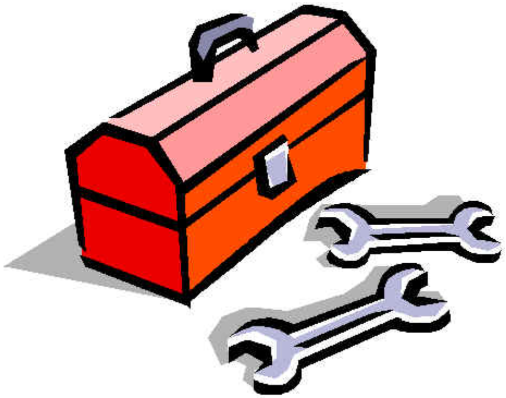
Toolbox



Challenges

1. More power per producer
2. Big heat exchange areas
3. Stop/prevent short circuits
4. Stop/prevent or reverse reservoir plugging or too much dissolution
5. C02 EGS – Use CO2 as the working fluid in the EGS reservoir
6. Capital intensive – buying your fuel source upfront!

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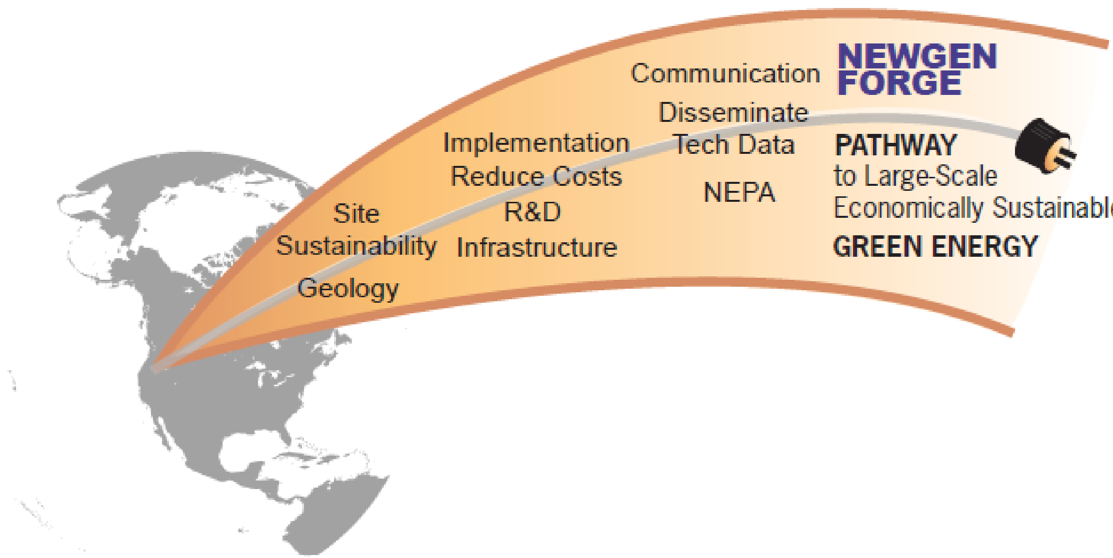
FORGE and NEWGEN FORGE Site



Presenter	Alain Bonneville
Affiliation	Pacific Northwest National Laboratory
Newberry Role/Title	Executive Director

GOAL

Support DOE to demonstrate transformational science and technology in EGS through research at a world-class field laboratory.

FORGE Objectives

August 5, 2014 presentation by DOE (paraphrased)

- *To design and test a rigorous & reproducible approach for developing large-scale, economically sustainable heat exchange systems that will reduce industry development risk & enable development of 100+ GWe of EGS power.*
- Dedicated site where scientific and engineering community develop, test and improve new technologies and techniques in an ideal EGS environment.
- Gain a fundamental understanding of the key mechanisms controlling EGS success
- Comprehensive instrumentation and data collection to capture high-fidelity picture of EGS creation and evolution processes
- Integrated comparison of technologies and tools in a controlled and well-characterized environment
- Rapid dissemination of technical data to the research community, developers, and other interested parties.

