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The Snake River Geothermal Consortium is a research partnership focused on advancing geothermal energy, hosted by Idaho National Laboratory.

Research and Development Implementation Plan

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FORGE
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  - Idaho State University – Geologic mapping and interpretation
  - University of Idaho – Geologic modeling and heat flow
  - University of Wyoming – Oil and gas technique/reservoir property estimation
- **Chena Power** – Topside design and integration
- **Geothermal Resources Group** – Drill site operations and drilling engineering
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- **Idaho Geologic Survey** – Geochemical analysis and geologic modeling
- **Idaho National Laboratory** – Consortium lead, operations and outreach, research and development planning, reservoir modeling, and funding opportunity announcement management
- **Lawrence Livermore National Laboratory** – Induced seismicity activities, geologic characterization, modeling, and simulation
- **Mink GeoHydro** – Science Technology and Analysis Team lead, research and development coordination, and stakeholder engagement
- **National Renewable Energy Laboratory** – Data dissemination, operations, and management
- **POWER Engineers –** Topside design activities, outreach, and commercialization
- **United States Geological Survey** – Groundwater characterization and aquifer analysis, as well as shallow well drilling
- **University of Oklahoma –** Rock characterization and testing activities lead and geomechanics
- **University of Utah/Energy and Geoscience Institute** – Geophysical characterization
- **U.S. Geothermal** – Reservoir and well field operations; paths to commercialization.

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EXECUTIVE SUMMARY

The Snake River Geothermal Consortium (SRGC) will provide the United States with the first fully dedicated geological site to develop, test, and accelerate breakthrough science and technology in enhanced geothermal systems (EGS), leading the Frontier Observatory for Research in Geothermal Energy (FORGE) for the U.S. Department of Energy (DOE). The project will support not only advanced research and development (R&D) of EGS technologies and techniques developed by SRGC partners but will also welcome a new, thriving, multi-disciplinary, multi-organizational user community from across the nation and world to test geothermal solutions in real time. The SRGC site, located within the track of the Yellowstone Hotspot, presents an exceptional geological test bed of ideal subsurface temperature and regional stress conditions. Together, detailed site characterization, National Environmental Policy Act permitting, advanced modeling and simulation of reservoir stimulation science, and innovative fracing techniques from oil and gas communities, are poised to accelerate the SRGC FORGE site from preliminary to full site readiness and implementation within 24 months (Phase 2). The project will be ready for its user community by the start of Phase 3 (~January 2019) and aims to be a reproducible EGS model for industry adoption by its conclusion, and a thriving scientific laboratory throughout its existence.

The Idaho National Laboratory (INL), a member of the SRGC and one of the DOE's largest laboratories, has dedicated approximately 110 km^2 (42.6 mi^2) of land to physically host FORGE. Working together since 2012, the SRGC's 19 partners from academia, national laboratories, state governmental agencies, and industry have established a management system and leadership team to realize innovative solutions within an ideal geological testing ground to drive EGS solutions for the nation. ***The overarching vision of the SRGC is to enable geothermal energy of the future by accelerating the commercialization of EGS.***

The FORGE mission, as defined by GTO, is to enable cutting-edge research and drilling and technology testing, as well as to allow scientists to identify a replicable, commercial pathway to EGS. In addition to the FORGE site itself, the FORGE effort will include robust instrumentation, data-collection, and data-dissemination components to capture and share data and activities occurring at FORGE in real time. The innovative research, coupled with an equally innovative collaboration and management platform and focused, intentional communications and outreach, is truly a first-of-its-kind endeavor.

Specifically, the SRGC FORGE team, joined by the oil and gas industry, geothermal specialists, small businesses, and the research community, will focus on:

- Understanding the key mechanisms controlling EGS success
- Adapting oil and gas technologies to initiate and sustain fracture networks in basement rock formations
- Designing and testing a reproducible model for developing large-scale, economically sustainable subsurface heat exchange systems
- Reducing risk to industry for EGS commercialization.

Preliminary R&D activities by SRGC members and FORGE partners will include (1) coordinated characterization efforts (2) geologic and reservoir modeling, (3) utilizing state-of-the-art drilling techniques, (4) innovative well completion and reservoir stimulation activities, (5) well connectivity and flow-testing efforts, and (6) detailed geological, geophysical, and geochemical data collection, mining, and cataloging for users.

User R&D activities will also play a critical role in the development and performance of FORGE, where open solicitations will allow users to test, synthesize, predict, and verify reservoir properties and performance for their own projects but with the results being shared with the broader scientific and engineering community.

The objectives of the SRGC are to:

1. Bring together the best-in-class community and test site to provide the science and engineering required for comprehensive EGS technology development
2. Drive innovation through annual EGS technical meeting followed by roadmapping efforts
3. Leverage innovative, nontraditional stimulation techniques to create a stable fracture network for geothermal energy transfer
4. Use advanced modeling and simulation tools (like Lawrence Livermore National Laboratory's GEOS framework and CAES' CAVE Visualization suite) to optimize reservoir energy output
5. Build and operate the FORGE Laboratory on the Snake River Plain for geothermal research, development, deployment, testing, and validation
6. Educate and inform the public about the promise of geothermal energy in general, and EGS specifically.

To meet its program objectives, the SRGC has developed an aggressive management plan for Phases 2 and 3 of the project complete with a set of detailed project goals. In Phases 2A and 2B, FORGE will achieve compliance with the National Environmental Policy Act; install a preliminary telemetered seismic array; finalize the induced seismicity mitigation plan; perform extensive, initial characterization activities; and update the site geologic model. The initial characterization activities will center on primarily geophysical methods such as gravity, magnetotelluric, and seismic surveys but will include drilling of a geothermal gradient hole and taking measurements in existing wells. In addition to these activities, INL's construction management group and SRGC's cost-share partners will begin the FORGE operations site conceptual design and preparation, which includes surveying, site layout planning, and infrastructure cost estimating. Phase 2C project goals focus on final site preparation and complete site characterization, including site establishment—e.g., constructing the operations pad, installing necessary electrical power, and installing support infrastructure.

The most significant characterization activity for Phase 2 is drilling a "pilot well" for deep characterization of in situ fracture sets, confirming the in situ stress conditions, and collecting rock core. Planned for Phase 2C, the SRGC will use consortium partner Baker Hughes's OnTrak™ integrated measurement-while-drilling and logging-while-drilling systems to document actual well position and collect information on reservoir properties while drilling the pilot well—all in preparation for Phase 3 operations.

Phase 3 R&D goals include continued site characterization, drilling, reservoir creation, and operational optimization. Initially, the Baker Hughes AutoTrak eXpress™ rotary steerable system will be used to sidetrack at least one optimally oriented lateral leg out of the pilot well and drill a second well, allowing for quantitatively testing well completion and stimulation techniques and evaluation of reservation creation methodologies. Additional wells may also be planned, depending on FORGE progress and annual program evaluations. Throughout Phase 3, R&D will transition from characterization and creation to intelligent flow control and heat recovery optimization.

SRGC has set up a flexible but performance-driven management plan to drive innovation through its various research thrust areas. A set of advisory boards oversee, assess, and advise the project against measured metrics for success that match the DOE Geothermal Technologies Office's FORGE project objectives. A team of technical experts (i.e., the Science Technology and Analysis Team) is set up to monitor and evaluate all project goals and redirect technical plans as needed against DOE performance requirements. A conflict resolution protocol is established based on these goals and objectives.

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ACRONYMS

CAES	Center for Advanced Energy Studies
CAVE	computer-assisted virtual environment
CFA	Central Facilities Area
CTC	Celle Technology Center
DOE	U.S. Department of Energy
DOE-ID	U.S. Department of Energy Idaho Operations Office
DOE-NE	U.S. Department of Energy Office of Nuclear Energy
EERE	Office of Energy Efficiency & Renewable Energy
EGS	enhanced geothermal systems
ES&H	environmental, safety, and health
ESRP	Eastern Snake River Plain
FOA	funding opportunity announcement
FOM	field operations manager
FORGE	Frontier Observatory for Research in Geothermal Energy
GRRA	Geothermal Resource Research Area
GTO	Geothermal Technologies Office
HDR	hot dry rock
HFAF	High Explosives Applications Facility
IDWR	Idaho Department Water Resources
INL	Idaho National Laboratory
IP	intellectual property
LLNL	Lawrence Livermore National Laboratory
LMT	leadership and management team
LWD	logging while drilling
MWD	measurement while drilling
NEPA	National Environmental Policy Act
NREL	National Renewable Energy Laboratory
NUSF	Nuclear Science User Facilities
NWTC	National Wind Technology Center
R&D	research and development
RD&D	research, development, and deployment
SME	subject matter expert
SMT	Site Management Team

SRGC	Snake River Geothermal Consortium
STAT	Science Technology Analysis Team
THMC	thermo-hydro-mechanical-chemical
TOP	transition to operations plan
TOT	Technical Oversight Team
TRL	technology readiness level
USGS	United States Geological Survey

Research and Development Implementation Plan

1. INTRODUCTION

This plan provides the approach for effectively managing and coordinating all aspects of testing and evaluating enhanced geothermal systems (EGS) at the Frontier Observatory for Research in Geothermal Energy (FORGE). FORGE marks the U.S. Department of Energy's (DOE's) largest effort to advance the deployment of EGS, which has the potential to tap into a conservatively estimated 100 GW of baseload power-generating capacity by harnessing the earth's heat through engineered geothermal reservoirs. The FORGE project aims to develop methodologies and technologies that will bring this resource into the nation's energy portfolio (Metcalfe, 2015). This project is being performed by the Snake River Geothermal Consortium (SRGC) at the 110-km^2 (42.6-mi^2) Geothermal Resource Research Area (GRRA) on the Idaho National Laboratory (INL) Site.

Located along the track of the Yellowstone Hotspot, the GRRA presents an exceptional and diverse geological testing ground, with ideal subsurface temperatures and regional stress conditions. And the SRGC—composed of 19 partners from academia, national laboratories, state governmental agencies, and industry—is an established management and leadership team that will provide innovative solutions to drive EGS research, development, and deployment. The combination of the GRRA and our deep pool of knowledge and experience in the area of geothermal energy will allow the team to realize the vision of the SRGC: ***Enable the geothermal energy of the future by accelerating the commercialization of EGS.***

Attaining this vision will help the United States to tap the geothermal energy sector's enormous potential to augment the nation's renewable energy portfolio. Although renewable energy sources make up 13% of the nation's overall electricity consumption (EIA, 2016), geothermal energy currently provides only a small fraction (0.4% in 2014) of the nation's electricity generation. And while geothermal energy generation occurs almost exclusively in hydrothermal systems, approximately 90% of the potential geothermal power resource in the United States has been estimated to reside in EGS settings (Phillips et al., 2013). Because EGS requires advancements in technology and in knowledge of deep subsurface systems, a significant investment in research and development (R&D) is required to jump-start the industry. ***The FORGE mission, as defined by the DOE Geothermal Technologies Office (GTO), is to enable cutting-edge research and drilling and technology testing, as well as to allow scientists to identify a replicable, commercial pathway to EGS***.

