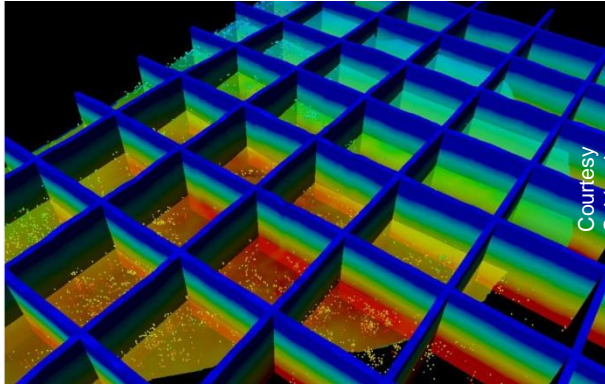


FORGE & EGS Program Outlook



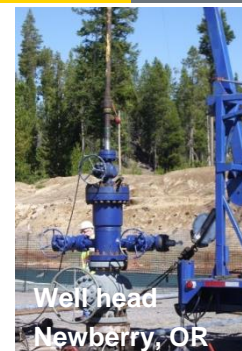
Lauren Boyd
EGS Program Manager
Geothermal Technologies Office

EGS Demonstration Portfolio

Core Area Results

U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy



Performer	Project Site	Site Information	Status	Funding
Ormat Technologies Inc.	Desert Peak, NV	Adjacent to existing hydrothermal development	<i>Successful stimulation completed - 1.7 MW additional capacity added</i>	\$ 4.3 M
Geysers Power Company, LLC	The Geysers, CA	Reopen two existing wells to deepen for injection and stimulation in inactive part of field	<i>Successful stimulation completed – 5 MW equivalent created</i>	\$ 6.2 M
University of Utah	Raft River, ID	Improve the performance of the existing Raft River geothermal field	<i>Successful Stimulation underway – injectivity increasing daily</i>	\$ 8.9 M
AltaRock Energy Inc.	Newberry Volcano, OR	High potential in an area without existing geothermal development	<i>Successful stimulation completed – multiple zones stimulated</i>	\$ 21.4 M
Ormat Technologies Inc.	Bradys Hot Springs, NV	Improve the performance of the existing Brady's geothermal field	<i>Initial stimulation complete & long term strategy under development</i>	\$ 3.4 M

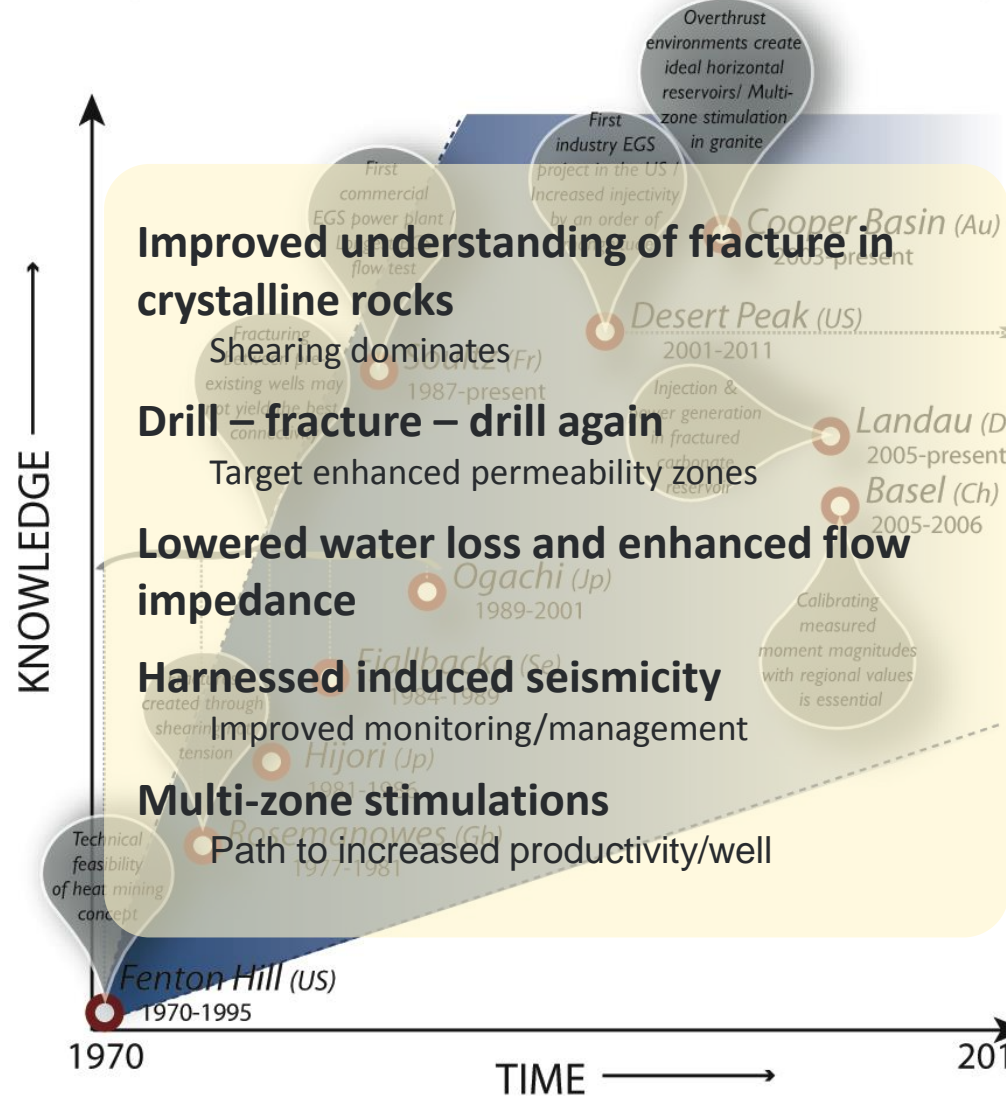
Critical Needs:

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

Path Forward:

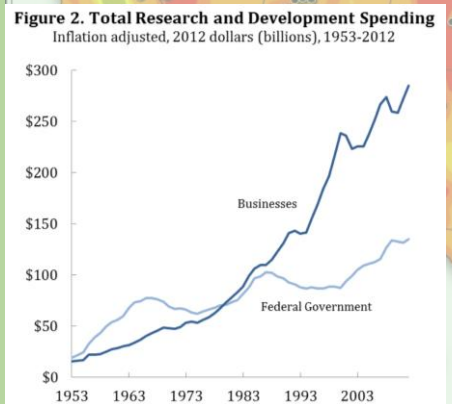
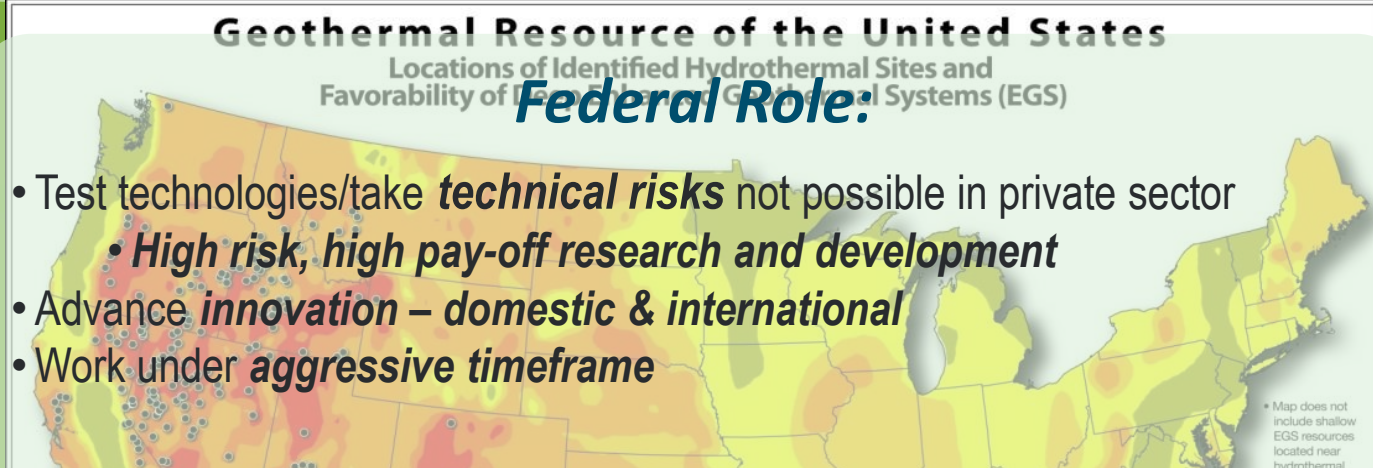
- Remaining gaps are the foundation of the EGS portfolio
- Most **technology needs** are **evolutionary- not revolutionary!**

Key Technical Advancements Through EGS History

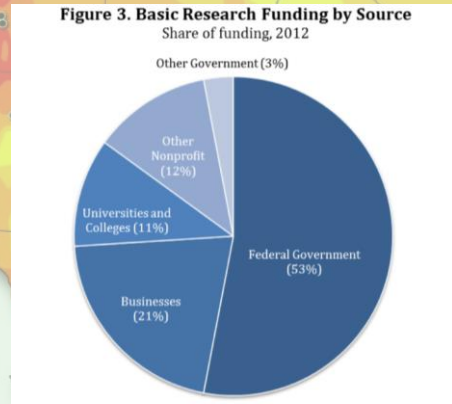


Opportunity Space

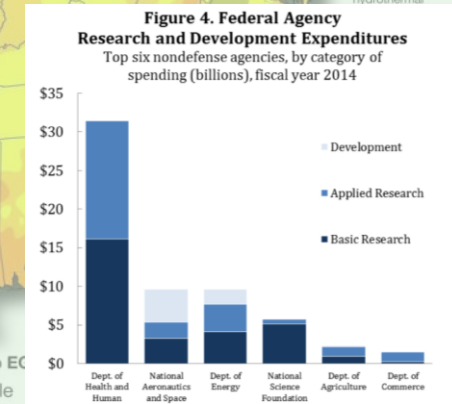
- Heat is present almost **everywhere at depth**
- Potential resource is estimated to be on the order of **100+ GWe** (USGS)



Source: JEC Democratic staff calculations based on data from the National Science Foundation, *National Patterns of R&D Resources: 2011-12 Data Update*, and the Bureau of Economic Analysis.



