Enhanced Geothermal Systems - DOE Field Demonstration Projects, R&D Innovations, and Roadmapping Efforts

APEC WORKSHOP ON GEOTHERMAL ENERGY DEVELOPMENT

June 26, 2013

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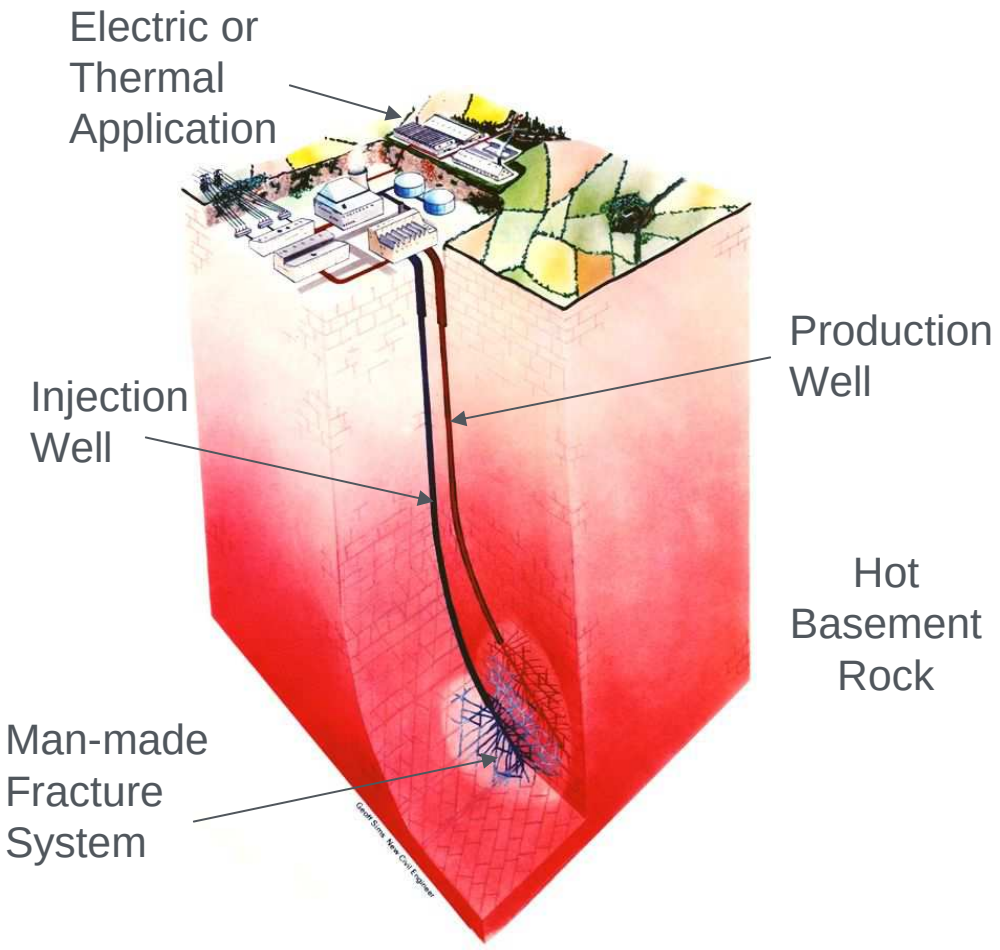
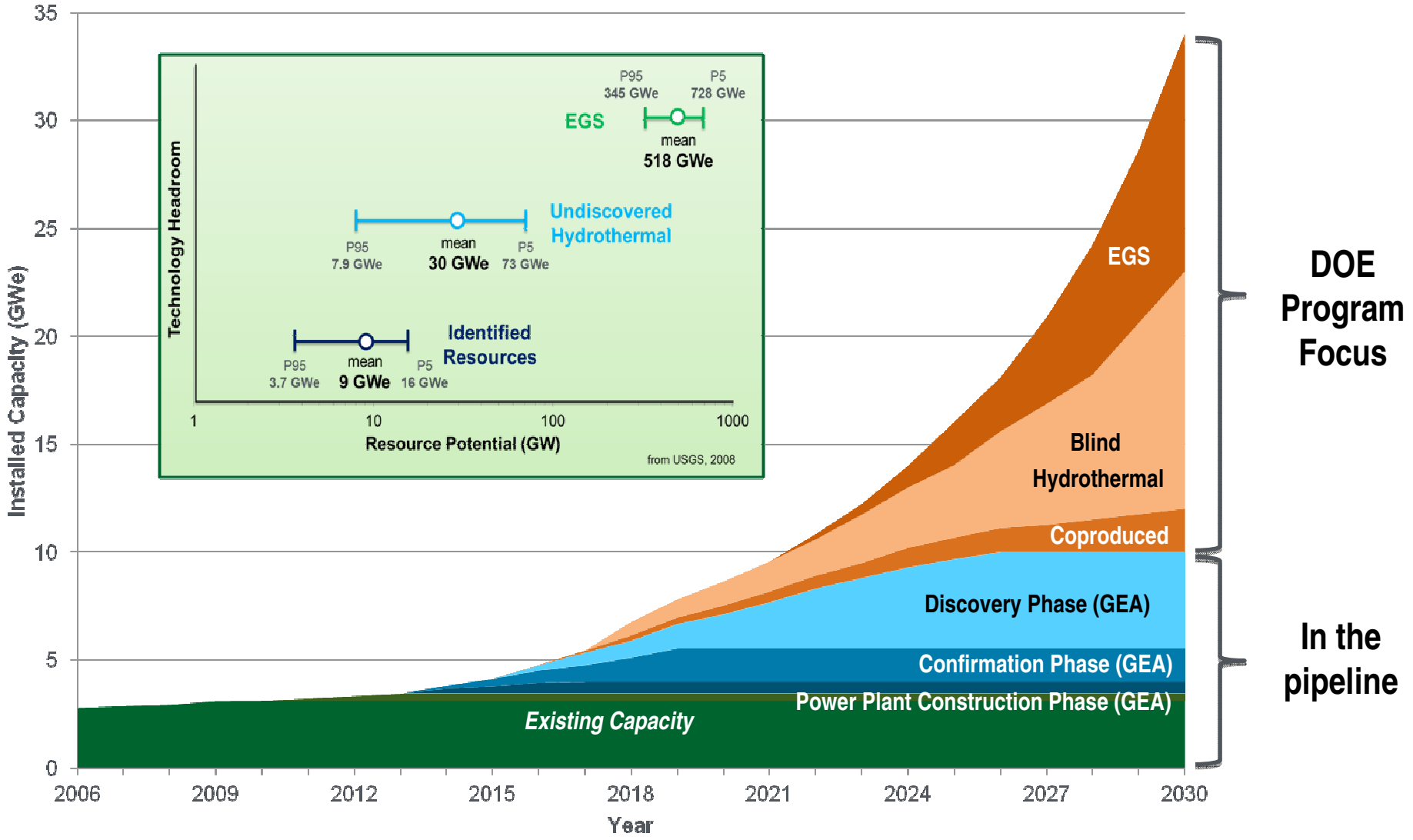
Enhanced Geothermal Systems