The SRGC is poised to accomplish the FORGE mission. In the process of doing so, we will capture and share data and information about our activities via robust instrumentation and data-collection and -dissemination components. The SRGC will conduct innovative research coupled with an equally innovative collaboration-and-management platform and focused, intentional communications and outreach.

1.1 Background

INL, an SRGC member, is one of the DOE's largest laboratories (2,300 km^2 [890 mi^2]) and has dedicated approximately 110 km^2 (42.6 mi^2) of land as the GRRA to physically host FORGE. The GRRA is located on Idaho's Eastern Snake River Plain (ESRP) and occupies what deep well data indicate is an area of high subsurface temperature, providing an exceptional test bed for EGS technologies. The GRRA also has abundant groundwater resources and water rights that can be utilized for geothermal R&D.

In addition to its favorable geothermal conditions, INL has a history of nearly 70 years of enabling innovation through large-scale demonstration projects. Working through the INL allows the SRGC to take advantage of INL's established permitting, regulatory, and environmental, safety, and health (ES&H) frameworks to quickly and cost-effectively establish FORGE.

The SRGC was established in 2012. A significant contribution to the SRGC FORGE management team comes from the Center for Advanced Energy Studies (CAES). CAES, located in Idaho Falls, Idaho, is the base of operations for the SRGC and is less than an hour's drive from the proposed FORGE site. CAES is a unique public-private partnership between INL and regional research universities focused on collaboration that inspires innovation, fuels energy transitions, and spurs economic growth for the future. As part of the CAES program, the State of Idaho constructed the 5,119-m^2 (55,000-ft^2) CAES research facility. Managed by SRGC partner Idaho State University, the laboratory and office space at CAES will be available to FORGE, providing a vehicle for FORGE collaboration and hosting visiting scientists and engineers.

1.2 The Research and Development Team

1.2.1 Snake River Geothermal Consortium

The SRGC staff has experience with the entire subsurface energy development cycle, from regulatory compliance and permitting to subsurface characterization, reservoir creation, and geothermal operations. Our members include three DOE national laboratories, six academic institutions, three federal/state agencies, and seven private/industry partners, as identified in Table 1 and shown on Figure 1. The SRGC will continue to identify additional members, as appropriate, specifically focused on augmenting FORGE Phase 2 and 3 needs. National Laboratories

INL leads the SRGC and will host the FORGE laboratory, providing the central physical location for the research. INL is a multi-program Federally Funded Research and Development Center, houses three user facilities, and is accustomed to hosting projects that are similar in scale and complexity to FORGE. Two additional national laboratories, the National Renewable Energy Laboratory (NREL) and Lawrence Livermore National Laboratory, are part of the SRGC and support the full spectrum of R&D for energy technologies.

1.2.2 Universities

Our academic partners, the University of Idaho, Idaho State University, Boise State University, the University of Wyoming, the University of Utah, and the University of Oklahoma, provide research innovation and diversity, and they network to the broader educational functions and outreach that will be instrumental in helping secure the long-term goals for EGS. The University of Oklahoma, the University of Wyoming, and the University of Utah have world-class oil, gas, and geothermal experience, as well as key technology backgrounds that can be migrated to EGS applications.

1.2.3 Industry

Our industry partners, such as Mink GeoHydro, POWER Engineers, and Baker Hughes, bring key perspectives to our research team, with complementary innovation and technologies. Industry provides a context for commercializing the research outcomes and adds impact to FORGE outcomes by building technology transfer into the core of the SRGC. Mink GeoHydro, led by Dr. Roy Mink, brings decades of geothermal- and water-related leadership to the SRGC. The Geothermal Resources Group, a group of well-drilling and completion specialists, provides leadership in well engineering. Baker Hughes, one of the world's largest drilling and reservoir-development service companies, brings worldwide experience from oil and gas industries, as well as geothermal energy sector. POWER Engineers brings its worldwide leadership position in siting and feasibility studies, including topside design expertise, while U.S. Geothermal, Inc. brings real-world geothermal operational expertise. Campbell Scientific, Inc. brings decades of leadership in data-acquisition systems, sensors, and programmable control. Chena Power adds practical application engineering experience.

Table 1. SRGC member institutions.

Team Member	Function
National Laboratories	
INL[a]	Leads SRGC; leads operations and outreach, R&D planning, funding opportunity announcement management, modeling, characterization
Lawrence Livermore National Laboratory[b]	Leads induced seismicity activities; contributes to characterization
National Renewable Energy Laboratory[a]	Leads data dissemination; contributes to operations and management
Academic Institutions	
CAES[a] Boise State University Idaho State University University of Idaho University of Wyoming	Leads characterization, communications, and education Active seismic Geologic mapping and interpretation Geologic modeling and heat flow Oil and gas technique/reservoir property estimation
University of Oklahoma[a]	Leads rock characterization and testing activities; geomechanics, reservoir engineering
University of Utah/Energy and Geoscience Institute[b]	Performs geophysical characterization
Industry Partners	
Baker Hughes[a]	Leads reservoir development activities; contributes to drilling and characterization, modeling, well design
Campbell Scientific Incorporated[b]	Performs data system design and integration
Chena Power[b]	Performs topside design and integration
Geothermal Resources Group[b]	Leads drilling operations and drilling engineering
Mink GeoHydro[a]	Leads the Science Technology Analysis Team, R&D coordination, and stakeholder engagement
POWER Engineers[b]	Leads the topside design activities; contributes to outreach and commercialization
U.S. Geothermal[a]	Conducts reservoir and well field operations; explores paths to commercialization
Federal/State Agencies	
Idaho Department of Water Resources[b]	Provides permitting, insight, and support
Idaho Geologic Survey[b]	Performs geochemistry and geologic modeling
United States Geologic Survey[b]	Performs groundwater characterization and aquifer analysis

a. Leadership team.
b. Teaming partner.

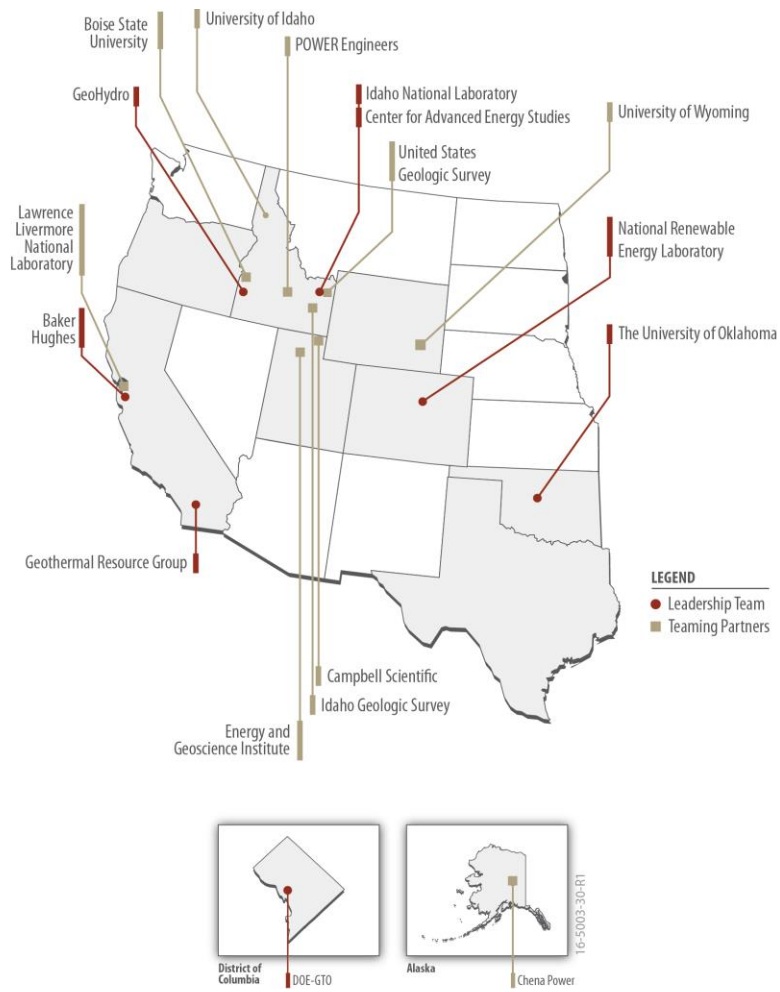

Figure 1. Location of the SRGC members.

1.3 FORGE as a Nucleus for a Regional Clean Energy Innovation Partnership to Enhance National and Global Impact

The SRGC has defined an innovative approach to developing FORGE. Our approach requires (1) industry partners, techno-economic analysts, and development life-cycle experts at the core of a think tank; (2) an R&D team that evolves as needs change; and (3) a flexible, proactive, agile management culture that encourages synergy and cohesion among investigators, infuses the SRGC with a culture of empowered central research management, and fosters free-thinking innovation throughout the EGS spectrum.

The vision for this approach called for a team that could not be found in any single existing institution and drove the creation of SRGC. We believe this approach and our consortium provide an ideal starting point for the development of a regional clean energy innovation partnership, where we create an “ecosystem” at FORGE that accelerates the pace of innovation in EGS and contributes to regional (and national) energy transitions and can enhance U.S. industrial competitiveness. Industry, research institutes, and private companies create a cohesive working arrangement, which provides quality R&D and drives innovation.

Combining the experience of SRGC members, we have defined a method that addresses essential elements for FORGE; these are:

1. Identify the most urgent technology issues and high-risk, high-reward R&D opportunities

2. Assess the complete geothermal development life cycle
3. Select the most appropriate point(s) of intervention, including economic, political, environmental, and market conditions
4. Identify the most direct path to commercialization at the outset.

This plan outlines a conceptual approach to dealing with the numerous factors affecting the development of the FORGE site into a field laboratory that addresses the GTO's research priorities, the needs of the scientific community, and the geothermal industry base. Topics addressed include the GTO vision and requirements; establishment and updating of the state of EGS practice; establishment of a baseline and goals; approach for R&D partnerships; concept of R&D operations; development of site operations; and management of relationships with R&D users.

1.4 SRGC Member Partnering Examples

SRGC members have partnered in numerous collaborative endeavors that have a direct bearing on our unique ability to establish and host FORGE. The following subsections summarize a few examples to further demonstrate our ability to carry out FORGE.