Source: JEC Democratic staff calculations based on data from the National Science Foundation, *National Patterns of R&D Resources: 2011-12 Data Update*.



Source: JEC Democratic staff calculations based on preliminary data for fiscal year 2014 from the National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 2012-2014*, Table 7.

* Figures from *The Role of Research & Development in Strengthening American's Innovation Economy, 2014*
 Joint Economic Committee | Democrats

This map was produced by the National Renewable Energy Laboratory for the US Department of Energy, October 13, 2009 Author: Billy J. Roberts

Least Favorable
 N/A
 No Data**

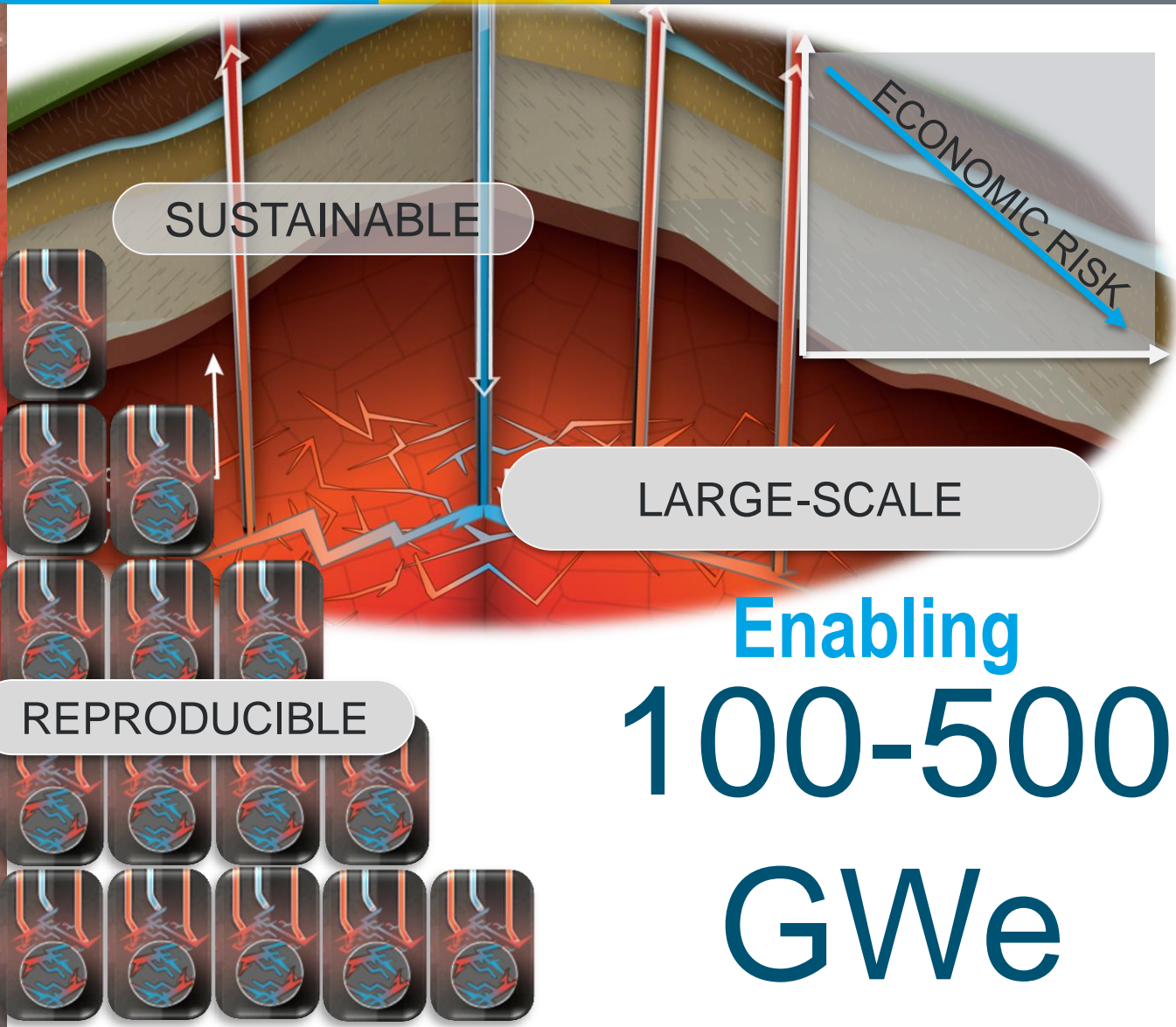
• Identified Hydrothermal Site ($\geq 90^{\circ}\text{C}$)



FORGE

U.S. Department of Energy

FORGE is an EGS laboratory where the subsurface scientific community can test and improve new technologies and techniques for creating and sustaining next-generation geothermal systems.



Enabling
100-500
GWe

SHARE, COMMUNICATE, and EDUCATE the broader technical and non-technical community

Systematic – Innovative – Community-Driven

- ❑ Gain a **fundamental understanding** of the **key mechanisms controlling EGS** success
- ❑ **Develop, test** and **improve** new **fundamental** and **techniques** in an ideal EGS environment.
- ❑ Make **Integrated comparison** of **technologies** and **tools** in a controlled environment
- ❑ Rapidly **disseminate technical data** and **communicate** to the research community, developers, and other interested parties.