FORGE Requirements

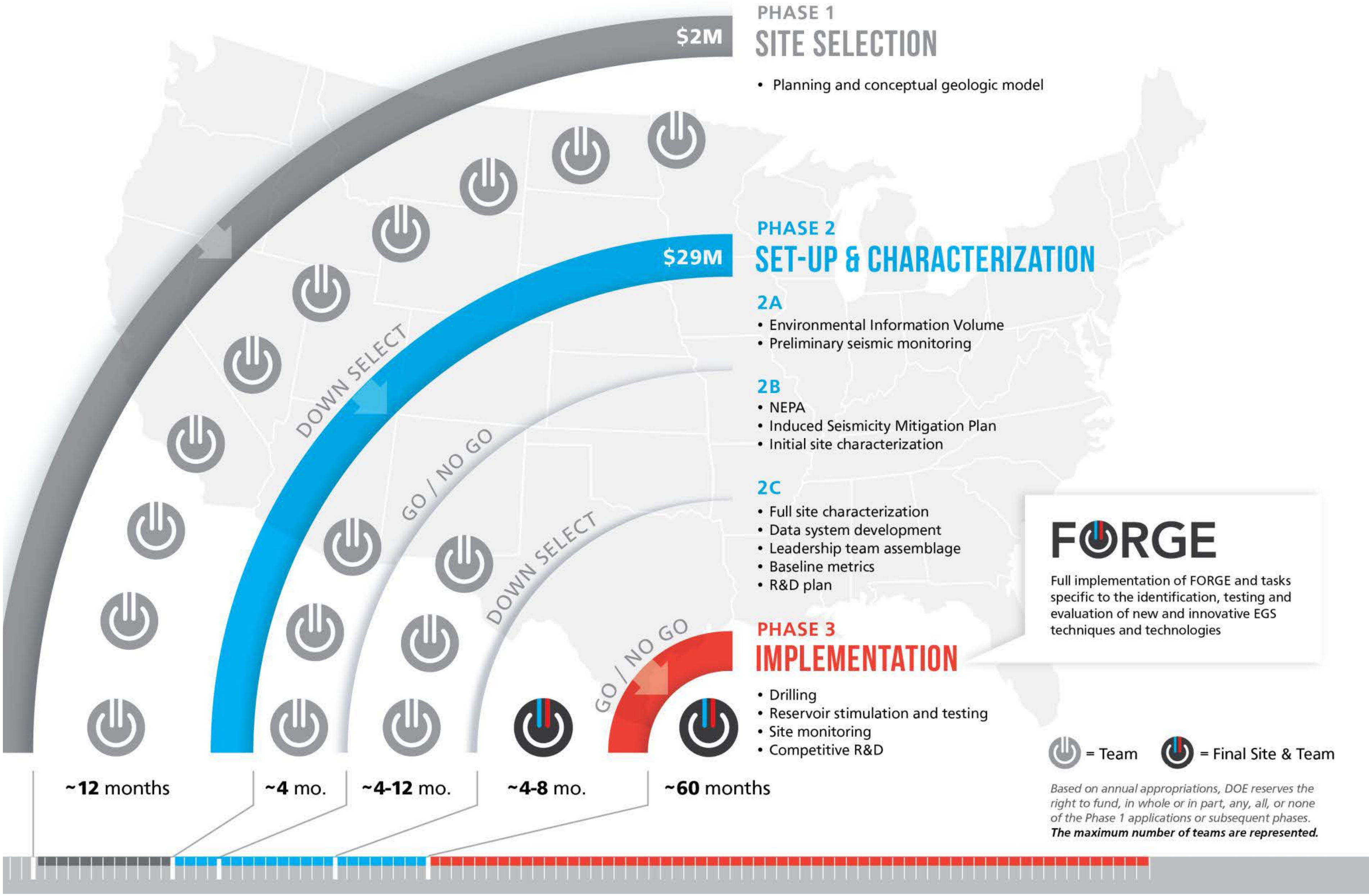
August 5, 2014 presentation by DOE

The ideal FORGE site is:

- Well characterized, with high temperatures in the target formation in the range of **175-225 °C**
- Moderate permeability of order **10^{-16} m^2**, below the limit that typically supports natural hydrothermal systems
- Target formation between **1.5-4 km depth**, to avoid excessive costs associated with the drilling of new wells
- Must **not be within an operational hydrothermal field**
- Does **not stimulate** or **circulate fluids through overlying sedimentary units**, if applicable.

Other site selection considerations include:

- **Owner/lease holder commitment** to the project
- **Environmental review** and **regulatory permitting**
- Existing **nearby infrastructure** necessary for carrying out the operation of FORGE


PHASE 1
SITE SELECTION
$2M
• Planning and conceptual geologic model
PHASE 2
SET-UP & CHARACTERIZATION
$29M
2A
• Environmental Information Volume
• Preliminary seismic monitoring
2B
• NEPA
• Induced Seismicity Mitigation Plan
• Initial site characterization
2C
• Full site characterization
• Data system development
• Leadership team assemblage
• Baseline metrics
• R&D plan
PHASE 3
IMPLEMENTATION
• Drilling
• Reservoir stimulation and testing
• Site monitoring
• Competitive R&D
DOWN SELECT
GO / NO GO
DOWN SELECT
GO / NO GO
FORGE
Full implementation of FORGE and tasks specific to the identification, testing and evaluation of new and innovative EGS techniques and technologies
= Team
= Final Site & Team
~12 months
~4 mo.
~4-12 mo.
~4-8 mo.
~60 months
Based on annual appropriations, DOE reserves the right to fund, in whole or in part, any, all, or none of the Phase 1 applications or subsequent phases.
The maximum number of teams are represented.

Phase 1 FORGE Teams

IDAHO NATIONAL LABORATORY
Location: Snake River Plain, Idaho
Key Partners: Snake River Geothermal Consortium, which includes the 2 National Labs, 6 universities, 2 consultants, 3 government agencies, US Geothermal and Baker-Hughes.

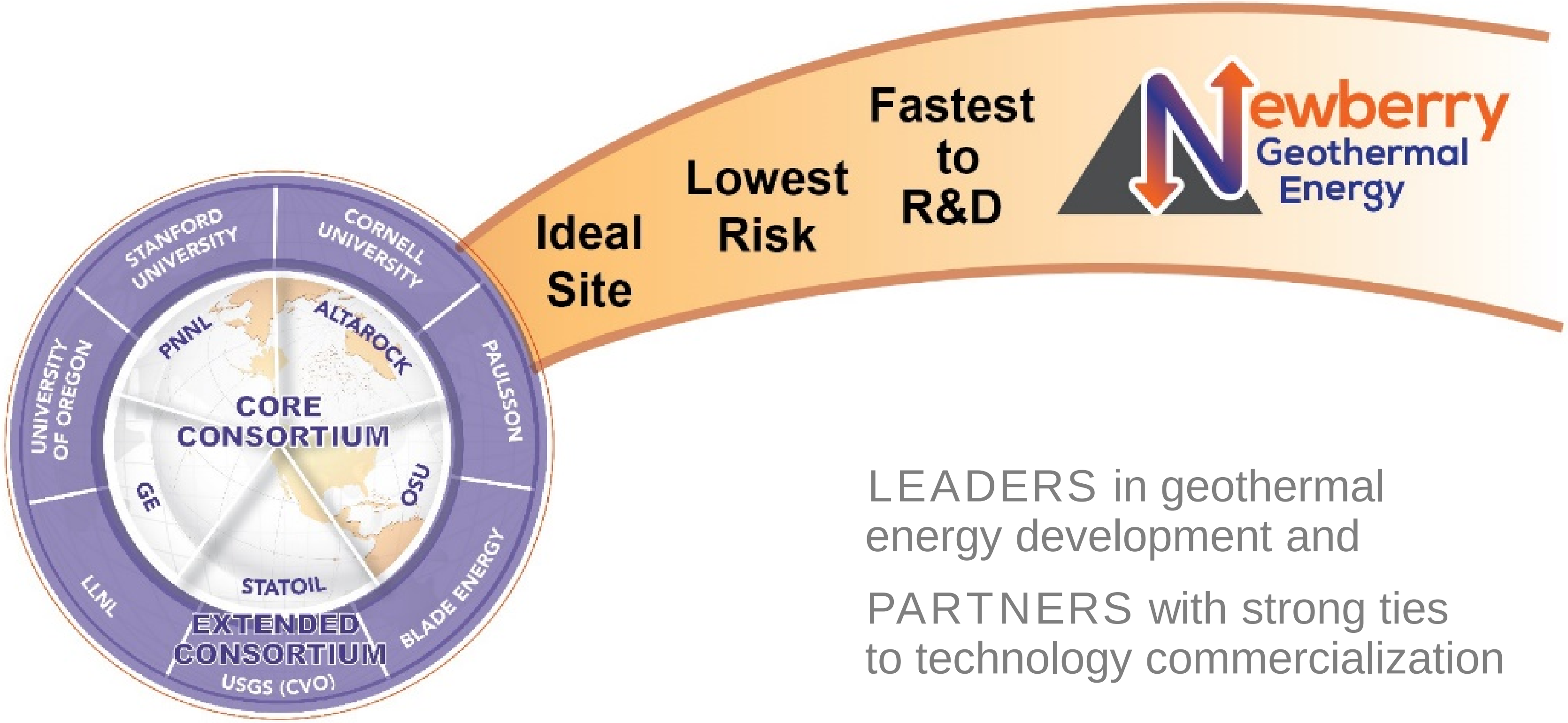
PACIFIC NORTHWEST NATIONAL LABORATORY
Location: Newberry Volcano, Oregon
Key Partners: Oregon State University and AltaRock Energy, Inc.,
GE Global Research, StatOil, others?