1.4.1 Scientific User Facilities and Collaborative Research Centers

SRGC members operate several national scientific user facilities and research centers, including the National Wind Technology Center (NWTC) at NREL, the Nuclear Science User Facilities (NUSF) at INL, the Biomass Feedstock National User Facility at INL, the National Advanced Biofuels Consortium at NREL, and the High Explosives Applications Facility (HFAF) at Lawrence Livermore National Laboratory (LLNL). SRGC drew upon this broad experience base in formulating our management and operations approach for FORGE.

The NWTC is the nation's premier wind energy technology research facility. The NWTC advances the development of innovative land-based and offshore wind energy technologies through its research and testing facilities. At the NWTC, researchers work side-by-side with industry partners to develop new technologies that can compete in the global market, increase system reliability, and reduce costs. The HFAF is a DOE/National Nuclear Security Administration complex-wide Center of Excellence for high-explosives research and development; it has enabled national leadership in the study of chemical high explosives. Scientists apply expertise in formulation and synthesis, integrating experimental data with computer simulations to understand energetic materials. The NUSF offer unparalleled research opportunities for nuclear energy researchers. Users are provided access to world-class nuclear research facilities at no cost, technical expertise from experienced scientists and engineers, and assistance with experiment design, assembly, safety analysis, and examination. Much like SRGC, the NUSF is a distributed partnership among universities and national laboratories.

It is important to note that establishing FORGE on SRGC's INL site allows us to leverage the INL's collaborative atmosphere, extensive infrastructure, and existing processes of several existing user facilities, easing the path for FORGE establishment.

1.4.2 Scientific and Commercial Modeling, Simulation, and Visualization

Modeling and simulation, as well as scientific visualization, are key components to planning, understanding, and communicating FORGE activities. We will use a combination of advanced oil and gas industry simulation tools, in conjunction with research codes, to drive FORGE planning and to better elucidate EGS behavior. These codes and the infrastructure discussed below offer unmatched interoperability and capacities available for FORGE.

We have used Baker Hughes' JewelSuite™ subsurface modeling software suite to define our geologic and reservoir development workflow. With JewelSuite subsurface modeling, team members from different SRGC organizations were able gain a better understanding of the subsurface to make better decisions on FORGE site placement, reserves estimation, and reservoir planning. The software suite has capabilities for geologic modeling, three-dimensional geomechanical modeling, reservoir engineering, and microseismicity. JewelSuite will be used for operational modeling at FORGE and to archive and share project data.

In addition to JewelSuite, SRGC will use LLNL's GEOS as a collaborative research code. GEOS was the main result of a strategic initiative investment of LLNL and represents the state-of-the-art modeling capabilities for subsurface processes, particularly for EGS. GEOS will enable the development of fit-for-purpose modules tailored for our FORGE site. The goal of the development and application effort is to gain better understanding of subsurface processes and evaluate innovative stimulation methods through advanced numerical simulation. GEOS has also served as the main collaborative simulation platform for a number of cooperative R&D-agreement/work-for-others projects sponsored by major private companies and government regulators in the energy sector, including Baker Hughes, ExxonMobil, Total, Pioneer Natural Resources, and the California Division of Oil, Gas, and Geothermal Resources. GEOS has also been applied in a number of DOE-GTO sponsored research projects.

The CAES computer-assisted virtual environment (CAVE), a three-dimensional immersive visualization suite, will be used to visualize and communicate the results of FORGE for scientific collaboration and discovery, as well as public engagement and education. Results from both can be displayed and manipulated in the CAVE.

1.4.3 Industrial and University Technology Centers

The FORGE team will engage with Baker Hughes's ongoing geothermal technology development at its Celle Technology Center (CTC) in Celle, Germany. CTC is a dedicated facility for research, engineering, and testing of drilling systems, telemetry, and logging-while-drilling (LWD) tools. CTC researchers focus on mechanical and electronic product development and manufacturing technology, modeling and solutions for drilling dynamics solutions, and sensor technology for drilling and evaluation. Innovations developed in CTC include the industry's first steerable motor system, and the AutoTrak™ Rotary Closed Loop System.

The CTC supports joint technology developments with operators and local universities, including R&D capabilities for drilling and production technology for the geothermal industry. A number of European collaborative projects are concentrating on more cost-efficient drilling technology and enhanced electronic submersible pumping systems for geothermal wells. Integral to this research is the Celle high-temperature test loop to perfect new high-horsepower, high-volume ESP system technology for geothermal energy.

The University of Wyoming's WPX Drilling Simulator provides students and educators with a fully visualized and interactive simulation of drilling rigs. The system is used to enable instructors and students from industry and academia to explore, test, and interact with an extensive array of drilling rig components. The lab is used for petroleum engineering and geoscience courses and provides students and industry personnel the opportunity to obtain professional well-control certifications and can be used to communicate lessons learned from FORGE drilling experience.

2. EGS DEVELOPMENT REVIEW

At the heart of the FORGE mission are the development, testing, and acceleration of breakthroughs in EGS technologies and techniques. A number of past and present EGS demonstrations and commercial ventures having varying degrees of success have been explored. To better plan for future EGS testing, a review of the previous attempts and past roadmapping activities is necessary. The sections below summarize some of these activities.

2.1 EGS History and Summary of Lessons Learned

Los Alamos National Laboratory first proposed EGS as a means of recovering heat from hot tight-rock formations in 1970. Field testing for this effort started 1973 at Fenton Hill, New Mexico. As many as 30 significant field-scale EGS tests have been conducted around the world since then.

Initially, research into EGS focused on low-permeability regions along the margins of existing hydrothermal fields. Today, the portfolio of EGS studies and deployment ranges from greenfield hot dry-rock research studies (e.g., Newberry, Oregon) to enhanced production at traditional hydrothermal locations (e.g., Raft River, Idaho). The wide range of geothermal conditions represented by the current projects means a large range of data and lessons learned is available to researchers. Examining the lessons learned will provide invaluable information related to the research and technology needed to bring competitively priced EGS resources to the marketplace to help meet the global energy needs. Appendix A is a summary of the EGS projects and the key lessons learned from each.

The four main EGS issues and the lessons learned about them are summarized below.

2.1.1 Seismicity

With the rise of induced seismicity associated with injection of produced water in the oil and gas industry, seismicity—or the perceived potential of seismicity—may be the most significant issue facing future EGS at any scale. Seismicity that can be felt at the surface is often an obstacle that is difficult or impossible for a project to overcome. Seismicity has caused the failure of several notable EGS projects (e.g., Basel, Switzerland). Microseismicity is a very useful data signal in imaging the stimulated volume of a reservoir and the location of fractures that can be used to connect injectors with producers.

2.1.2 Stimulation

Stimulation methods have had varying degrees of success for EGS projects. In some locations, stimulation can be carried out successfully, but it has failed at other locations. Coupling hydraulic shearing with more advanced oil- and gas-industry stimulation methods, such as hydraulic fracturing, chemical stimulation, acidification, viscous gels, and the use of proppants, seems to increase success. This is especially true in cases where proppants are used. Also, longer-duration thermal stimulation methods have been shown to increase well performance.

2.1.3 Drilling

Without a significant decrease in drilling costs (and risk), geothermal energy production cannot move forward at the scale needed to make a difference in the global energy market. Successful EGS encompasses larger drill holes, directional drilling, and innovative completions to access multiple fracture sets within a single borehole. High-temperature downhole tools are also needed.

2.1.4 Cost

Most companies that are involved in EGS are very small and have little operating capital. As a result, most projects are small, and their applicability to large-scale (>100 MW) development efforts are limited. FORGE research must enable the opening of markets to companies with smaller levels of operating capitol.

2.2 GTO Roadmaps and Reports

EGS programmatic documents provide guidance on what GTO sees as priorities for the FORGE R&D portfolio. However, GTO does not have an active multi-year R&D plan like some of the other entities within the DOE Office of Energy Efficiency & Renewable Energy (EERE), so alternative documents must be consulted. SRGC used the following documents, as well as the lessons learned from previous

EGS studies, as initial guides to develop our vision and approach to FORGE R&D. We will also engage the Science Technology Analysis Team (STAT) to develop our multi-year R&D plans:

- GTO EGS Roadmap (Ziagos et al., 2013). "A Technology Roadmap for Strategic Development of Enhanced Geothermal Systems," Stanford Geothermal Workshop, February 2013 – This paper establishes a roadmap for the EGS program. This roadmap is the source of the "reservoir characterization/creation/operation" topic areas referenced in this plan. General time lines through 2030 are provided, but this roadmap does not go into specifics.
- GTO Hydrothermal Roadmap (Phillips et al., 2013). "A Roadmap for Strategic Development of Geothermal Exploration Technologies," Stanford Geothermal Workshop, February 2013 – This paper establishes a roadmap for the hydrothermal program; however, to the extent that it is focused on technology development, it is relevant in that FORGE might become a test bed for some of these technologies.
- GTO Peer Review Report. This bi-annual report provides reviews of all active projects that GTO is sponsoring. As such, it provides information that can be used to develop a baseline of current research and the state of technology.
- GTO Annual Report. This annual report provides information on new EGS awards and progress on existing awards. As such, it provides the latest information on the GTO portfolio; however, the information is written for the general public and does not contain details.
- JASON Report (Jeanloz, R., et al., 2013). "Enhanced Geothermal Systems," December 2013 – This DOE-commissioned study provides a broad discussion of all factors related to EGS, but included within this discussion is information on technology gaps and opportunities for improvement. This document represents an independent evaluation, so it does not directly reflect the GTO portfolio. It does, however, provide a good starting point for strategic thinking around portfolio development.

We recognize the major commitment that FORGE represents for GTO and that it requires strong efforts in portfolio development and management. Over the course of FORGE, we will work with GTO and the STAT to build upon this base of existing documentation and develop an active multi-year R&D plan similar to those produced by other EERE offices

3. TECHNICAL VISION FOR FORGE

The SRGC has developed a vision for Phase 3 of FORGE that leverages advances made in the oil and gas industry, specifically shale gas development, and brings those advances to the development of geothermal energy. Specifically, we will bring, develop, and refine technologies for applying advanced well technology, horizontal well drilling, and reservoir stimulation—all of which aim to create and access a reservoir of sufficient volume to support commercial flow rates and to create electricity at competitive rates.

In Phase 2C of the FORGE project, we plan to initially drill a vertical pilot well to a depth between 2,500 and 4,000 m (8,200 and 13,100 ft), depending on the final measured geothermal gradient. This pilot well will serve two purposes. The first is to allow for detailed characterization of the entire vertical section at the FORGE site. Drilling a pilot well will allow for deep characterization of in situ fracture sets and determination of the in situ stress conditions, as well as collection of rock core. We intend to test the Baker Hughes OnTrak™ integrated measurement-while-drilling (MWD) and LWD systems to obtain a better understanding of the actual well position and reservoir properties. The second purpose is a cost-saving measure; we plan to sidetrack out of the pilot well at the initiation of Phase 3 using the AutoTrak eXpress system. The AutoTrak eXpress system has continuous-string rotation while eliminating sliding and orienting for extended laterals. A high-power mud motor that increases the rate of penetration by adding revolutions per minute and torque at the bit can also be used.