- Such systems require increasing permeability by stimulating fracturing and shearing of fractures through fluid injection
- Fluid circulated between injection and production wells to capture and extract heat
- Systems can be considered as in-field, near-field, and green field projects relative to existing hydrothermal systems



High Potential Impact of EGS



International State of EGS Technology

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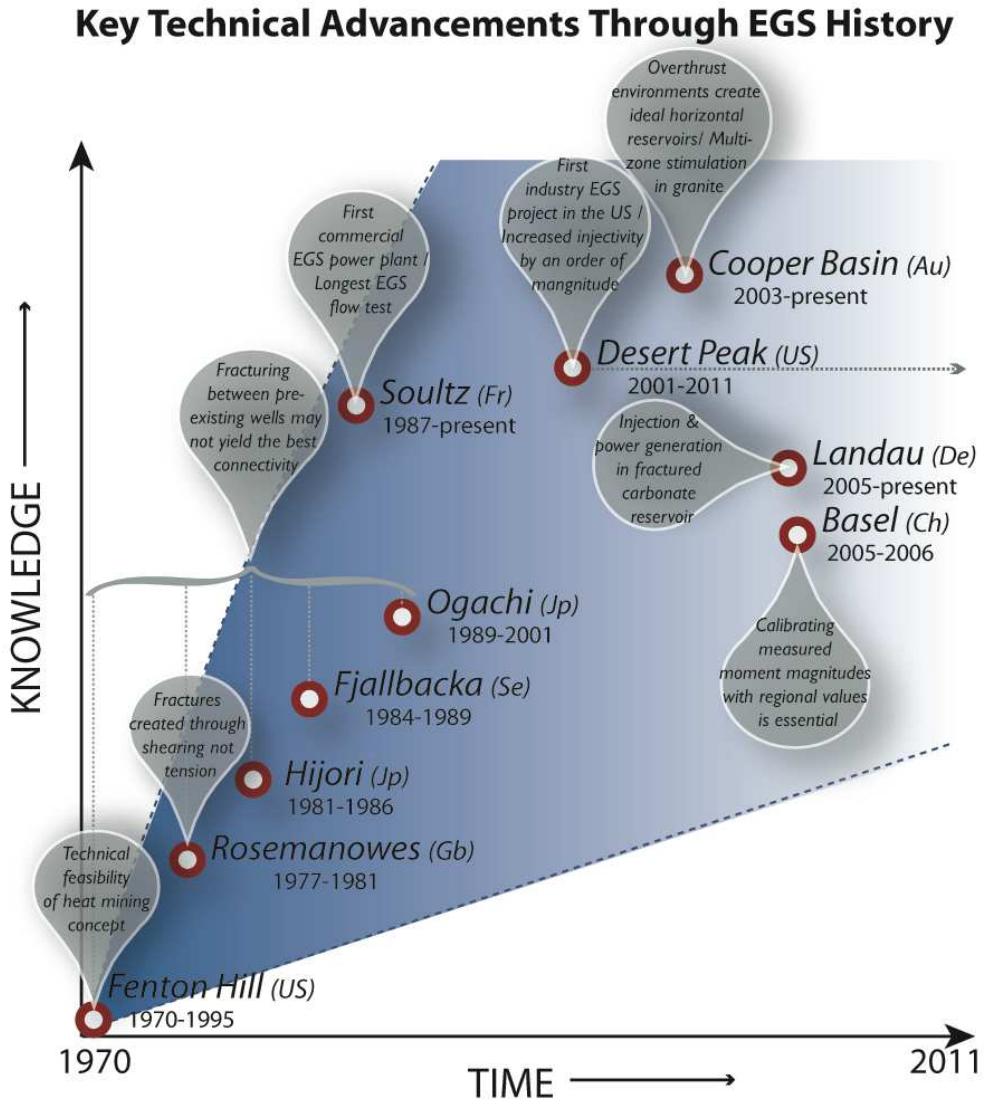
- **Improved understanding of fracture in crystalline rocks**
  Shearing dominates
- **Drill – fracture – drill again**
  Target enhanced permeability zones
- **Lowered water loss and enhanced flow impedance**
- **Harnessed induced seismicity**
  Improved monitoring/management
- **Multi-zone stimulations**
  Path to increased productivity/well