SANDIA NATIONAL LABORATORIES
Location: Coso, California
Key Partners: Lawrence Berkeley National Laboratory, U.S. Geological Survey, University of Nevada-Reno, GeothermEx/Schlumberger, U.S. Navy, Coso Operating Company LLC, and Itasca Consulting Group

SANDIA NATIONAL LABORATORIES
Location: Fallon, Nevada
Key Partners: Lawrence Berkeley National Laboratory, U.S. Geological Survey, University of Nevada-Reno, GeothermEx/Schlumberger, U.S. Navy, Ormat Technologies Inc., and Itasca Consulting Group

UNIVERSITY OF UTAH
Location: Milford City, Utah
Key Partners: Utah Geological Survey, Murphy-Brown LLC, Idaho National Laboratory, Temple University, Geothermal Resources Group Inc., and U.S. Geological Survey

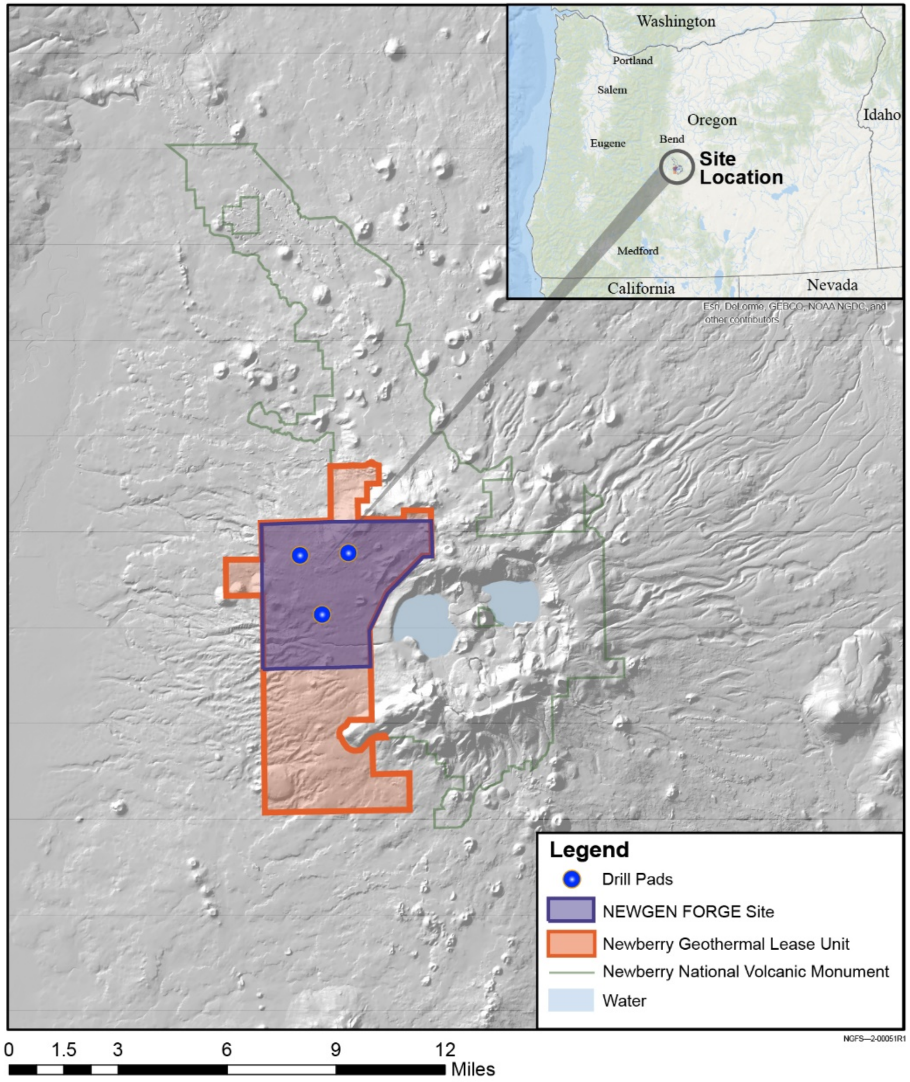
The NEWGEN Consortium Will Deliver a World-Class Field Laboratory



LEADERS in geothermal energy development and

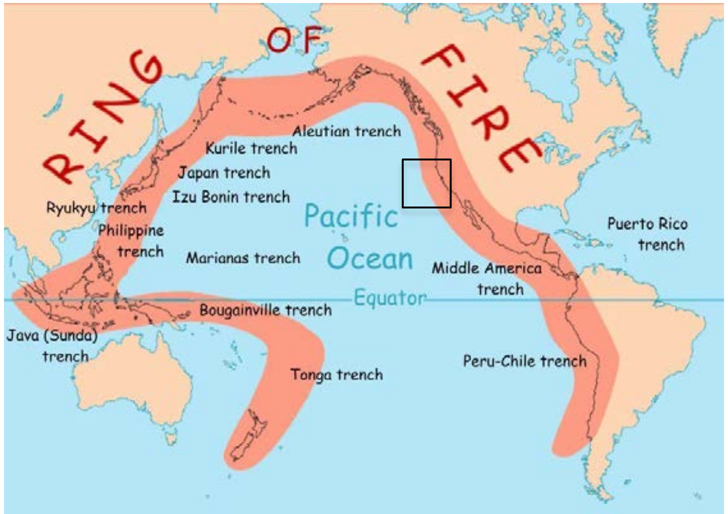
PARTNERS with strong ties to technology commercialization