The SRGC has defined five focus areas that were chosen to allow us to concentrate on important aspects of FORGE creation and operation. These areas align with the key EGS technical needs, so that we strategically advance EGS at FORGE. The focus areas were developed to also align with the functional stages of developing EGS reservoirs described by Ziagos (2013), namely *characterize*, *create*, and *operate*. The focus areas, and the associated lead organizations, are:

- Site characterization (CAES)
- Well drilling and stimulation (Geothermal Resources Group)
- Reservoir development (Baker Hughes)
- Reservoir engineering and control (University of Oklahoma)
- Topside engineering and integration (POWER Engineers).

Figure 2 illustrates the functional stages of EGS reservoir development and SRGC focus areas. Highlighted are selected site characteristics of our proposed ESRP FORGE location. Numerous site characteristics are ideal for developing the FORGE laboratory on the ESRP at INL. Also shown on Figure 2 is transition of focus area involvement with FORGE maturity. Table 2 identifies how the EGS functional stages overlap with the FORGE Phases.

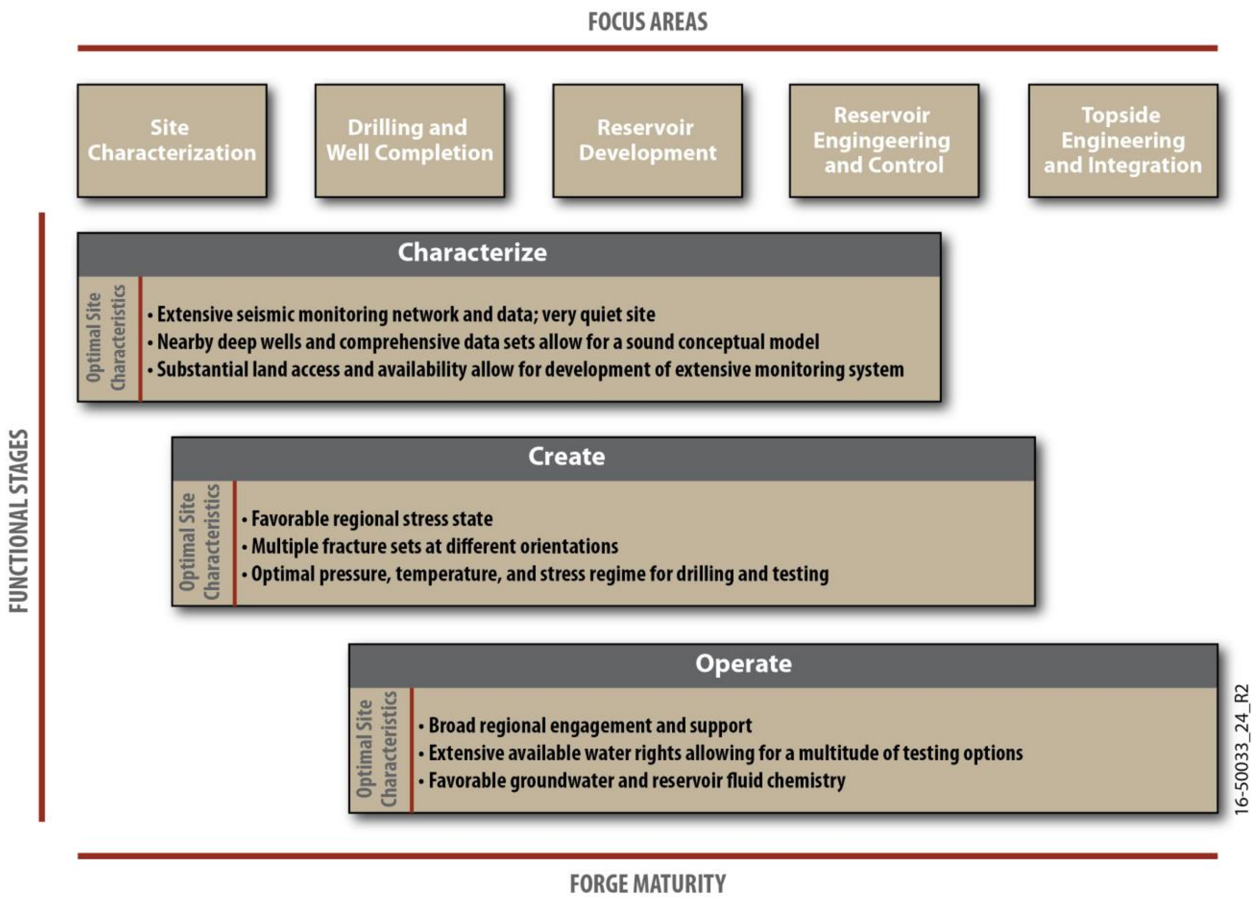

Figure 2. Functional stages of EGS reservoir development, SRGC focus areas, and selected site characteristics of our proposed ESRP FORGE location.

Table 2. Overlap of EGS functional stages with the FORGE phases.

FORGE Phase	EGS Functional Stage (Phillips et al., 2013)	Focus Area Involved	Notes
1	Pre-characterize Characterize	Site characterization is primary; all others contribute.	Pre-characterize is not identified by (Ziagos et al., 2013). Do the planning and preparation for FORGE site establishment.
2A	Characterize	Site characterization and topside engineering are primary; all others contribute.	
2B	Characterize Create	Site characterization and topside engineering are primary; all others contribute.	In this instance, "create" refers to creating the site for FORGE, not creating a reservoir.
2C	Characterize Create	Site characterization, reservoir development, and reservoir engineering are primary; others contribute.	In this instance, "create" refers to creating the site for FORGE, not creating a reservoir.
3	Characterize Create Operate	All focus areas contribute; transition from reservoir development and reservoir engineering to topside engineering as Phase 3 evolves.	At this point, the FORGE site has been "created," and now we focus on reservoir creation.

After site characterization (Phase 2C), we will sidetrack out of the pilot well using the OnTrak™ system, along with Baker Hughes' AutoTrak eXpress™ rotary steerable system. This will allow us to gain positional certainty and steer the sidetracked legs of the well so that they will be either optimally aligned with and in existing fracture systems (for shear stimulation) or in regions with a few fractures and at an orientation that favors tensile failure. Multiple wells and multiple legs are envisioned so that we can quantitatively test well completion and stimulation techniques and stimulate a commercial volume of the subsurface. As Phase 3 of the FORGE project progresses, R&D will transition from the *characterize-create* periods to the *operate* period, during which we intend to demonstrate the **capacity to flow the newly created reservoir and intelligently control it**, optimizing the heat extraction and longevity of the system.

3.1 Well Completion Scenarios

The goal of the well completion tests is to have multiple lateral legs with completion at a depths ranging from 2,400 to 3,800 m (7,900 to 12,500 ft), *each at similar pressure, temperature, and stress conditions*. These legs will be used to test and compare well completion and stimulation technologies currently used in the geothermal and shale-gas industries, ***quantitatively***. The final depth will be determined during Phase 2B characterization efforts.

Having multiple legs or intervals within a single leg available at the same depth allows for detailed comparison of well completion, stimulation techniques, and reservoir management/optimization techniques. Potential lateral legs include:

- Cemented-tubular, perforation-gun or laser, multi-stage reservoir creation via shear failure
- Cemented-tubular, perforation-gun or laser, multi-stage hydraulic fracturing via tensile failure
- Open-hole completion, zonal-isolation, shear stimulation

- Open-hole completion, zonal-isolation, energetic stimulation
- Open-hole completion, zonal-isolation, deflagration stimulation
- Slotted-liner, potential-zonal isolation, multiple stimulation techniques.

3.2 Reservoir Configurations

While our immediate focus for Phases 2A and 2B is on site characterization and R&D plans for Phase 2C, the activities conducted in the first year of Phase 3 will have an impact on the potential work in the following years; therefore, planning for reservoir optimization at the onset is critical. Options for optimization include connecting one well to another, but tensile or sheared fractures between two wells have to date not created enough reservoir volume to be commercially sustainable. A number of additional analyses will be conducted during Phases 2A and 2B—for example, detailed modeling and monitoring of the reservoir creation process and evaluation of the potential for stimulation in one leg to interfere with potential neighboring legs.

3.2.1 The Status Quo and a Modification

The common vision for EGS systems involves a well doublet, in which an injection well is first drilled and then stimulated followed by the drilling of an extraction well into the stimulated zone (Figure 3). Past experience has shown that this approach cannot engineer reservoirs of sufficient size for commercial adoption.

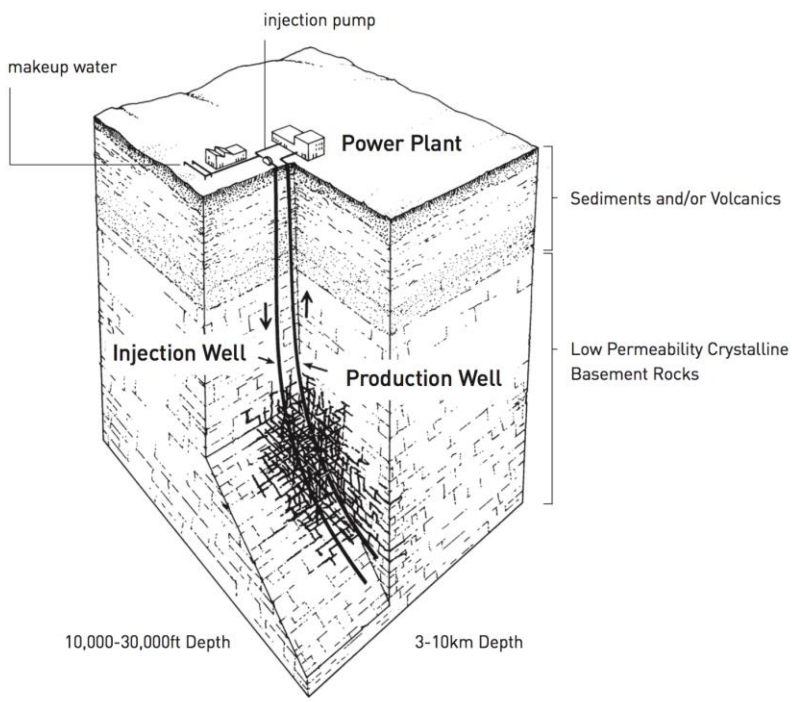

Figure 3. Illustration of EGS doublet; reprinted from (Tester et al., 2006).