DEVELOPING
METHODOLOGIES



R&D COMMUNITY

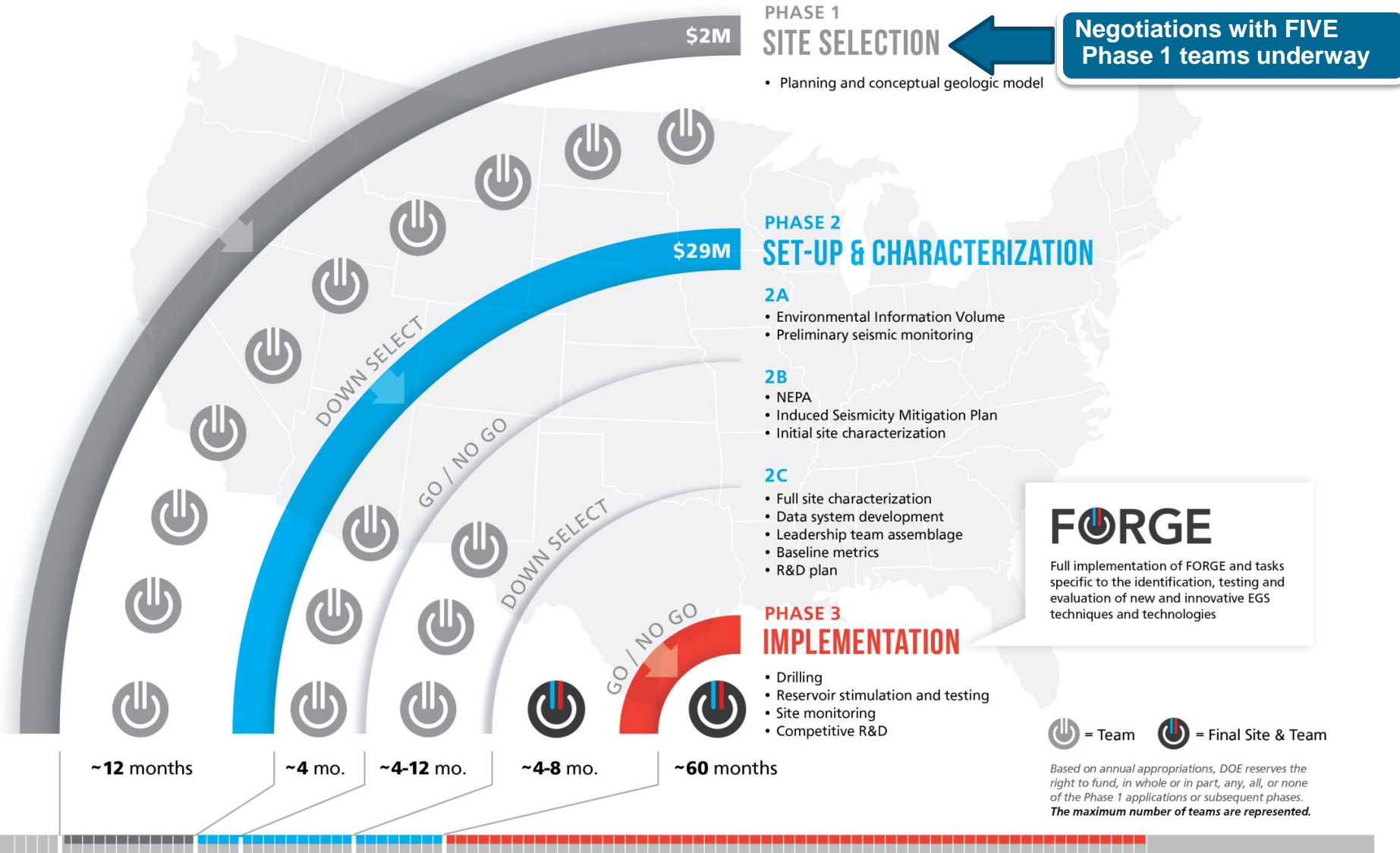
BENCHMARKING



- Well characterized, with high temperatures in the target formation in the range of **175-225 ° C**
- Moderate permeability of order **10⁻¹⁶ m²**, 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 while attaining stress and temperature characteristics that are suitable to EGS and advancement of new technologies
- Must **not be within an operational hydrothermal field**
- Does **not stimulate** or **circulate fluids through overlying sedimentary units**, if applicable

Other site selection considerations included:

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



Duration: 1 year

Up to 10 projects

Total Federal Funds available \$2M

The Phase 1 objective is to complete mission-critical technical and logistical tasks that demonstrate site viability and the Applicant's full commitment and capability to meet envisioned FORGE objectives through Phases 2 and 3. Minimum requirements for Phase 1 include:

- Assess all available site characterization data;
- Compile site data into a conceptual geologic model of the proposed site;
- Archive site data used to support the conceptual geologic model to GTO's Existing NGDS Node, the Geothermal Data Repository (GDR)
- Finalize all teaming and cost-sharing arrangements; and
- Develop the key operational plans
- Develop Environmental Information Synopsis