Enhanced Geothermal Systems

State of the Technology – 40 yrs of progress

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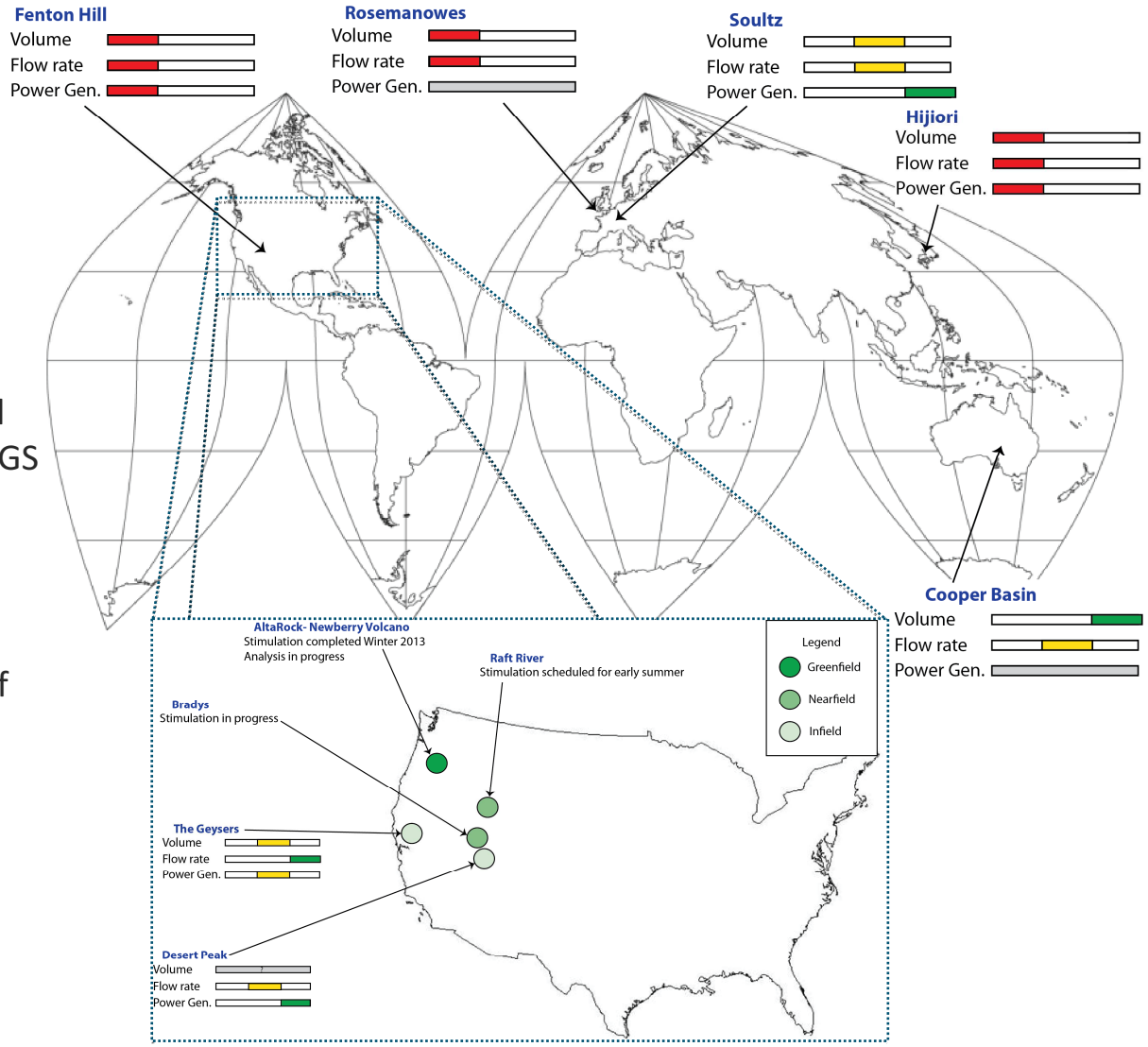
Critical Needs:

- ***Characterization*** of ***local stress***, ***chemical potential***, and ***thermal pathways***
- Achieving ***sufficient productivity*** (and stimulated volume) for commercial EGS power generation

Path Forward:

- Remaining gaps are the foundation of the EGS portfolio
- Most ***technology needs*** are ***evolutionary- not revolutionary!***



Concept proven but not yet commercial scale

Core Area Results

EGS Demonstration Projects

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Performer	Project Site	Site Information	Stimulation Timeline	Funding
Ormat Technologies Inc.	Desert Peak, NV	Stimulate well to provide additional injection capability to field	***Successful stimulation completed- additional work underway***	**$ 4.3 M**
Geysers Power Company, LLC	The Geysers, CA	Reopen two existing wells to deepen for injection and stimulation	***Successful stimulation***	**$ 6.2 M**
University of Utah	Raft River, ID	Improve the performance of the existing Raft River geothermal field	Underway	**$ 8.9 M**
Ormat Technologies Inc.	Bradys Hot Springs, NV	Improve the performance of the existing Brady's geothermal field	Underway	**$ 3.4 M**
AltaRock Energy Inc.	Newberry Volcano, OR	High potential in an area without existing geothermal development	***Initial data indicates multiple zones stimulated***	**$ 21.4 M**

The Geysers, CA

(The Geysers Power Co.)

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Project Objectives:

DOE: $ 6,248,370
Total project cost: $ 10,720,909

- EGS creation in the Northwest Geysers, CA
  - Largest producing geothermal field in the world
  - Currently producing ~830 MW
  - High temperature zone in NW Geysers was previously abandoned because of high NCG, HCl
- Systematically inject cool water into an undeveloped, high temperature zone (>250° C)
  - Reopen and deepen two existing wells for injection and stimulation in the high temperature zone
  - Cool water will induce shear reactivation of fractures, connecting high temperature zone to normal steam reservoir

The Geysers, CA
(Source: Calpine)

Status Updates:

Project Period: 2009-2013

- Steam entries containing approximately 91,000 lbs. of steam were encountered during re-opening of Prati-32 at a depth of 3,200m, with a BHT of 400°C
- Saw significant decrease in non-condensable gas contents, increase in reservoir pressure following injection
- Injection continues in Prati-32 , production at Prati 25
  - Stimulation of Prati-32 began on October 6th 2011
  - Established connection between Normal- and High-Temperature Reservoirs
  - **~5 MW new production potential** in previously abandoned portion of hydrothermal field
- Lawrence Berkeley National Lab is monitoring microseismic activity on a real-time basis throughout the stimulation

Early EGS Success

Demonstration Project at The Geysers, CA

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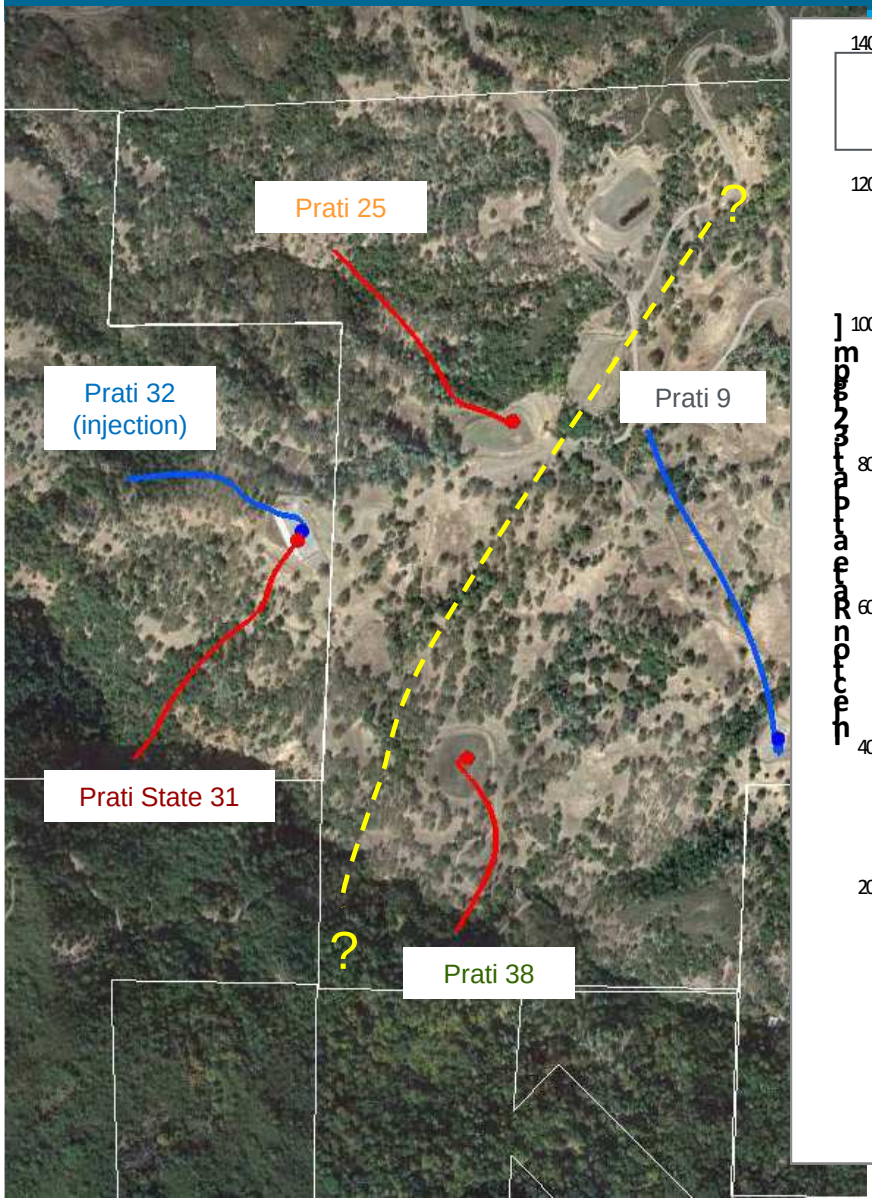