As a first step of Phase 3, we plan to evaluate multiple fracture sets so that a larger reservoir can be stimulated using directional drilling and selectively stimulating specific intervals of the injection and production wells.

Well completion and lateral design in the first year of Phase 3 focus on two individual wells, both with (at least partially) cemented tubulars in the lateral legs. The first lateral leg will be sidetracked out of the pilot well for a distance of up to 1,000 m (3,300 ft), with the path determined during Phase 2C, and adjusted on the fly using the LWD and MWD information such that the lateral leg will encounter multiple fracture sets at angles favorable for both shear and tensile failure.

The second well will be drilled after the stimulation of the first well is completed. Once again, we plan for a lateral distance of up to 1,000 m (3,300 ft), with the path determined based on the stimulation results of the first well and the LWD/MWD information. In both wells, stimulation experiments will begin from the toe of the well and progress toward the heel, with initial stimulation efforts concentrated on the 25% of the well closest to the toe, leaving the rest of the lateral leg available for future testing. Designing the lateral legs with cemented tubulars will allow for repeated reentry of the wells and numerous subsurface experiments while minimizing the risk to the well.

An additional lateral leg may be drilled out of the each of the initial two wells, if appropriate, or additional new wells may be drilled in Years 2 and/or 3 of Phase 3 depending on the previous year's results and available funding. Differing completion configurations and additional stimulation methodologies would be the focus, with the final determination coming from funding opportunity announcement (FOA) solicitations or as the results of our detailed planning meetings with the SRGC, STAT, GTO, and the community at large.

3.2.2 Horizontal 5-Spot

Five-spot well patterns are common for optimizing sweep efficiency in oil and gas reservoirs and can potentially be used to incrementally develop EGS reservoirs. Figure 4 illustrates a horizontal 5-spot, in which horizontally or highly deviated wells are individually drilled, as described above. All wells will be stimulated to increase their effective radius. With this configuration, two wells can be drilled and stimulated in the first year of FORGE, with additional wells of the 5-spot being drilled in following years.

Planning a configuration such as this from the beginning will ensure FORGE research and experiments work in an additive fashion. We envision that all well drilling (at least with GTO funding) will be accomplished by Year 3 of Phase 3, which will allow for detailed operational and real-time control experiments in Years 4 and 5.

3.2.3 Forced Gradient EGS

Increasing resonance time in fracture networks can also be accomplished by increasing the flow path length. The forced-gradient EGS concept essentially uses the optimally orientated well described above and uses a second well that originates from the opposite direction and is connected in the subsurface (Figure 5). By plugging the wells at the ends to force flow through the reservoir and matching the regional heat flow and the effective radius and length of the loop, a sustainable reservoir that interrogates a large volume of the subsurface could be produced. Controlling the hydraulic gradient and differential (and absolute) pressures will allow for active manipulation of the fracture apertures and fluid velocities, potentially enabling management of the subsurface like a true-engineered system.

This concept is aspirational and likely cannot be accomplished during Phase 3 of FORGE; it is actively being explored by SRGC/INL Principal Researcher Robert Podgorney, who has filed an INL Invention Disclosure Record (EGS IDR BA-880) as part of a potential post-FORGE role for the site. The SRGC's plans for FORGE after the completion of Phase 3 will be presented in the Phase 2 project management plan.

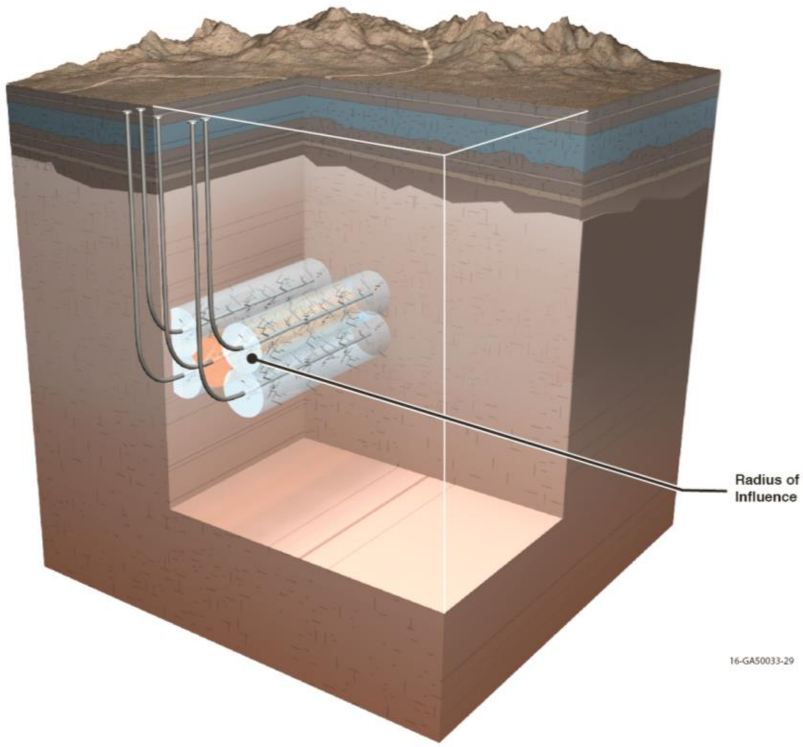

Figure 4. Conceptual illustration of the horizontal 5-spot.

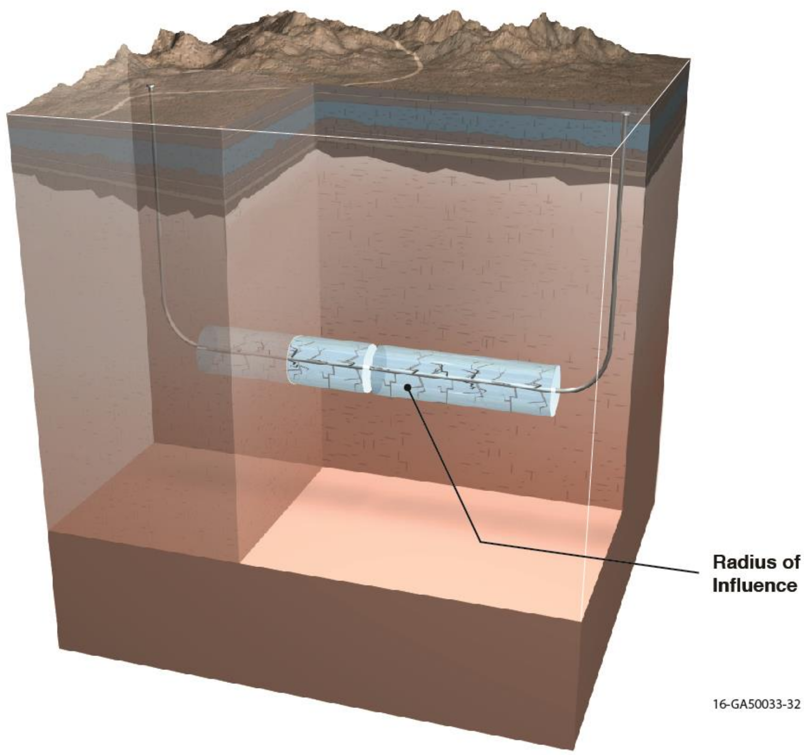

Figure 5. Illustration of forced-gradient EGS concept (EGS IDR BA-880).

3.3 Potential FORGE Experiments

Although the engineering of wells and reservoirs under conditions that are representative for the commercial deployment of EGS will be an important focus for FORGE, this engineering must also enable a much broader range of R&D. The well and reservoir configurations discussed above will enable many experimental investigations to be conducted with a minimum of interference between them. Our approach to FORGE will facilitate and encourage cooperation between the research teams that conduct experiments at their site and support integration of experimental activities with numerical modeling of reservoir performance. The well and reservoir configurations discussed above will allow for additional R&D opportunities, as discussed below.

In any configuration of horizontal wells, control of the flow through the fractures connecting the injection well and the production well(s) will be important in order to avoid "short circuits." Inflatable packers, controllable valves, down-hole pumps, or potentially pressure-sensitive sliding sleeves combined with quasi-continuous temperature and flow monitoring would be required to optimize power generation.

By using multiple wells with a 5-spot previous discussed, or a similar configuration, it will be possible to perform a large number of experiments of various types, **simultaneously**. For example, by starting at the far end (toe) of the horizontal legs, it might be possible to test various hydraulic fracturing and propping technologies by hydraulically fracturing and propping stage by stage while working toward the near end (heel). High-risk experiments will be conducted at the far end of one or more horizontal legs. This will allow any damaged zone resulting from a failed experiment to be isolated. We intend to conduct a detailed evaluation of the required technologies while the scientific tests at FORGE are in progress.

A wide variety of experiments will be solicited and potentially conducted at the FORGE site, with a final test plan developed in conjunction with the STAT and GTO.

Proposed experiments at the FORGE site include:

- Reservoir Stimulation Technologies – As discussed above, we will design our wells so that multiple stimulation experiments can be conducted, including quantitative evaluation of stimulation methodologies. We also have the infrastructure to conduct both short-duration and long-term stimulation experiments.
- Use of Proppants – Our wells will be drilled and designed using standard oil field approaches, allowing for selective emplacement of proppants into limited intervals of the wells.
- Restimulation and Cyclic Stimulation – Leveraging our proposed well design, and having access to a large, low-total-dissolved-solids water, onsite electrical power, and dedicated high-pressure injection pumps will allow for conducting long-term fluid-injection tests, cyclic-restimulation experiments, etc.
- Survivability of Down-Hole Equipment and Measurement/Monitoring Methods – We intend to construct the pilot well such that monitoring equipment can be emplaced in the deepest interval of the vertical portion of the well, below a whipstock, where equipment and sensors can be emplaced for long periods of time and then retrieved for inspection.
- Corrosion and Corrosion Inhibition Testing – We intend to include a side stream in our production piping system such that materials and corrosion tests can be conducted at a multitude of pressures and temperatures. The ability to perform long-term corrosion tests will be an asset for FORGE.
- Chemical Treatments to Improve Fracture Conductivity – Chemical stimulation methods and reservoir treatments have been shown to increase reservoir performance and can be evaluated at the FORGE site.
- Scale Inhibitor Testing (scale inhibition in propped fractures and in the well) – Similar to the chemical treatments and the corrosion testing side-stream capability mentioned above, experiments of scale inhibition in both wells and fractures can be conducted.

- Heat Transfer Fluids – While our original vision for long-term FORGE operations relies on our abundant water resources, the potential exists for testing other working fluids (e.g., CO_2) and additives (e.g., nanoparticles).
- Induced Seismicity Monitoring and Detection – The well field and down-hole signal generators can be used to advance signal-processing methods so that more signal can be obtained from data streams.
- Coupling Reservoir Operations with Numerical Models of Reservoir Performance – In the later years of Phase 3, operation control experiments can be conducted by linking reservoir models, data/monitoring systems, and flow control at the site to conduct optimization experiments.
- CAVE – We will utilize the CAES Advanced Visualization Laboratory to evaluate and optimization proposed field-scale experiments.