End Phase 1: down select to 1-3 sites via Renewal Application

Duration: 1-2 years

1- 3 projects

Total Federal Funds available \$29M

- *The objective of Phase 2 is to fully instrument the site and bring FORGE to full readiness for the testing of new technologies and techniques in Phase 3.*
- Phase 2 is split into the following three sub phases:
 - Phase 2A – Environmental Information Volume (EIV) and Preliminary Seismic Monitoring
 - Phase 2B – NEPA Compliance, Final Induced Seismicity Mitigation Plan, and Initial Site Characterization
 - Phase 2C – Subsurface Characterization and Site Readiness

Phase 2A

4 months – 1-3 Teams – *\$2M*

- **Environmental Information Volume** : skeleton of NEPA document
- **Surface MEQ monitoring array**: At least 5 surface stations operational, with telemetry and collecting data

GO/NO-GO at conclusion of PHASE 2A

Phase 2B

4-12 months – 1-3 Teams – *\$17M*

- Implementation & completion of **National Environmental Policy Act**
- Comprehensive **site characterization & monitoring**:
 - Seismic, Geological analysis, Conceptual Modeling
 - Development of **Induced Seismicity Mitigation Plan**

DOWNSELECT at the end of Phase 2B

Phase 2C

4-8 months – 1 Team – *\$10M*

- **Full site characterization** (subsurface and invasive characterization)
- Develop and **deploy data-system** to serve live site data for project life
 - Real-time data sharing via data system
- **STAT Charter** and governance document
- First round of **R&D solicitation**
- **Baseline metrics**
- Updated **geologic model**