Newberry Volcano, Oregon



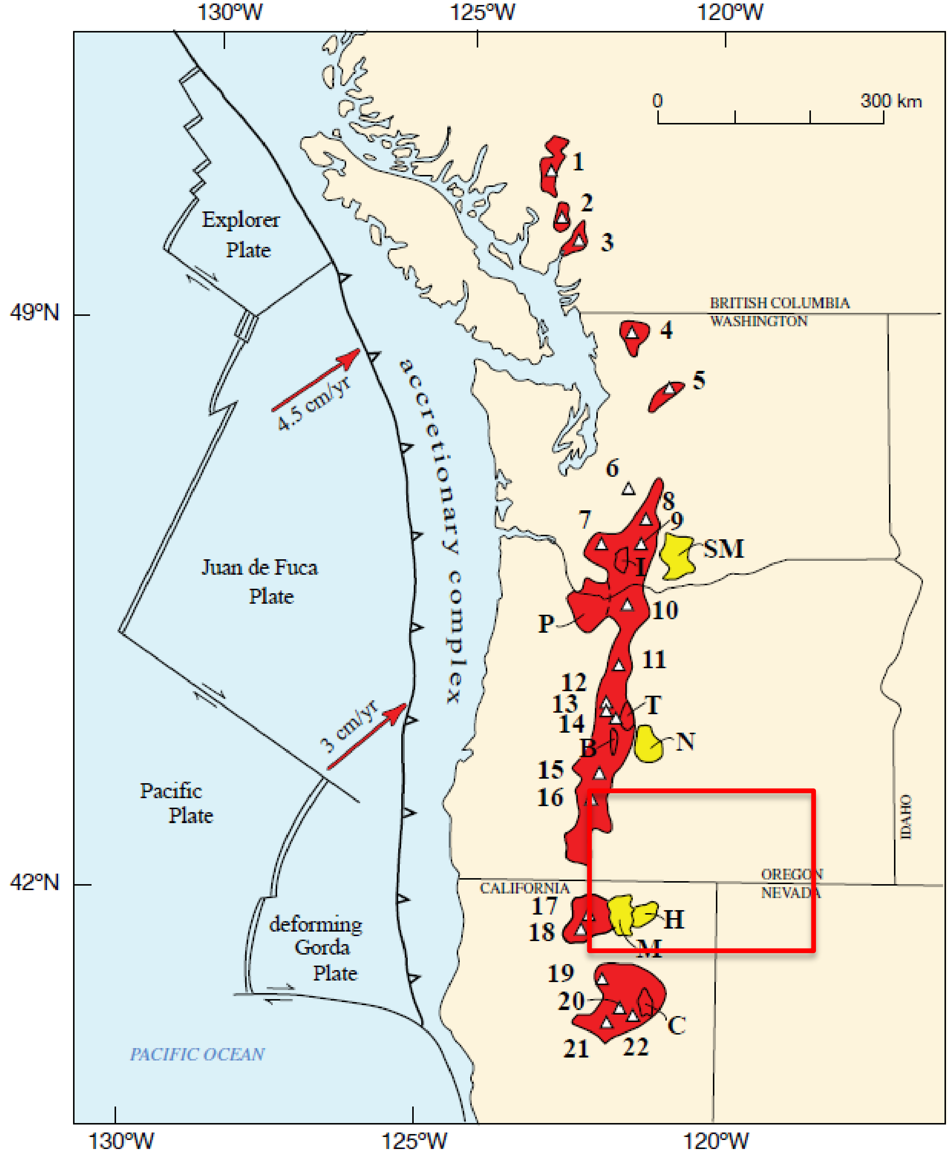
- The NEWGEN site is perfectly suited for FORGE, validated in the field, and is a low risk site based on existing permits, extensive physical and scientific infrastructure.
- The NEWGEN approach combines unique infrastructure with experienced administration of competitive, collaborative field research.

Ring of Fire / Quaternary Cascades Arc / Newberry



Newberry Volcano

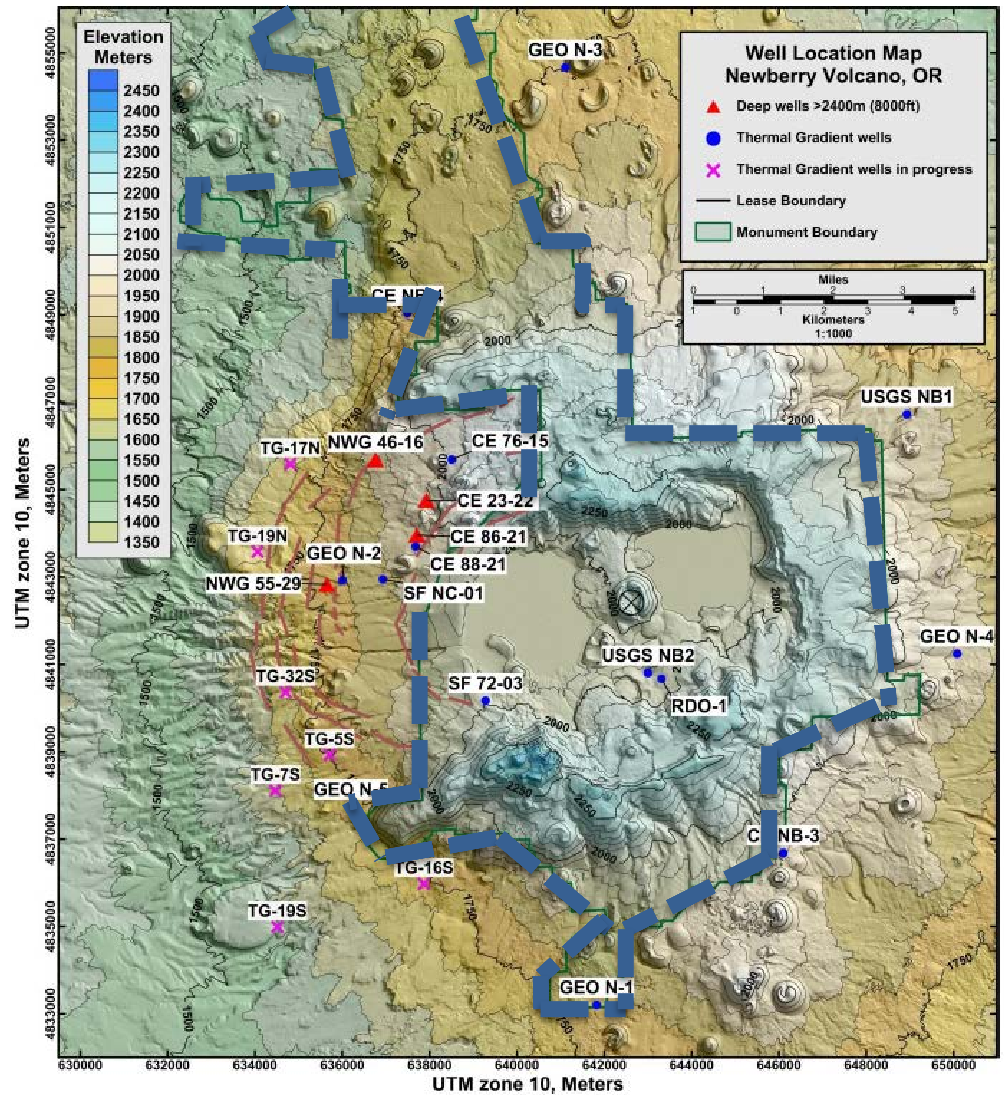
- ❑ Major rear-arc complex
- ❑ Adjacent to Cascades
- ❑ Mafic shield-form edifice
- ❑ In the transition to B&R
- ❑ >450 vents
- ❑ Largest volcano in Cascades!