The evaluation of proposed onsite experiments will be much more complex than evaluation of experiments at a typical user facility, where experiment evaluation is based primarily on the balance between cost (instrument time, processor hours, beam time, etc.) and the probable value of the results that will be obtained. At FORGE, there is a much higher likelihood that one experiment will negatively impact others being conducted at the same time or in the future. There is also a much higher risk that an experiment will cause damage that is very expensive to repair. Section 6 documents our approach to R&D planning and management.

In addition to the onsite FORGE experiments, the facilities at CAES will be available to the FORGE team and users. These facilities include the CAES Fluids Laboratory and the Microscopy and Characterization Suite. The 370-m^2 (4,000ft^2) Fluids Laboratory is designed to support high-pressure, high-temperature geofluids research experiments. Specific features include a specialized clean cell designed for trace element pre-concentration in aqueous fluids; 8-Parr, 1-L, bench-scale pressure cells; an Agilent 7500 inductively coupled plasma mass spectrometer with a Babington nebulizer and electron multiplier detector; and nuclear magnetic resonance spectrometry (400 MHz and 600 MHz [1H]) broadband instruments for solutions, solids, and microimaging. The Microscopy and Characterization Suite houses equipment for a variety of geologic media characterization, including an environmental scanning electron microscope, atomic force microscopy, and a transmission electron microscope for analysis of structure and mineralogy at the microscale. An additional tool that CAES provides is an advanced CAVE. The CAVE laboratory provides a unique tool to visualize computational remote-sensing models of the FORGE subsurface.

4. PATH TO FORGE ESTABLISHMENT

4.1 Infrastructure Review and Needs

Table 3 provides a preliminary overview the physical infrastructure for FORGE establishment and operations on the INL Site. A detailed site characterization plan is presented in the FORGE *Geologic Conceptual Model* (St. Clair et al., 2016).

We have selected a site for FORGE at INL that simultaneously minimizes risk to establishment and operations while maximizing the use of existing infrastructure. As Table 3 documents, significant infrastructure and support exist at INL that is available to aid FORGE, including easy year-round access provided by the Idaho Department of Transportation, ample area for operations and experiments both on the FORGE site itself and within the GRRA, a large available water right, a United States Geological Survey (USGS) office at INL focused on groundwater resources and well drilling, and dedicated support and emergency services located only 11 km (7 mi) away.

Locating FORGE on DOE property (i.e., the INL Site) also allows for significant leveraging and cooperation with other DOE offices and federal programs. INL is an applied-engineering laboratory focused on energy integration and hybridization. And SRGC's efforts during the past 4 years have been successful in getting senior INL and DOE Idaho Operations Office (DOE-ID) leadership to share the vision for FORGE, which is now seen as an integral part of INL's long-term mission.

Table 3. Infrastructure status.

Infrastructure Type	Status
Road access	Road access will be from U.S. Highway 20/26, approximately 11 km (7 mi) from the INL Central Facilities Area (CFA) and 84 km (52 mi) from Idaho Falls. Approximately 0.4 km (0.25 mi) of gravel road will require improvement. We have an agreement from the Idaho Department of Transportation to supply the materials/road base and some engineering and labor support for this road improvement.
Well/operations pad	An approximately 2-hectare (5-acre) well/operations pad will have to be constructed. We have an agreement from the Idaho Department of Transportation to supply the materials/road base and some engineering and labor support to construct the operations pad.
Electrical power	Commercial electrical transmission lines are available within approximately 150 m (492 ft) at the FORGE site. A small substation will be required to step down the voltage from transmission to distribution levels. Rocky Mountain Power is engaged and on our advisory panel. INL power-distribution lines are also available near the FORGE site and are already at distribution voltages. These lines are approximately 5.6 km (3.5 mi) away and have enough capacity to support FORGE operations. Final selection of the power source will be made as part of the detailed infrastructure assessment in Phase 2 of the FORGE project.
Water supply	A water-supply well is needed onsite for drilling of the deep geothermal test well and for long-term FORGE operations. This well is anticipated to be approximately 190 m (623 ft) deep and drilled using an air-rotary drilling method. A USGS drilling crew is onboard to drill this well. It will fall into the USGS monitoring network once FORGE activities are complete. INL has a large and lightly used water right and has allocated 4.5 cfs for FORGE activities. Additional water is available if needed.
Medical facilities/ emergency response	The FORGE site is located at INL along U.S. Highway 20/26, approximately 11 km (7 mi) from the INL CFA, where fire-station and medical facilities operate 24 hours a day, 7 days a week, offering fire and ambulance services. The ambulance responds to emergencies on the INL Site and on the highway. INL has a good-neighbor agreement with the Butte County Emergency Services as well.
Road maintenance and material handling	INL facilities and services are located 11 km (7 mi) from the FORGE site and will be available to support FORGE needs. Year-round access on this portion of the highway is maintained by the Idaho Department of Transportation.
Site security	The INL Site is protected by a dedicated security force that patrols the interior and outer boundaries of the INL Site on a routine basis, 24 hours a day, 7 days a week. In addition to INL security, the proposed FORGE location is under the protection of the Butte County Sherriff's Department and the Idaho State Police.
Visiting researcher and/or vendor on-boarding	Facilities for visiting scientists and researchers are located at CAES in Idaho Falls, Idaho. CAES facilities are less than an hour's drive (90 km [56 mi]) from the proposed FORGE location and can embrace students and foreign visitors in its 5,110 m^2 (55,000 ft^2) LEED Gold facility with eight research laboratories.

4.2 National Environmental Policy Act and Permitting Activities

Our FORGE project team has held numerous meetings with regulatory and permitting agencies and has an in-house National Environmental Policy Act (NEPA) group that works closely with the DOE-ID. As discussed in the FORGE *Environmental Information Synopsis* (Irving and Podgorney, 2016), DOE requires an environmental assessment for FORGE that will likely take 8 to 10 months spread between Phases 2A and 2B to complete. The environmental assessment will identify permitting requirements related to geothermal well drilling and stimulation activities and will identify other permitting or survey actions, as discussed in the following subsections.

We have established a graded approach to permitting FORGE activities and will use action-specific environmental checklists for evaluating research and characterization activities that need to occur prior to completing the full NEPA analysis, as described in the FORGE *Environmental, Safety, and Health Plan* (Smith et al., 2016).

The following subsections discuss the major surveys and permits that will support the NEPA evaluation and FORGE establishment.

4.2.1 Cultural Resources Surveys

The INL Cultural Resource Management Office maintains detailed records of all cultural resource sites identified on INL land and has developed a statistically based model of prehistoric archaeological sensitivity in unsurveyed areas to facilitate long-term planning for future projects. Initial cultural resource management surveys indicate that much of the proposed FORGE operations area contains no historic or prehistoric archaeological sites, and identification of cultural resources within the area selected for active FORGE construction and operations is unlikely. A field survey of the site will be conducted by qualified archeologist to confirm that the FORGE activities will not impact cultural resources.

Our early consideration of cultural resources in FORGE planning efforts should prevent unresolvable issues related to cultural resources as the project is fully implemented. Potential adverse impacts to any cultural resources that are discovered will be avoided or mitigated primarily by moving the selected location slightly or, if necessary, in consultation with the State Historic Preservation Office and representatives from the Shoshone-Bannock Tribes, in accordance with procedures outlined in the *Idaho National Laboratory Cultural Resource Management Plan* (DOE-ID, 2013).

The Shoshone-Bannock Tribes of the Fort Hall Reservation support FORGE being located at INL.

4.2.2 Flora and Fauna Surveys

The proposed FORGE location is within the INL Site Sage-Grouse Conservation Area but is not a sage-grouse habitat. INL and the U.S. Fish and Wildlife Service have jointly created the *Candidate Conservation Agreement for Greater Sage-Grouse on the Idaho National Laboratory Site* (2014) to manage and guide mitigation of potential issues related to sage-grouse.

Ecology surveys of wildlife and vegetation resources on the INL Site are required prior to any construction activities. These surveys are planned at the appropriate time of year to provide greater certainty in analysis of potential impacts and to minimize the potential for unforeseen problems.

4.2.3 Well Permitting

Several types of well-drilling permits will be required for FORGE. These are described individually below.

4.2.3.1 Groundwater Production Wells

A drilling permit from Idaho Department Water Resources (IDWR) is required before constructing a groundwater production well to meet FORGE water needs. INL has permitted numerous production wells in the past; this is an ordinary part of operations and can be completed without difficulty.

4.2.3.2 Monitoring Wells

In Idaho, drilling permits are required for monitoring wells for both groundwater and seismic stations. INL has negotiated a permitting procedure with the IDWR that allows INL to drill and install wells as needed and without prior notice, permitting wells annually rather than individually. The drilling permit application and applicable fees are submitted by the end of January each year to cover the previous year's drilling and installation. After completing the wells, construction diagrams and well information are submitted to IDWR by the end of June each year.

4.2.3.3 Geothermal Production Wells

By statute, INL is required to submit an application at least 20 days before constructing a geothermal production well. To facilitate EGS well permitting, the SRGC has planned a "permitting roadmap" task for later phases of the FORGE operations and has secured technical participation from IDWR staff as part of the SRGC. During discussions with the IDWR to date, IDWR has encouraged us to plan all FORGE operations into the initial permit application (drilling, injection, tracer testing, stimulation), and IDWR has assured us that the permit can be issued in approximately 90 days.

4.2.3.4 Geothermal Injection Wells

Geothermal injection wells require two permits, one for the geothermal resource and one to inject fluids into the well. The SRGC is required to submit an application to IDWR for each injection well. The IDWR recommends submitting the geothermal permit application and injection well application simultaneously. A public notice will be issued by the IDWR for public comment. The public comment period is a minimum of 30 days. Key environmental non-governmental organizations have been engaged in regard to our activities and have committed their support for FORGE in principle. The Idaho Conservation League, a leading advocate for groundwater and air protection, is represented on our advisory panel. INL has been engaged with the Idaho Conservation League for nearly 4 years regarding geothermal energy and EGS.

4.3 Initial Characterization Needs

Details on the initial characterization needs are presented in the FORGE G*eologic Conceptual Model* (St. Clair et al., 2016), which provides a detailed characterization plan for FORGE Phases 2A, 2B, and 2C. Figure 6 summarizes the Phase 2 characterization plans, as well as activities that will be conducted in preparation for construction of the FORGE site, as discussed in Section 4.4.