Duration: 5 years

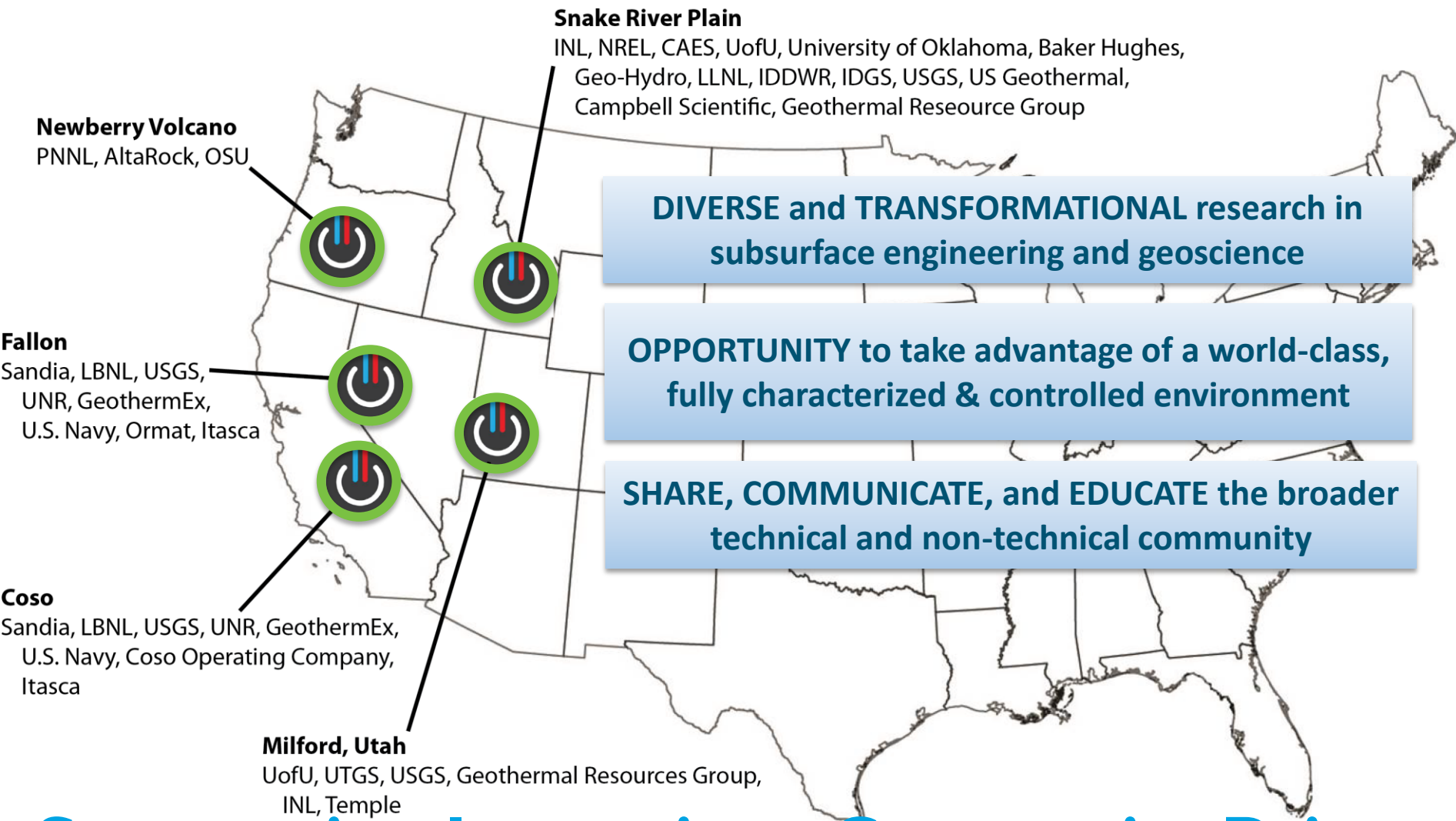
1 project

Total Federal Funds available subject to appropriations

- *Phase 3 involves full implementation of FORGE and tasks specific to the solicitation, selection, testing and evaluation of new and innovative EGS tools, techniques, and supporting science.*
- Requires drilling of two or more full-sized wells, reservoir stimulation, connectivity and flow testing, dynamic reservoir modeling, and continuous monitoring
- Annual R&D solicitations will be issued with 10-20 subcontracts awarded for research and technology testing per competition (subject to annual appropriations) in the following categories:
 - Reservoir characterization (coupled imaging, drilling for interrogation and monitoring, high-temperature tools and sensors)
 - Reservoir creation (formation access, fracture characterization, zonal isolation, stimulation technologies)
 - Reservoir sustainability (long-term testing, monitoring, and operational feedback)
- All entities (including industry, universities, Federally Funded Research and Development Centers, non-profit organizations, government agencies, etc.) will be eligible to submit proposals for testing and evaluating innovative tools and techniques at FORGE.
- **At least 50% of annual Phase 3 FORGE funding must be directed towards competitive R&D solicitations, exclusive of funds dedicated to innovative drilling and flow testing.**

Selected Teams

Broad Collaboration & Data Rich Sites



DIVERSE and TRANSFORMATIONAL research in subsurface engineering and geoscience

OPPORTUNITY to take advantage of a world-class, fully characterized & controlled environment

SHARE, COMMUNICATE, and EDUCATE the broader technical and non-technical community

Systematic – Innovative – Community-Driven

facebook Sign Up

Timeline Photos

Back to Album: U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Energy Efficiency and Renewable Energy Page

INFOGRAPHIC: See how Enhanced Geothermal Systems work & learn about our new EGS efforts ▶ 1.usa.gov/1EA3jP8 pic.twitter.com/okez2VezmQ

10:30am · 28 Apr 15

DOE Press Staff @EnergyPressStaff

U.S. Department of Energy Announces Project Selections in First Phase of Cutting-Edge Enhanced Geothermal Systems Effort 1.usa.gov/1PO0BAV

5:05pm · 27 Apr 15

24 RETWEETS · 1 FAVORITE

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Energy Department Announces Project Selections in First Phase of Cutting-Edge Enhanced Geothermal Systems Effort

April 27, 2015 - 6:31pm

NEWS MEDIA CONTACT

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WASHINGTON, DC - As part of the Obama Administration's all-of-the-above energy strategy, the Energy Department today announced five projects selected for a total of \$2 million for the first part of the multiphase Frontier Observatory for Research in Geothermal Energy (FORGE) effort. This field laboratory, dedicated to cutting-edge research on enhanced geothermal systems (EGS), could unlock access to a domestic, geographically diverse, and carbon-free source of clean energy with the potential to supply power to up to 100 million homes in the United States. The first two phases of FORGE will provide a total of up to \$31 million over two years for selected teams.

"Through these kinds of critical investments in renewable energy, the Department is helping develop cost-effective technologies for engineering geothermal systems that supply affordable, zero-carbon energy to millions of American homes and businesses," said Under Secretary for Science and Energy Lynn Orr. "Enhanced geothermal systems could represent the next frontier of renewable energy and hold the potential to diversify the nation's energy portfolio while reducing greenhouse gas emissions into the atmosphere."

EGS are engineered geothermal reservoirs, created beneath the surface of the earth, where there is hot rock but limited pathways through which fluid can flow. During EGS development, underground fluid pathways are safely created and their size and connectivity increased. These enhanced pathways allow fluid to circulate throughout the hot rock and carry heat to the surface to generate electricity. EGS development could lead to more than 100 gigawatts of economically viable electric generating capacity in the continental United States, representing a two-orders-of-magnitude increase over present geothermal capacity.

The FORGE initiative consists of three phases. The first two phases will—over the next two years—focus on selecting both a site and an operations team, as well as preparing and fully characterizing the site.

The five selected teams announced today represent proposed projects in California, Idaho,

48 AP story hits

23 articles

PLUG INTO THE PLANET ▶ **FORGE**
U.S. Department of Energy
FRONTIER OBSERVATORY FOR RESEARCH IN GEOTHERMAL ENERGY

NATURAL GEOTHERMAL SYSTEMS
The presence of hot rocks, permeability, and fluid underground creates natural geothermal systems. Small underground pathways conduct fluids through the hot rocks, carrying energy in the form of heat through wells to Earth's surface when the conditions are just right. At the surface, that energy drives turbines and generates electricity.

ENHANCED GEOTHERMAL SYSTEMS
Sometimes conditions are not perfect for natural geothermal systems: the rocks are hot, but they are not very permeable and contain little water. The injection of fluid into the hot rocks enhances the size and connectivity of fluid pathways by re-opening fractures. Once created, an enhanced geothermal system (EGS) functions just as a natural geothermal system does. The fluids carry energy to the surface, driving turbines and generating electricity.