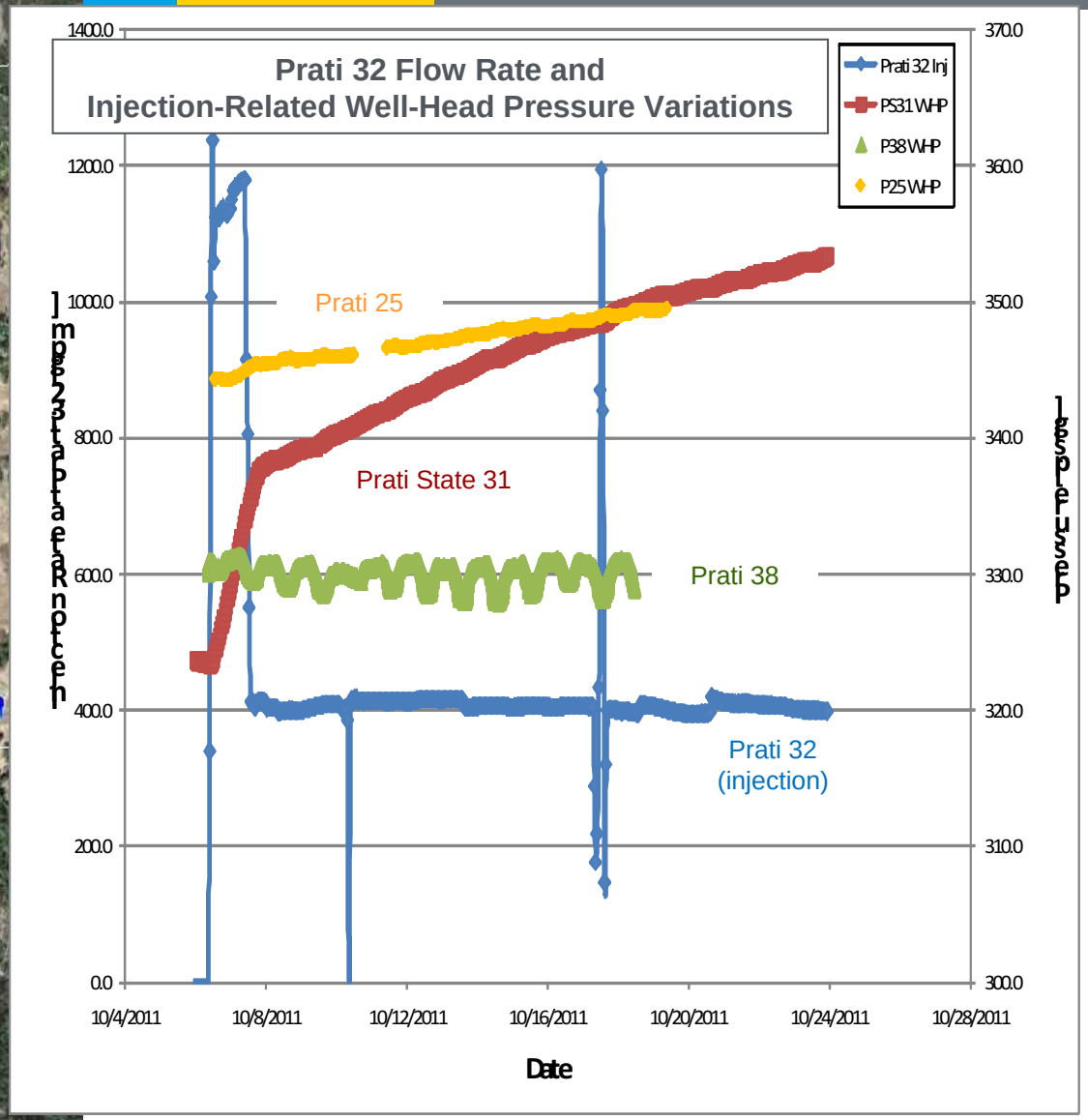

Calpine NW Geysers EGS Demonstration

Seismicity Analysis: 01 September 2011 to 05 March 2013

LBNL events with ErH (horizontal error) and ErZ (vertical error) less than 1 km

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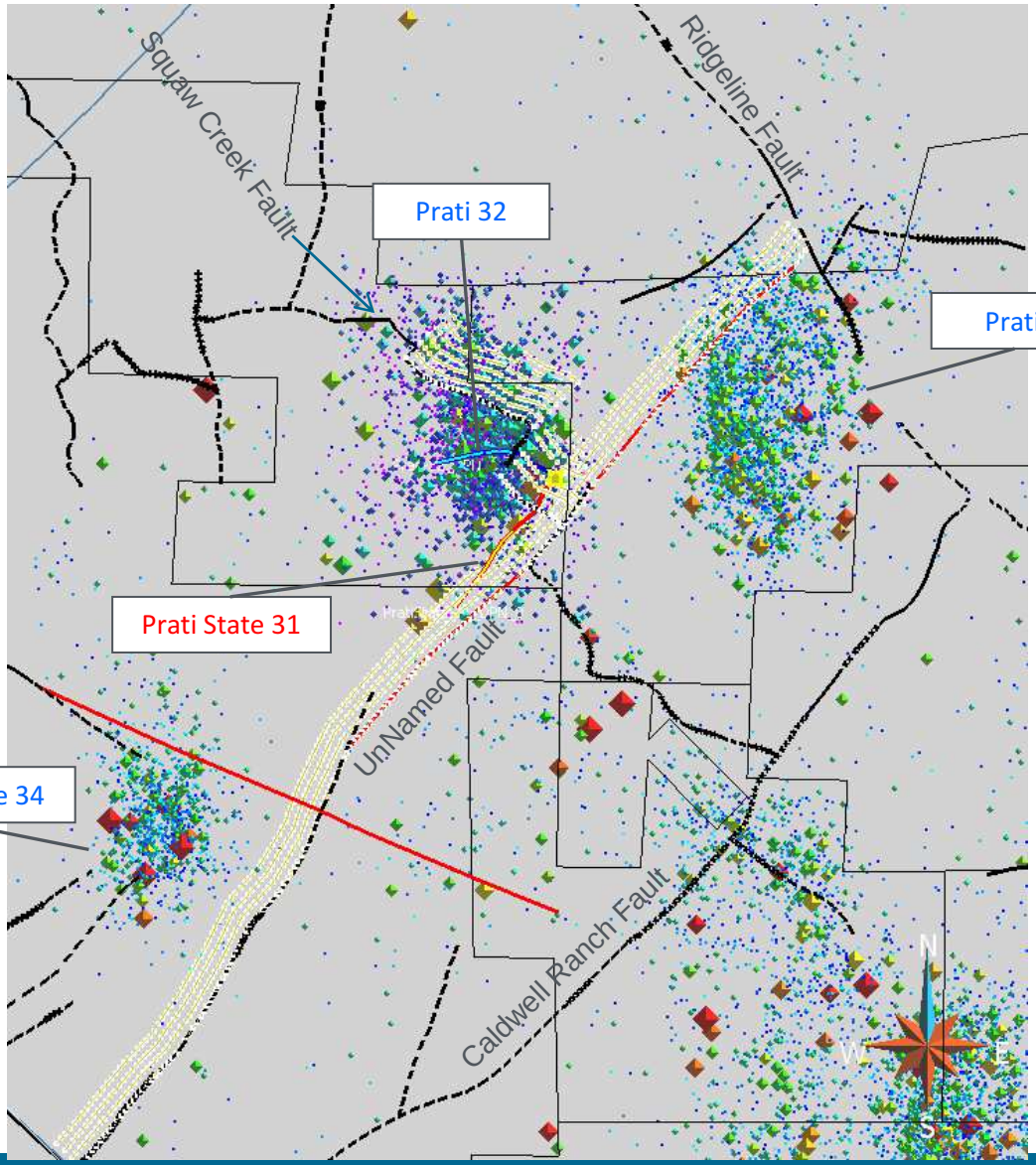

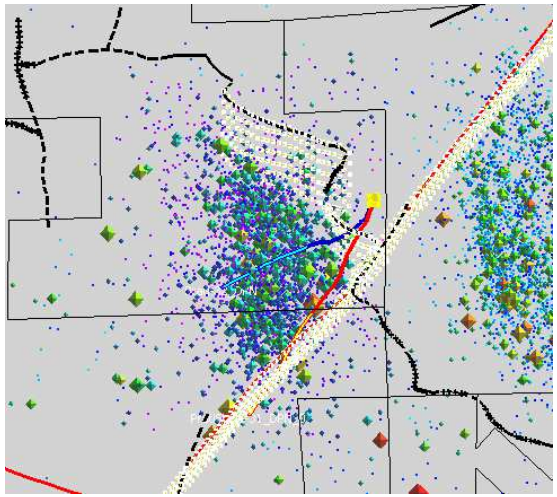

Zoom of Prati 32 and Prati State 31 Area
Oblique View (west of vertical)

Desert Peak, NV
(Ormat Nevada, Inc.)

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Project Objectives:

DOE: $4,953,982
Total project cost: $7,579,682

- Demonstrate the application of EGS techniques in a Basin and Range setting in Nevada:
  - Seeks to enhance or create permeability in a subsurface environment that is common in the region
- Proven hydrothermal reservoir adjacent to the Brady-Desert Peak Geothermal power complex:
  - Temperatures > 210° C
  - Fluid entries at 1,000m and 1,400m
  - Current plant generating 11 MWe- goal is to increase production by 1-2 MWe