Our characterization approach is to analyze direct and indirect indicators of the geologic regime and the drilling environment to ascertain the suitability of the GRRA for EGS. Our workflow is driven by the FORGE schedule, which as summarized on Figure 6 and provides an outline of escalating levels of field activities over the course of the project.

We will use state-of-the-art methods for geophysical imaging during Phase 2B coupled with data integration and modeling. The Phase 2B results will be used to optimize well design for Phase 2C, which will include the drilling of two wells.

Our EGS target is a large volume of intra- or inter-caldera rhyolite deposits similar to what was encountered near the bottom of wells INEL-1 or WO-2, as described in the FORGE *Geologic Conceptual Model* (St. Clair, 2016). This large volume must be at a temperature between 175 and 225°C (347 and 437°F) at a depth of less than 4 km (13,100 ft). Characterization efforts will focus on addressing the greatest risks posed by the uncertainties in the subsurface geology.

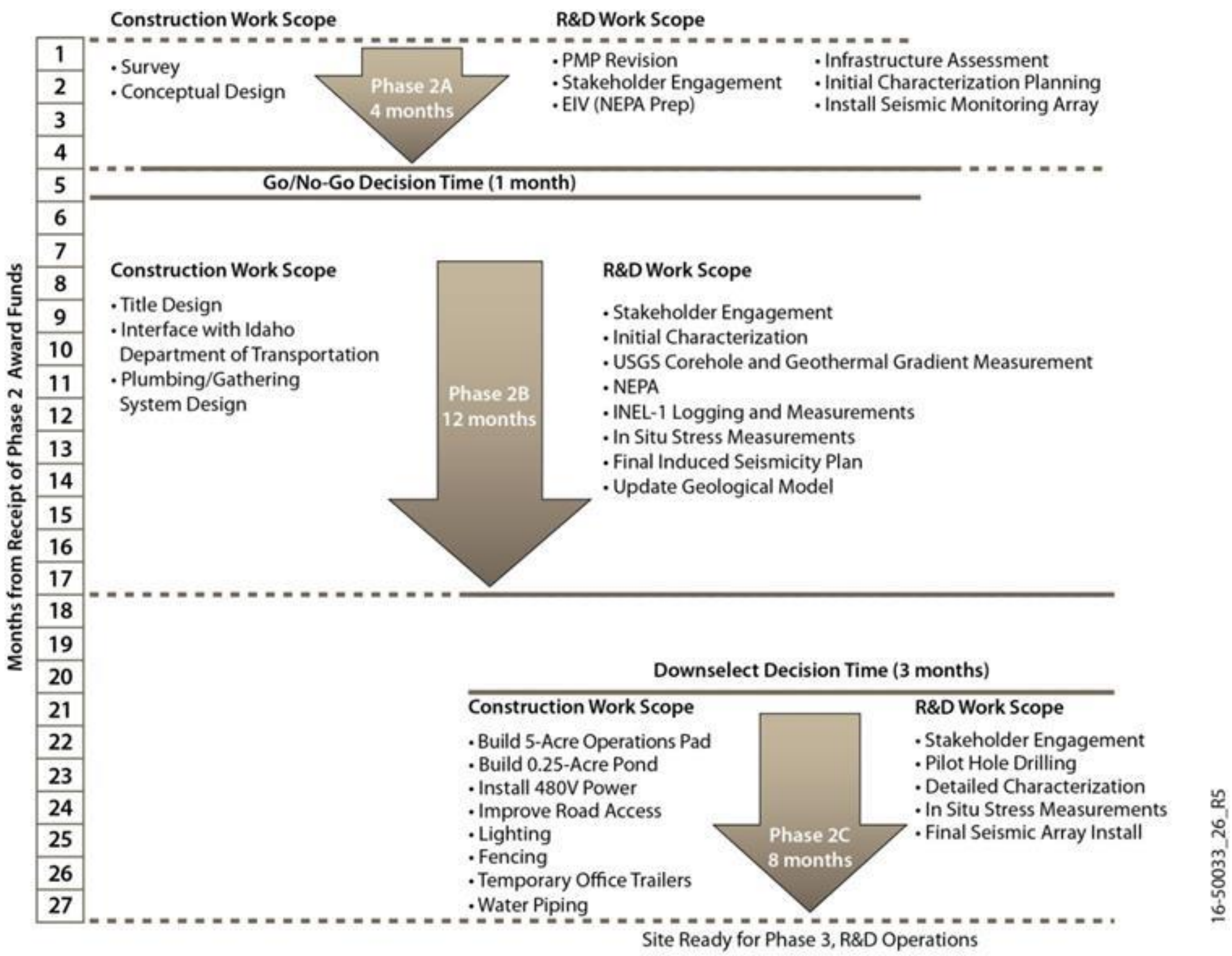

Figure 6. R&D and construction work breakdown for Phase 2.

4.4 Construction Activities and Construction Management

INL has dedicated engineering, project-management, and construction-management groups responsible for designing and managing construction activities on the INL Site. Construction of key FORGE site infrastructure, such as the access road, well/operations pad, water storage pond, piping, and electrical power, will be managed by INL's construction management office. Design of these infrastructure elements will be shared between the SRCG, our cost-share and community partners, and the INL construction design team.

Preparation for the construction aspects of the FORGE laboratory are part of Phase 2A (conceptual design). This conceptual design will be closely coordinated with the infrastructure assessment and will allow for detailed cost planning for establishing FORGE. One component of the conceptual design is a conceptual layout of the proposed FORGE site (shown on Figure 7). This layout is configured for the early stages of FORGE operations, primarily the initial drilling activities. Accommodating a 23-m (75-ft) safety setback from operational activities and all necessary equipment requires the operations pad to be approximately 2 hectares (5 acres) in size, with dimensions of 144.8 × 144.8 m (475 × 475 ft). Not included in this acreage is the land used for temporary office trailers, onsite equipment/material storage, and a water storage pond.

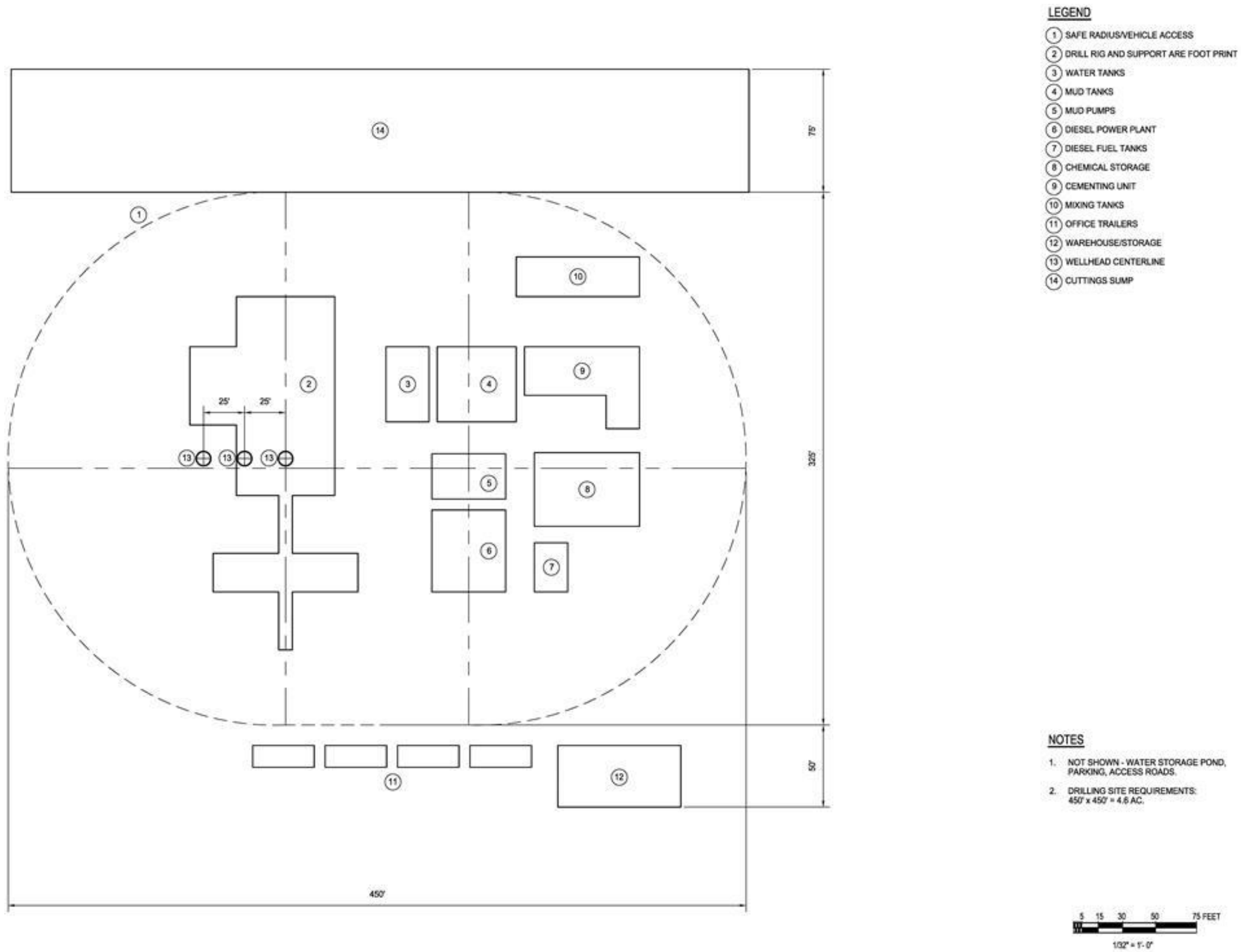

Figure 7. Site layout drawing of the proposed FORGE operations pad.

In Phase 2A, we will survey the site so that detailed material and time estimates can be developed; this will support formal title designs that will be prepared in Phase 2B. The title design will allow for the preparation of bid packages for the major earth-moving aspects and supporting services, such as power interconnects, plumbing/gathering systems, and fire prevention.

Actual construction activities will take place in Phase 2C. Once these initial site-establishment activities are complete, the site will transition from a construction site to a research laboratory.

4.5 Transition from Construction to R&D Operational Status

Portions of the initial phases of the FORGE project will be managed as a construction project, including establishing an operating pad, installing power, and providing all support structures. Once this is completed, the project will transition fully to R&D operations. The process for transferring responsibility of FORGE from construction to operations will follow standard INL procedures. Planning for the turnover is initially defined here but will be more detailed during Phase 2C. The detailed turnover plan will be documented in a transition to operations plan (TOP).