USGS PP 1744, W. Hildreth, 2007

Previous Exploration and Research History

- ❑ 1970's Santa Fe, Phillips Petroleum
- ❑ 1980's USGS, Universities, National Laboratories *(1988 JGR special issue)*
- ❑ Monument designation 1990
- ❑ CalEnergy 1992-1999
- ❑ Davenport Newberry 2006-2008
  - ✓ Geophysical Surveys
  - ✓ Two deep wells drilled
- ❑ Seismic monitoring by the Cascade Volcano Observatory since 2011
- ❑ Dept. of Energy 2009-2015
  - ✓ Davenport Innovative Exploration Project
  - ✓ Newberry EGS demonstration
  - ✓ OSU/NETL 4D EGS mapping
- ❑ Ongoing structural, geochemical, geophysical work by researchers at OSU, UO, DOGAMI, SMU, etc.



Frone, PHD Thesis, SMU, 2015

NEWGEN meets FORGE temperature requirements at shallow depths

Newberry Geothermal Energy

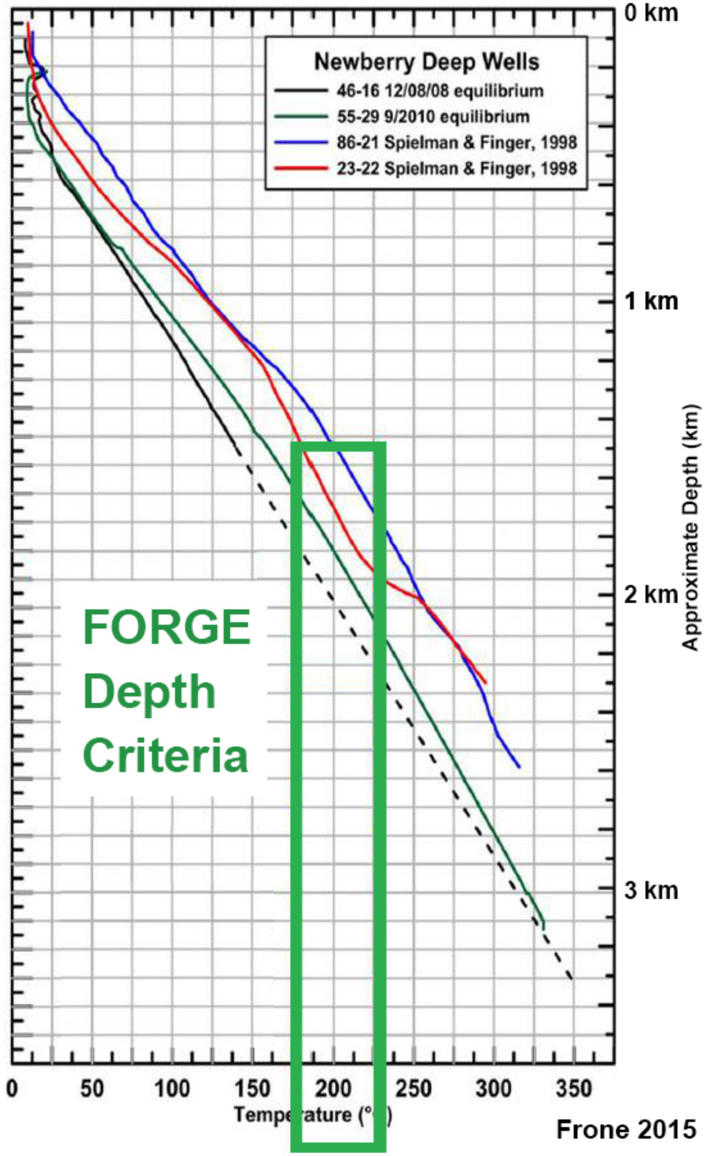
Requirement: 175°C–225°C at 1.5–4 km

Evidence: Deep wells confirm temperature range between ~1.6 and 2.2 km

Linear temperature gradients indicate conductive heat flow

Thermal conductivity of 1.5–2.2 W/(m.K)