Desert Peak (Source: Ormat Nevada, Inc)

Status Updates:

Project Period: 2002-2013

- Initial stimulation procedures were performed August 2010 - April 2011 with clear indications that the reservoir volume increased, the target well flow rate was increased from nearly zero to hundreds of gallons per minute
- Tracer tests completed, inter-well communication is apparent
- Ormat performed a hydraulic pulse stimulation in late 2011, well workover in 2012, high flow rate stimulation in January 2013, and a long-term stimulation below fracture propagation pressure in March 2013
- **Commercial injectivity rate of 2.1 gpm/psi achieved (175 times initial well injectivity)**
- Ormat will detail their stimulation in an upcoming report and updated reservoir model and sustainability study

Desert Peak, NV

MEQs aligned along Rhyolite Ridge Fault Zone

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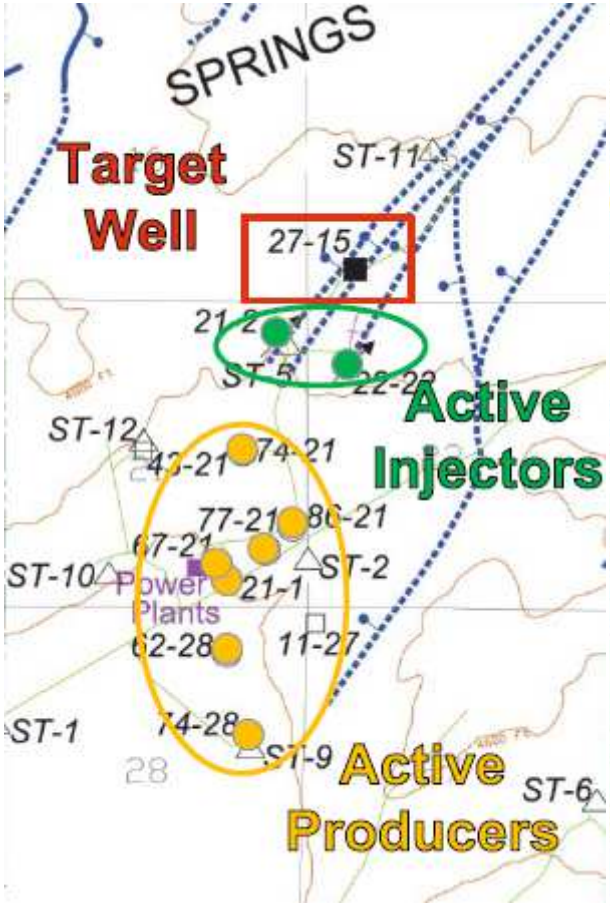