Hot Rocks | Undergroud Fluid | Natural Permeability | Hot Rocks | Injected Fluid | Enhanced Permeability

Depth: 1.5-4 km

FORGE
U.S. Department of Energy

FORGE is an EGS laboratory where the subsurface scientific community can test and improve new technologies and techniques for creating and sustaining next-generation geothermal systems.

CHARACTERIZING THE ROCKS | TESTING NEW TOOLS | MONITORING RESERVOIRS | DEVELOPING METHODOLOGIES | REPRODUCIBLE RESULTS = TREMENDOUS POTENTIAL

CREATING RESERVOIRS | SHARING DATA | COLLABORATING | BENCHMARKING

R&D COMMUNITY

100+ GWe
ECONOMICALLY VIABLE CAPACITY
More than 100 GWe (gigawatts electric) of economically viable capacity may be available in the continental United States, representing a nearly 100-fold increase over present geothermal power generating capacity.

100 MILLION
AMERICAN HOMES POWERED WITH GREEN ELECTRICITY
This potential could supply power to 100,000,000 homes in the United States, and it represents a domestic energy source that is clean, reliable, flexible, and renewable.

ENERGY.GOV/FORGE

ENERGY THAT Works AROUND THE CLOCK

EGS is a reliable, baseload energy source. It can provide power 24 hours a day, 365 days a year, independent of weather conditions and with the flexibility to meet consumer demand.

GREEN TECHNOLOGY FOR A GREENER WORLD

Power plants built for EGS emit **LESS** little CO₂ over their lifetimes.

CO₂ Emissions

0.05 kg
Geothermal Binary Closed Loop Plant
Life Cycle of 30 years

8.91 kg
Using 1 Gallon of Motor Gasoline

CLEAN ENERGY FOR AMERICA'S HOMES

If this house represents all the households in Chicago, EGS has the potential to power this:

ENERGY | Energy Efficiency & Renewable Energy | Geothermal Technologies Office

Natural Geothermal Systems

To generate power from natural geothermal systems you need:

Abundant heat found in rocks at depth + Fluid to carry heat from the rocks + Small pathways to conduct fluid through the hot rocks

Problem

Despite the presence of heat, sometimes conditions are not ideal for power generation from natural geothermal systems. In these cases you have:

Abundant heat found in rocks at depth + Insufficient fluid to carry the heat + Limited pathways to conduct fluid

ENHANCED GEOTHERMAL SYSTEMS

Solution

A man-made enhanced geothermal system (EGS) can extract the abundant heat resource tens of thousands of feet below the surface and put it to good use. This would require:

What makes EGS?

An abundant, previously-stranded, heat source + Fluid injected from the surface + Permeable pathways enhanced by injected fluids

With an enhanced geothermal reservoir, you can generate power anywhere with hot rocks at depth!

Develop a comprehensive and innovative plan for communications, education, and outreach in collaboration with DOE and stakeholders to increase geothermal science technology literacy

- Variety of communications, education, and outreach methods will be utilized
- Education and workforce development to occur through engagement of students and educators (K-12 and higher education) onsite and in the classroom regarding EGS science and technology
- Frequent public meetings to report on FORGE status to take place with local stakeholders and the broader technical community

- Community engagement
 - Communications
 - Science Technology Analysis Team
 - EGS Roadmap 2.0
- Community driven transformational research
 - Deep Underground Science and Engineering Lab (DUSEL)/ Sanford Underground Research Facility (SURF)
 - NSF Plate Boundary Observatory (PBO)
 - The San Andreas Fault Observatory at Depth (SAFOD)

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FORGE is an EGS laboratory where the subsurface scientific community can test and improve new technologies and techniques for creating and sustaining next-generation geothermal systems.

R&D COMMUNITY

SAFOD Middle Mountain Surface Trace of San Andreas Fault

Depth, km

Vertical Drilling

- Rotary drill to 2 km depth
- Case and cement
- Spot coring, fluid sampling and hydrologic/stress testing

Directional Drilling

- Rotary drill to 4 km depth, with spot and sidewall coring
- Wireline logging and LWD/MWD
- Case, cement and perforate through fault zone
- Fluid sampling and hydrologic/stress testing through perforations

Continuous Coring

- Core four, 250-m-long side tracks through fault zone
- Install slotted liner in one core hole for later hydrologic monitoring

Long-Term Monitoring (~20 years)

- Install monitoring string across fault zone (seismometry, fluid pressure, temperature and deformation)