Impact: Significant cost savings related to drilling and site infrastructure

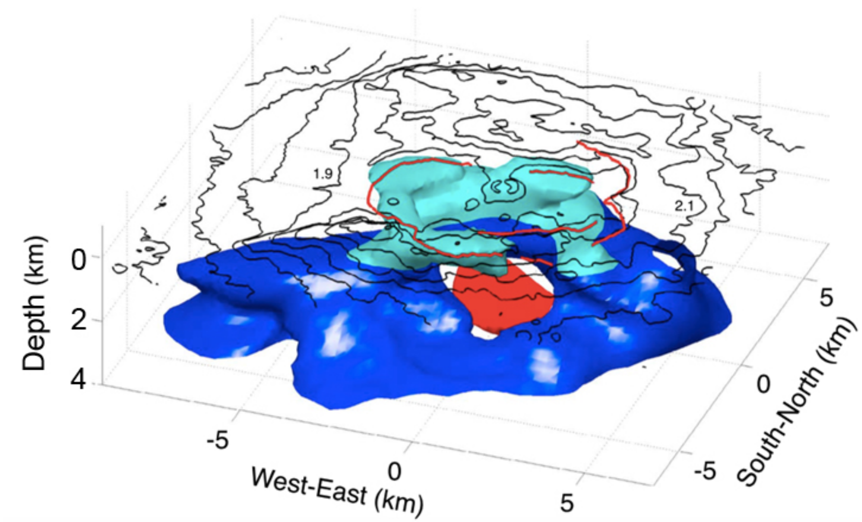


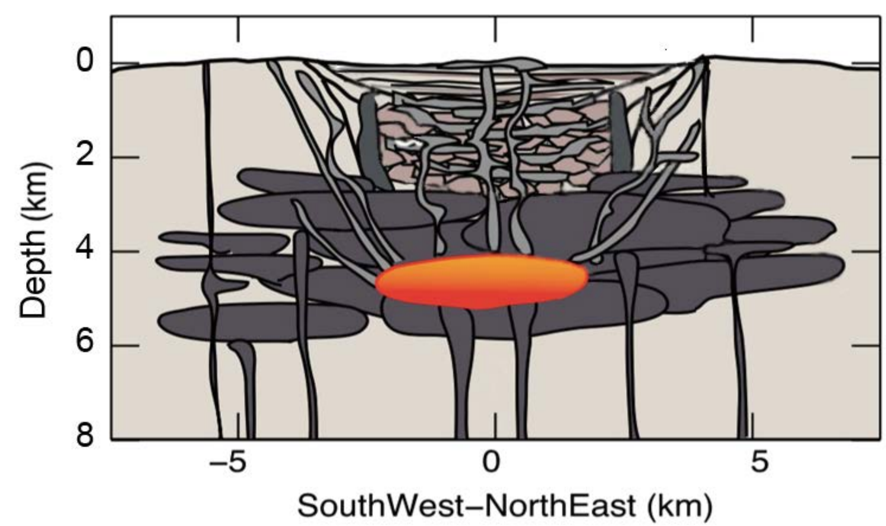
Newberry provides an ideal heat source at shallow depth

Requirement: Well characterized heat flow

Evidence: Seismic surveys showing tomographic fast/slow anomalies and recent volcanism supports heat source

Impact: Site has well-imaged heat source supplementing regional heat source, self-consistent with thermal models





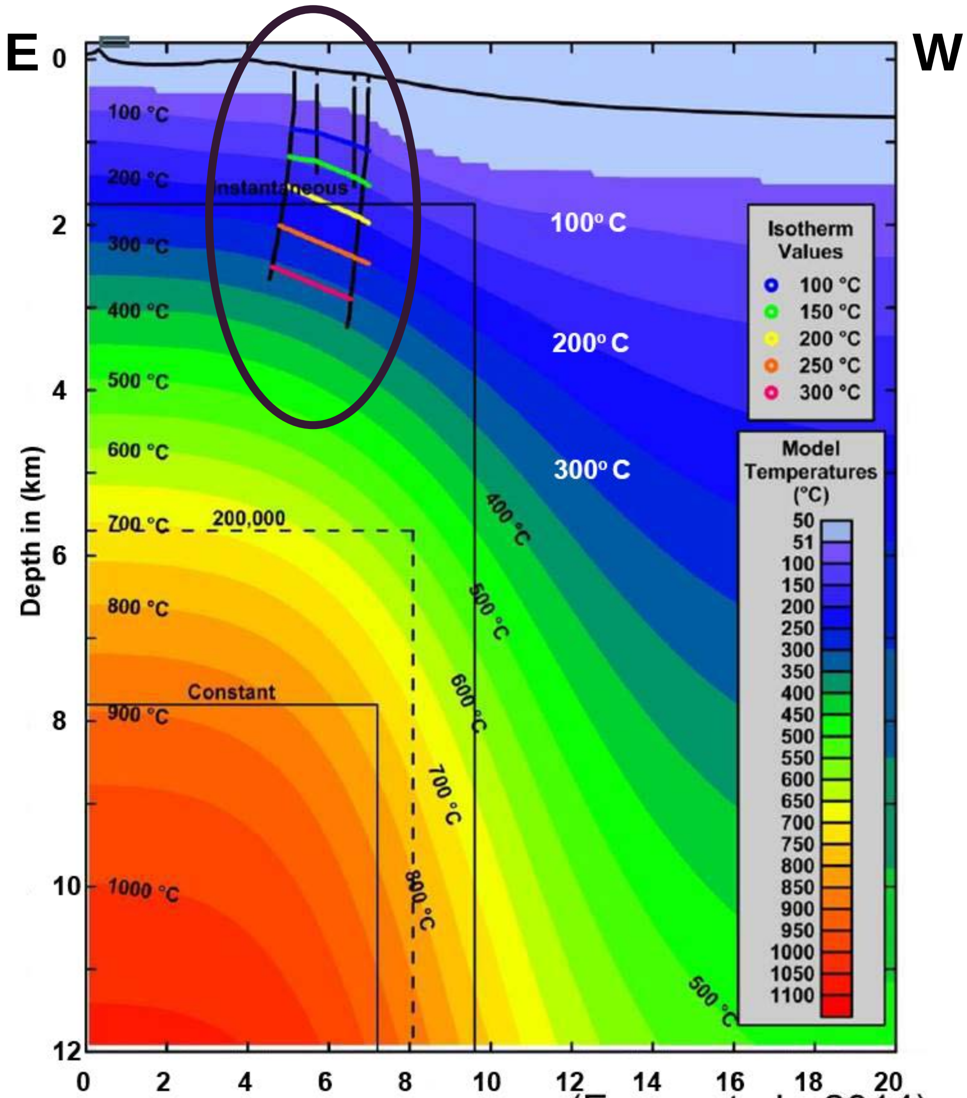
Multiple lines of evidence confirm NEWGEN target reservoir is a broad, shallow conductive heat flow anomaly

Newberry Geothermal Energy

Requirements: Well characterized thermal gradients and conductive heat flow regime

Evidence: The available temperature data on the west flank of the volcano can be explained by silicic sill intrusions recurring at a 200,000 year rate over the 500,000 year lifetime of the volcano. (Frone et al. 2014)