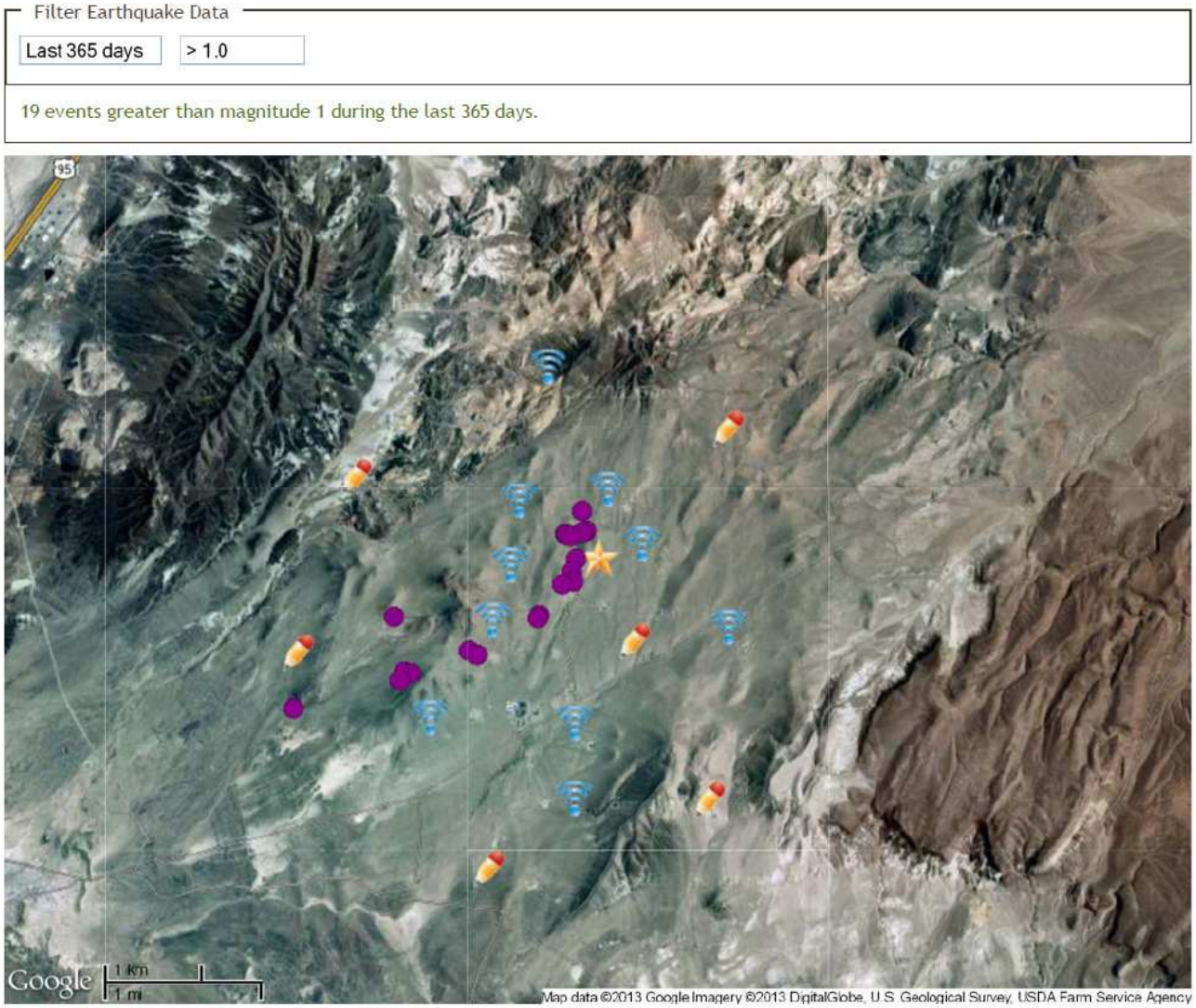

Desert Peak EGS Photos

Low pressure stimulation – Oct. 2010

High flow rate stimulation – Jan. 2013

Newberry, OR
(AltaRock Energy)

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Project Objectives:

DOE: $21,450,000
Total Project Cost: $43,506,918

- Develop and operate an EGS demonstration at Newberry Volcano, in central Oregon:
  - Existing well 55-29 was stimulated (serving as injector)
  - Two additional production wells will be drilled into the stimulated zones.
- Newberry is situated in the Cascade Range and thought to have significant EGS potential.
  - Reservoir characteristics:
    - Large, high-temperature, conductive thermal anomaly
    - Wells with very low permeability (orders of magnitude less than conventional hydrothermal wells)


Newberry Caldera, Oregon

Status Updates:

Project Period: 2010-2015

- AltaRock's Environmental Assessment complete, FONSI/DR signed on April 5th, 2012
- Installed the microseismic array and surface equipment in preparation for well stimulation during the summer of 2012
- Stimulation commenced October 17, 2012 and completed December 7, 2012, with three separate steps
- EGS reservoir created with potential volume of up to 1.5 km^3
- Next tasks and Phase 2.1 Report currently under review with DOE and Technical Monitoring Team
- Planned activities this summer include flow and injectivity tests
- Go/No Go decision prior to drilling production wells

Newberry EGS Photos

Raft River, ID
(*University of Utah*)

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Project Objectives:

DOE: $7,391,766
Total Project Costs: $10,558,415

- Project will develop improved methods for creating permeable fracture volumes in EGS reservoirs:
  - Employ a staged stimulation program to document the growth of fracture volume in creating and sustaining a reservoir
  - ***Improve performance*** of the Raft River geothermal field
- Current reservoir at Raft River:
  - Reservoir ***temperature ~130-200° C***
  - Reservoir depth ~1,271 - 1,828 m
  - Stimulate well that is not currently connected to the reservoir
  - Plant currently producing ***11.5 MW***

Status Updates:

Project Period: 2009-2014

- In March 2012, U of U successfully completed well rework, minfrac, and televiewer logging operations on the target well.
- Microseismic array operational, stimulation plan is designed and ready to implement
- A one day interval of low pressure injection was performed in late May
- DTS used to identify possible permeable zones in well
- First stage of stimulation (low pressure, cold water injection) is in progress

Bradys Hot Springs, NV
(Ormat Nevada, Inc.)