<http://pbo.unavco.org/safod>

DUSEL Deep Underground Science and Engineering Laboratory at Homestake, SD

6 1/2 Empire State Building for scale

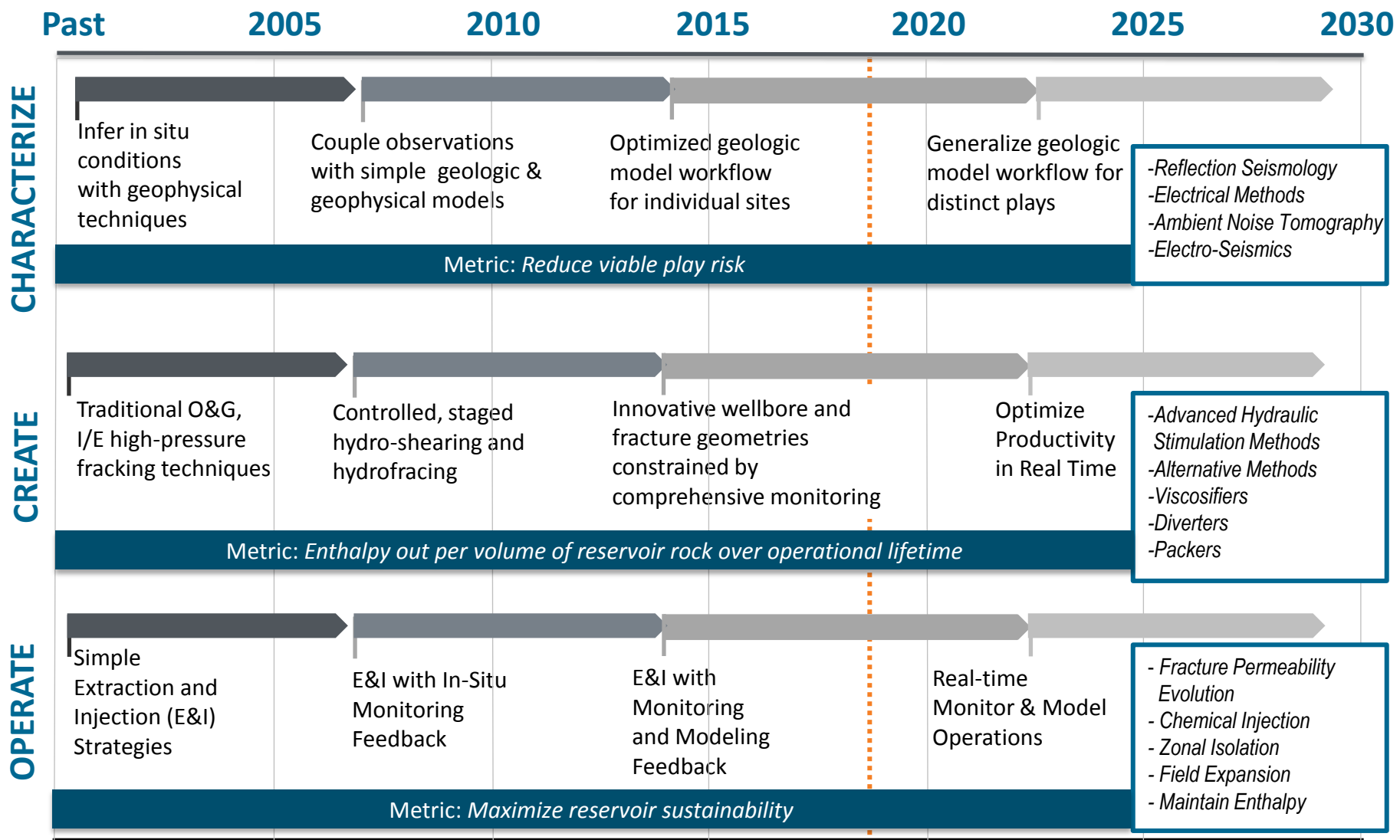
Shallow Lab Mid-level Deep Campus

Engineering Geoscience Physics Astrophysics Biology

http://www2.lbl.gov/nsd/homestake/images/dusel_h.jpg

EGS Technology Evolution

Characterize, Create and Operate



EGS Technology Pathway Metrics

Measuring R&D Progress

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.

- At the start of Phase 3 demonstrate full functionality of an NGDS-compatible, data-sharing mechanism (FORGE Data System/Node) for real-time sharing of all site characterization and monitoring data.
- At the conclusion of year 1, design of first FORGE well based on in-situ stresses and informed by continuously updated reservoir models. Initiate drilling of first well in year 2.
- Issue R&D solicitations annually and ensure all awards are made and work initiated within the fiscal year of solicitation release.
- Demonstrate sustained functionality of transient reservoir interrogation tools at 200 ° C for at least 6 months or in-situ monitoring tools for at least one year.
- Demonstrate at least three innovative stimulation techniques for initiating or re-opening fractures.
- **Demonstrate the ability to enhance multiple reservoir volumes from a single wellbore and correlate to progressively-increased well performance as a function of number of stimulated zones.**
- **Demonstrate innovative precision geophysical methods that increase spatial resolution of subsurface features over state-of-the-art and validate methods with actual subsurface data or mine back.**
- Demonstrate the functionality of innovative drilling tools and components capable of operating at 200+ °C in crystalline rock, uninterrupted for 30 hours.
- Demonstrate validation of reservoir and site models based on ability to predict post-stimulation fracture initiation directions, total reservoir volume, and connectivity.
- Validate the capability of new tracers to improve flow path, volume, and fracture surface area estimates.
- **Develop sufficient flow paths between wellbores over a reservoir volume greater than 1 km³ and quantitatively constrain their capacity to sustain production with less than 2°C temperature decline over one year.**
- Demonstrate a methodology for reproducible EGS reservoir creation and sustainability.

PLUG INTO THE PLANET ▶



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