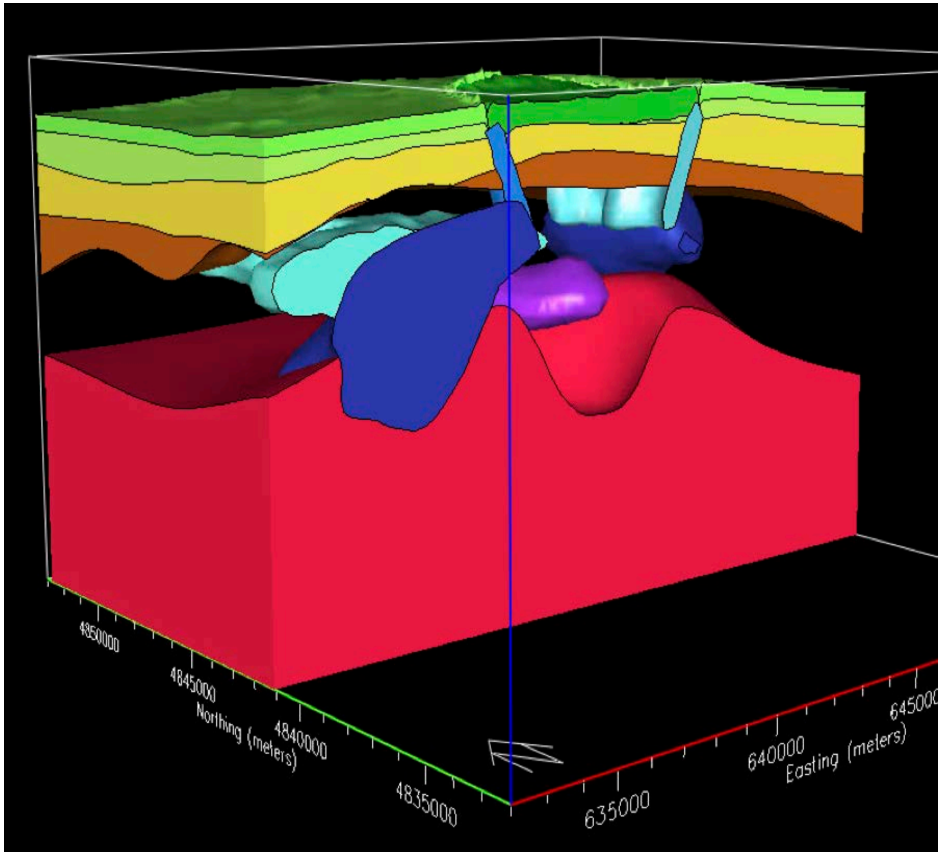
Impact: Enormous reservoir of heat with >2.4 GW potential



(Frone et al., 2014)

Conceptual Geologic Model confirms suitability of the site

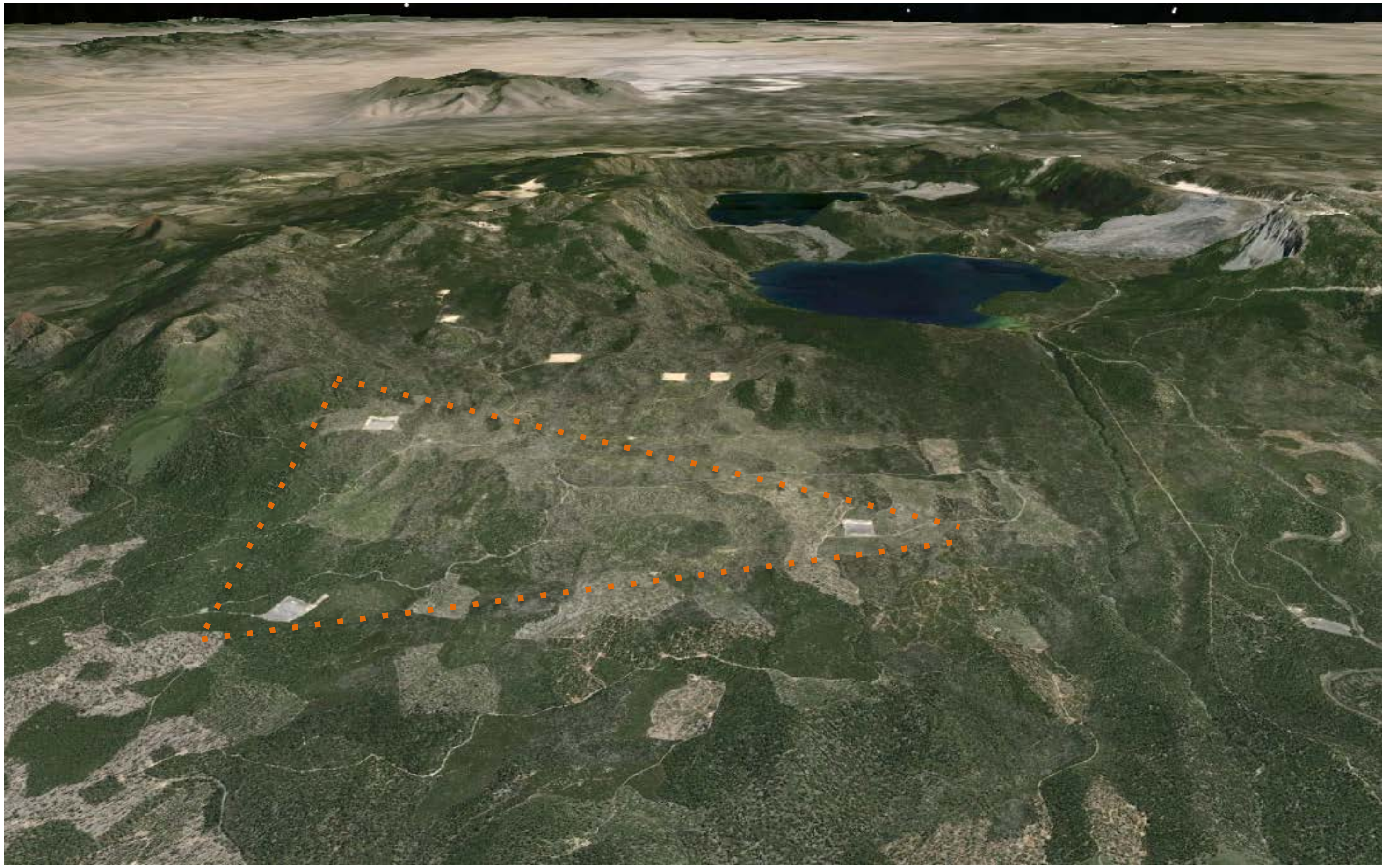
- **Ideal temperature** profiles validated by measurements in multiple deep wells
- **Low permeability** and absence of hydrothermal activity
- **Enormous reservoir** of heat with 2.4 GW potential
- Builds on **40+ years** of intensive characterization of Newberry Volcano
- **Reduced uncertainties** based on existing wells and a known seismic response to injection based on more than 4 years of microseismicity data



Integrated Model

Conductive heat flow regime

Low permeability in Newberry FORGE area; conductive rather than advective heat flow regime



View from west to east of FORGE site

The west flank of the volcano (FORGE site) is separated from hydrothermal activity within caldera by an impermeable barrier zone; characterization work to-date finds an absence of hydrothermal activity in the FORGE site area