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Project Objectives:

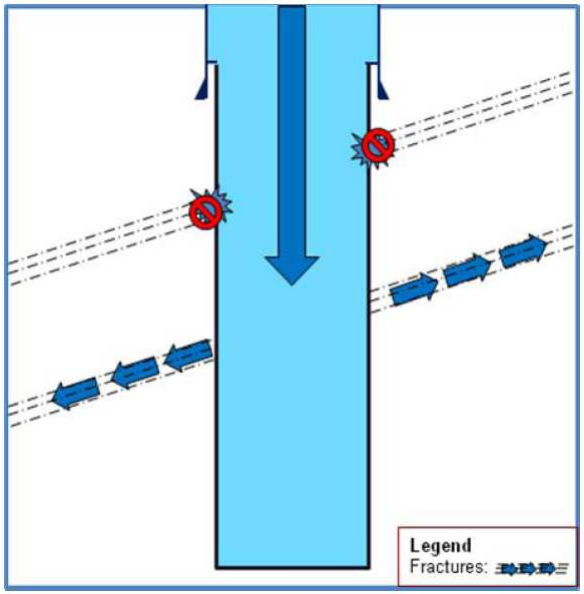
DOE: $4,482,796
Total project cost: $6,375,264

- Increase power production at Brady's power plant and characterize low permeability area of field:
  - Temperatures ***>400 F*** → Increase current ***production (14MW) by 2-3 MW***
  - Stimulating wells in the southwestern part of geothermal field, along the extension of the Bradys fault south of the production area
  - Target well, 15-12 used as either production well (directly adding additional power) or injection well (sweeping more heat toward existing production wells
    - Completed to ***5096 ft in fractured meta-tuff***
- Test and validate hydraulic and chemical stimulation techniques to improve well productivity and inter-well connectivity
  - Evaluate connectivity with tracer tests.

Status Updates:

Project Period: 2009-2015

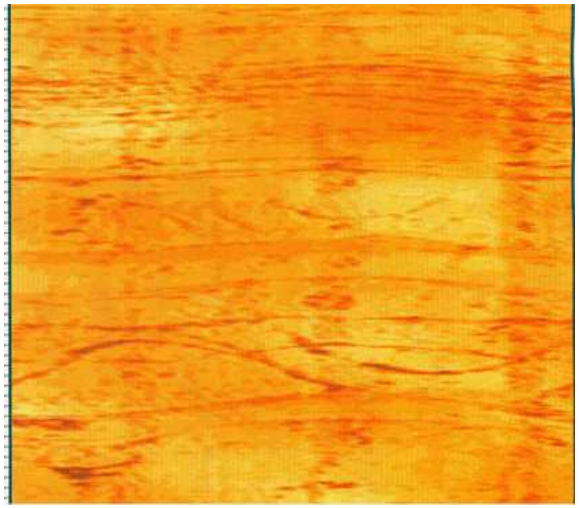
- The Ormat-Bradys project received a conditional "go" decision for Phase II (Well Stimulation) of the project as a result of the stage gate meeting in July 2012.
- Stimulation design complete and ready to implement
- Initial low pressure injection phase conducted in May 2013
- Stimulation activities will continue in July 2013 using packers to isolate different intervals within open hole.



AltaRock Energy & CSI Technologies- DIVERTERS

•Facilitate multi stage fracturing using chemical diverters in high-temperature (>200°C) environments to increase power production per well.

- Two successful field tests in high temperature reservoirs
- Transmissivity calculations post testing imply the material fully degraded.



Baker Hughes - Geothermal Ultrasonic Fracture Imager

- Development of a downhole wireline tool to characterize fractures in EGS wells in temperatures up to 300°C and depths up to 10,000 m
  - Transducer 300°C demonstration test completed
  - 25KPsi/260°C test of tool transducer assembly completed Jan 2012

EERE Strategic Planning
GTO's EGS Technology Roadmap

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WHY

To support visions, goals, and missions articulated in strategic plans.

•To present a ***strategy*** for ***promoting technology advancements*** necessary to optimize EGS.

•Forms the basis for current and future ***EGS R&D investment strategies***.

•***Communicate*** the EGS Program R&D strategy to:

- •stakeholders, members of other subsurface science and energy sectors
- •legislative and policy administrators.

HOW

Drafted in collaboration with experts and stakeholders

•Informed by ***expert feedback*** and ***multiple workshops*** with industry, academia, national laboratories, trade associations.

WHAT

Represent the consensus thinking on major barriers and potential avenues of research to address barriers.

•Illustrates technical research paths over time:

- •***Past*** practices
- •***Current*** GTO efforts
- •***Desired future capabilities and outcomes***

Workshop Results

EGS Technology Needs

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3 high-level EGS R&D topics & 8 unique tech paths identified to communicate EGS research needs

CHARACTERIZE	CREATE	OPERATE
- Identify natural fractures and flow paths	- Create new fractures and flow paths	- Manage fractures and flow paths
	- Monitor flow paths	- Monitor flow paths
	- Zonal Isolation	- Zonal Isolation
- Drilling	- Drilling	- Drilling
- Modeling	- Modeling	- Modeling
- Tools	- Tools	- Tools