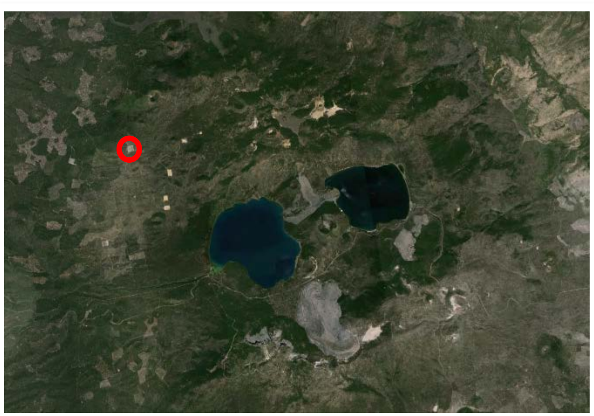
Results from 2014 EGS stimulation at 55-29 consistent with low permeability in surrounding formations at reservoir depths of 2-3 km

Newberry Geothermal Energy

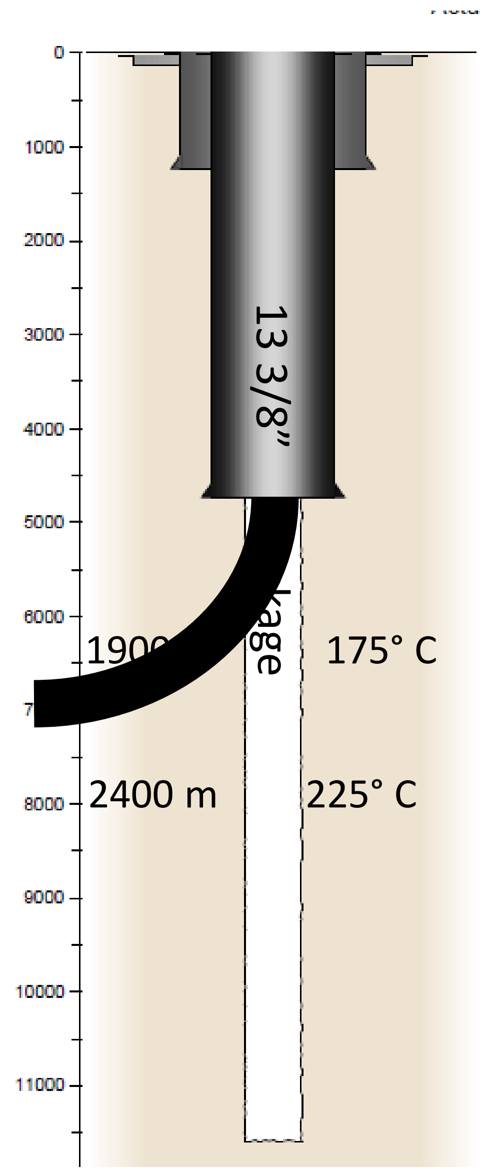
Potential FORGE Site 1: Pad 17

- Elevation 5540 ft, 8 miles from HWY
- 5 acre pad and large sump
- 225m deep, cased well
  - Currently used for borehole seismometer
  - Designed for 1000 m TCH

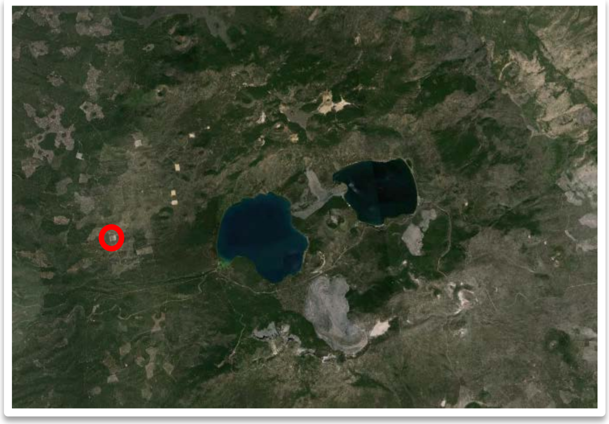
Potential FORGE Site 2: 46-16

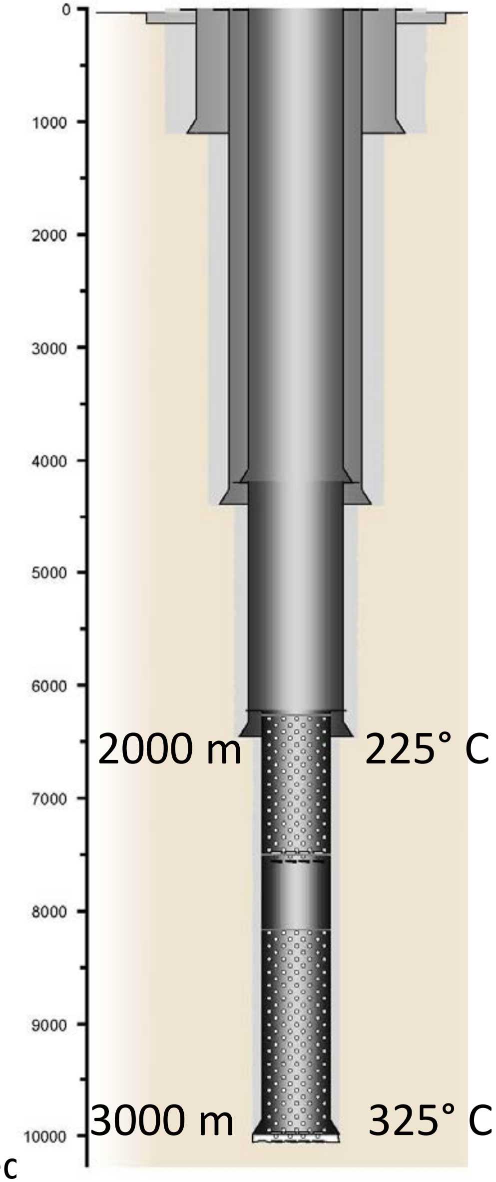


- Sump and Water well
- Deep geothermal well with 13 3/8” casing
- FORGE Sidetrack target?



Potential FORGE Site 3: 55-29





- Deep geothermal well
- Water well
- Site of 5 year EGS Demonstration
- EGS fracture network created in 2014
- Production well planned and permittec
- 55-29 available now!

Newberry Geothermal Energy

To conclude...

- AN IDEAL SITE
- TRACK RECORD
- STRONG TEAM
- ROBUSTNESS
- FLEXIBILITY
- START-UP ON DAY 1

- **The NEWGEN Consortium will deliver a site ideal for EGS R&D to achieve DOE GTO goals and Objectives.**
- Phase 1 lessons learned increase confidence in Geologic Model, strengthen team, expand options, and lead to earlier R&D start
- Deep expertise of leadership team ensures strong technical and management oversight
- Robust plan to engage research community in development of FORGE R&D strategy
- NEWGEN offers multiple options to test EGS technologies in parallel
- NEWGEN will be ready to start operation on Day 1 of Phase 3

Newberry Geothermal Energy