EGS Technology Evolution

Characterize, Create and Operate

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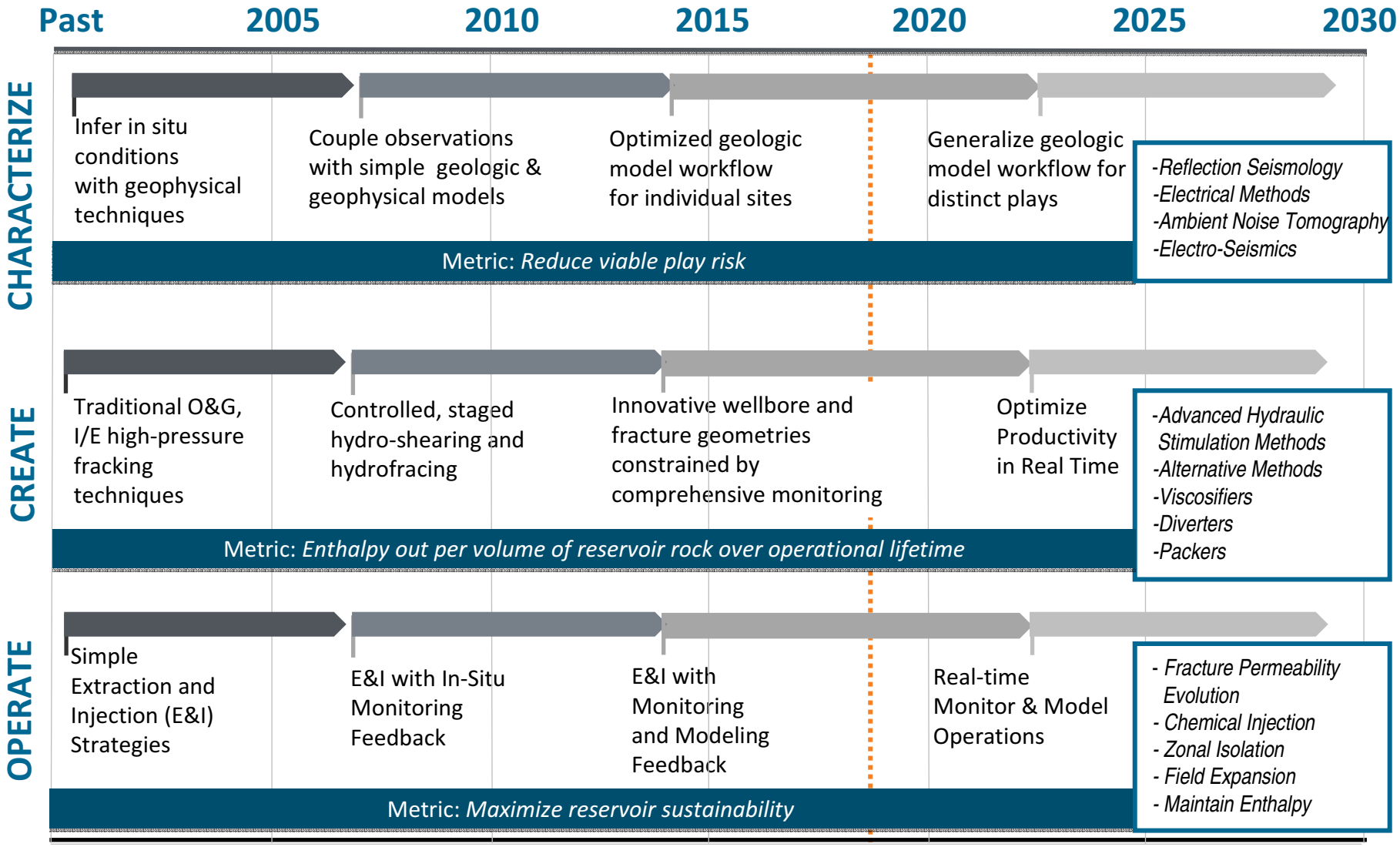

EGS Technology Pathway Metrics

Measuring R&D Progress

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Topic	Metric	Technology Pathway	Metric	Description
Characterize	Risk Reduction	Identify Natural Fractures and Flow Paths	Spatial resolution and ability to predict a priori reservoir performance	Develop precision geophysical methods, validated play books, and improved tools for subsurface.
Create	Reservoir Performance	Create New Fractures and Flow Paths	Fractured rock volume ability to predict a priori reservoir performance	Develop techniques to maximize heat extraction from a given volume of reservoir rock with a minimum of boreholes.
Create/Operate	Reservoir Performance	Monitor Flow Paths	Enthalpy and/or fractured rock volume	Develop ability to more accurately monitor and control flow paths in the reservoir.
Create/Operate	Reservoir Performance	Zonal Isolation	Enthalpy and/or fractured rock volume	Demonstrate the ability to isolate sections of the wellbore and reservoir.
Operate	Reservoir Performance	Manage Fractures and Flow Paths	Thermal drawdown and reservoir sustainability	Develop the ability to manage EGS reservoirs improving reservoir lifetime and productivity.
All	RR and RP	Drilling	ROP/Costs	Develop next generation rock reduction, drilling and well completion technologies.
All	RR and RP	Modeling	Ability to predict a priori and manage in real time reservoir performance	Develop robust, capable, and validated models of the subsurface.
All	RR and RP	Tools	T/P limits, sensitivity and durability	Develop tools that can withstand hostile EGS environments.

FORGE

Frontier Observatory for Geothermal Energy

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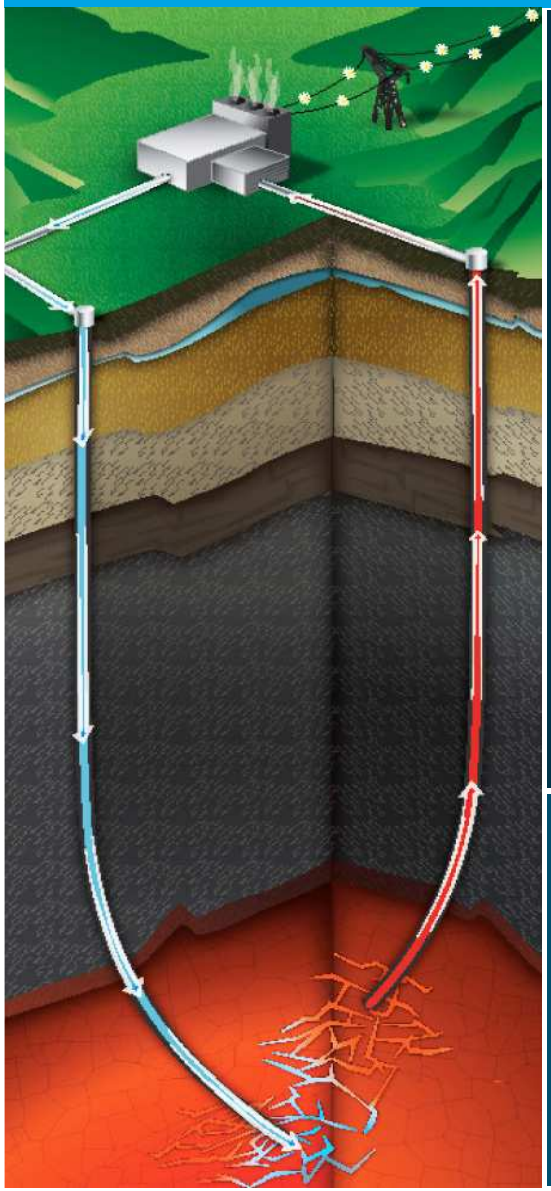


WHY?

Promote transformative science and engineering to:

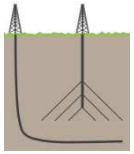
- Address key barriers
- Validate and optimize EGS technology
- Capture high fidelity data
- Ensure deep understanding and reproducibility for commercial scale-up

Federal Role:

- Test technologies/take technical risks not possible in private sector
- Work under aggressive timeframe
- Gather and disseminate comprehensive data sets

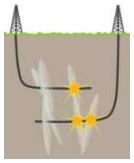
Direct benefits to all areas of research in the geothermal space

TECHNICAL CHALLENGES



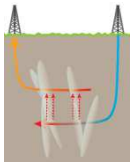
Reservoir Access

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

- Test site could promote international collaboration for addressing key technical challenges associated with EGS
- Cross over benefit to conventional hydrothermal systems

Addressing Barriers:

- High Cost of Drilling
- Subsurface Characterization
- Creating a Reservoir
- Sustained Reservoir Production
- Risk Management & Mitigation