Project turnover planning will be developed in cooperation with the research/operations team and construction management, allowing for a complete integrated project team approval for turnover and acceptance activities. The TOP will:

- Identify and plan for project transition-phase activities roles and responsibilities
- Include the key performance parameters that are defined based on functional and operational requirements
- Define an efficient and effective management process for transitioning scope, aligning schedules, identifying resources required to facilitate project transition, and providing proper customer/sponsor/stakeholder interfaces
- Identify the transition team members so they can be assembled to perform overviews of construction component testing to be done by the subcontractors and perform the checkouts and testing as part of acceptance for turnover to operations
- Ensure testing follows appropriate procedures based on results of the hazard analysis (discussed further in the FORGE *Environmental, Safety, and Health Plan* [Smith et al. 2016]).

A punch list will be used to record visual inspection results, verify deficiencies are recorded, track deficiencies to correction, and ensure conditions are acceptable for construction to proceed. The list will start as construction begins, will proceed through the final transfer of the system to research/operations, and will be used as a final checklist for project turnover. Any project team member can perform the visual inspection and report the findings to construction management personnel on the project who are responsible for keeping the punch list. Specific steps for turnover once construction is complete include:

- Obtaining final approval of the TOP from construction and research/operations
- Revising the ES&H plan
- Generating as-built drawings
- Correcting major deficiencies identified in the punch list (must be completed before turnover)
- Correcting minor deficiencies identified in the punch list (may be completed after a partial turnover)
- Completing the required operational testing (systems operability of pumps, valves, etc., as necessary) and verifying key performance parameters have been achieved
- Correcting any deficiencies identified during initial testing
- Verifying the contractor has completed all contractual requirements (i.e., all items on the punch list have been resolved)

- Completing the final transfer checklist and routing it for signature
- Completing final administrative and financial tasks, generating lessons learned, and preparing a final construction project closeout report.

4.6 Interface with INL Support and Emergency Services

All work conducted at the FORGE site will be coordinated with INL operations. The FORGE field operations manager (FOM) will notify INL operational control staff on a daily basis when active operations will be occurring at the FORGE site. The FOM will be the main point of contact for all FORGE users and researchers and will coordinate FORGE activities and make any and all necessary notifications to INL operations control staff.

Contractual and environmental compliance for FORGE activities will be managed and overseen by the FOM working with the INL operations support staff, and activities performed elsewhere will be the responsibility of the host institution(s). The SRGC will enforce a work plan review and approval, known as a "readiness review," before funds are released or work starts, regardless of where the work occurs. The readiness review will be based on the Integrated Safety Management System program used at INL.

4.6.1 Support for Phase 2 Construction or R&D Work Scope and Phase 3 Operations

INL possesses an extensive suite of support organizations available to provide technical staff and subject matter expert (SME) support to FORGE Phase 2 construction planning and R&D work scope activities in addition to Phase 3 R&D operations alike. Available on an as-needed basis, INL support services organizations can provide expertise in areas that include:

- Mechanical, electrical, chemical, and civil engineering design and analysis
- Electrical and mechanical construction workers
- Electromechanical and instrumentation and controls
- ASME code-compliant, high-pressure systems/pressure vessels
- Subcontractor field work management
- Industrial safety
- Industrial hygiene
- Cultural resources management
- NEPA compliance
- Multi-media permitting – air, water, soil
- Waste management
- Emergency response – first responders and communications
- Personnel security.

Additional services are detailed in the FORGE *Environmental, Safety, and Health Plan* (Smith et al., 2016).

Involvement with or support from the above organizations and individuals would normally be at the request of the FORGE operations manager in consultation with the SRGC director. The need for such support may be identified by the FORGE operations manager, FOM, field team leaders, the FORGE user community, or other individuals involved with planning and conducting work at the FORGE field site or CAES laboratories. INL SMEs and related support services technical peers are, to a large extent, funded by INL's indirect funding mechanism to support projects and programs such as FORGE at little, if any, expense to the project. If the level of effort for a given support function becomes extensive, very simple processes, such as the Task Baseline Agreement, are in place whereby FORGE can quickly purchase an agreed upon service for a fixed, competitive price. The breadth of the INL's support services that are available, combined with competitive pricing and ease of securing these services, ensures that FORGE technical needs are covered quickly and efficiently.

4.6.2 Emergency Services

As discussed in the FORGE *Environmental, Safety, and Health Plan* (Smith et al., 2016), INL has established procedures for conducting field work on the INL Site. These procedures address approval for field access, needs for equipment and communications, and responsibilities of participating personnel. FORGE users who will be working in the field will be trained to the relevant work planned and briefed such that they are aware of their ability and responsibility to use the INL Warning Communications Center in certain situations. The INL Warning Communications Center provides a single point of contact for collection and dissemination of emergency and nonemergency information and provides communications services to the DOE-ID and INL contractors. In the event of an impending emergency that may dictate evacuation of the FORGE site, the FOM would call the FORGE operations manager and/or other onsite personnel to provide evacuation guidance.

5. SCIENCE TECHNOLOGY ANALYSIS TEAM

The STAT is a key organization within the FORGE Site Management Team (SMT). SRGC intends to use the STAT to inject technical innovation into FORGE planning and operations. The STAT's technical experts track and assess integration of science and innovation across all FORGE focus areas. The STAT tracks progress to ensure the technologies meet the overall project performance deliverables. STAT will be a key organization within the SMT and will have primary involvement with the development and management of the FORGE R&D portfolio. STAT represents the strategic level of planning for FORGE activities, and it will be the organization where the collective views of SRGC, DOE, academia, and industry are discussed.

In addition to technical planning activities performed by the STAT, SRGC will establish processes and procedures for ensuring DOE participation in decision-making. SRGC will establish regular meetings with GTO management; the regular participants in these meetings will be the SRGC director, deputy director, and chief scientist, with others included as required. Figure 8 shows how STAT and DOE are integrated into the SMT and how coordination between the SRGC technical and operations teams and the STAT will be accomplished for long-term FORGE planning.

Table 4 shows the potential technical makeup of the STAT. The STAT will be chaired by the SRGC chief scientist, Roy Mink, with NREL's Chad Augustine acting as the STAT coordinator.

5.1 Preliminary STAT Charter

The STAT is as an independent oversight and leadership body formed to ensure that FORGE is performing its intended R&D mission. The STAT contributes to the planning and vision of FORGE research and reviews the quality and the timeliness of the research and programs conducted at the FORGE laboratory. STAT also advises the SRGC SMT and GTO management on the performance of FORGE in meeting EERE's objectives.

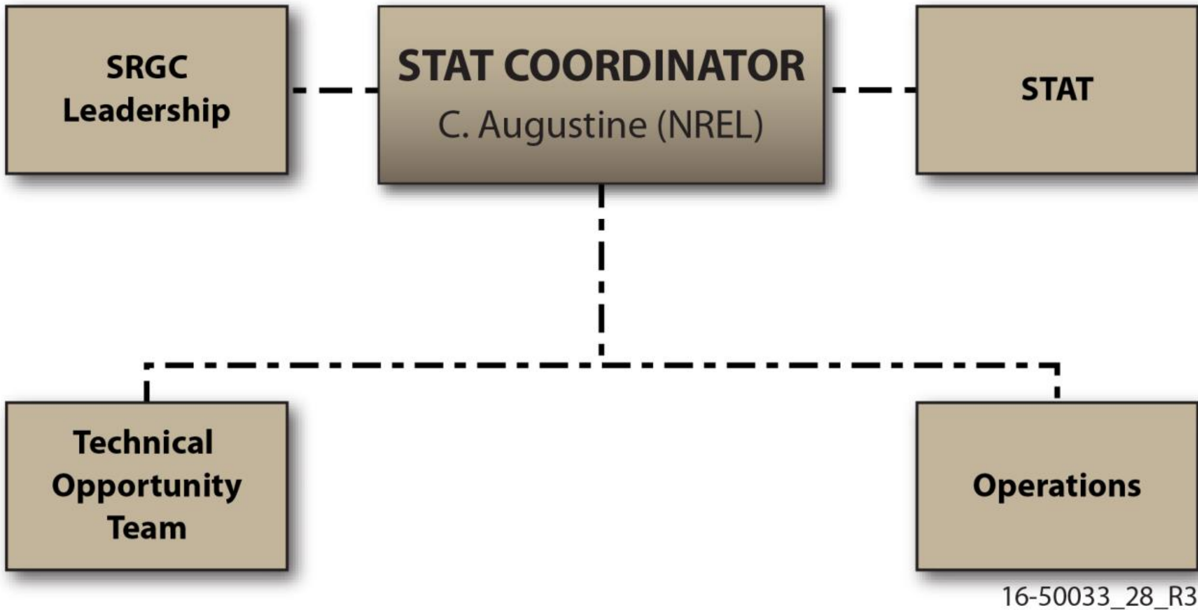

Figure 8. SMT-STAT integration and long-term technical planning organization chart.

Table 4. Potential STAT makeup and members.

Individual	Role or Justification
Chad Augustine	Coordinator, not a voting member (NREL)
Roy Mink	Chair and lead of the STAT (Mink Geohydro)
Keith Evens	EGS expert (ETH-Zurich)
Mark Grublich	Energetic stimulation expert (Sandia National Laboratory)
Norm Warpinski	Oil and gas service industry reservoir-development SME (Pinnacle)
Joe Moore	Sustainability and geochemistry expert (Energy and Geoscience Institute, University of Utah)
Jeff Tester	Innovation injector and EGS SME (Cornell University)
GEA or GRC rep	Industry needs and goals
Klaus Regenauer-Lieb	Innovation injector (University of New South Wales)
Peter Meier	Industry lessons learned and technology transfer (Geo Energie Suisse)
Neil Snyder	SRGC representative (NREL)
DOE assignee	
DOE assignee	
DOE assignee	
DOE assignee	

The STAT:

- Advises on the strategic objectives for FORGE in concert with the needs of DOE and other scientific and industry users
- Verifies that the scientific and technical objectives of FORGE are being met and makes recommendations regarding additional experimental capabilities that could be added to increase the value of FORGE to the research community
- Provides periodic updates to the INL deputy laboratory director for Science and Technology as well as EERE management
- Provides an annual report to SRGC and GTO on the impact of the experimentation performed at FORGE and the effectiveness of FORGE operations.

The STAT will not have direct oversight responsibility for specific FORGE projects or programs or for day-to-day operations of FORGE, since SRGC and/or INL are responsible for elements such as subcontract management and ES&H. However, the STAT may make recommendations that could fall under the responsibility of the SRGC to implement.

5.2 Appointment of STAT Members and STAT Composition

The SRGC leadership team and GTO appoint members of the STAT. Senior industry representatives, university professors, and representatives of EERE and other organizations with a stake in geothermal industry science and technology serve on the STAT. Members are appointed as individuals for their expertise rather than in a representative capacity.

The STAT consists of 14 members and a non-voting coordinator. Members will be selected to ensure that the STAT has expertise in:

1. U.S. DOE GTO goals and objectives
2. Geothermal industry science and technology needs
3. U.S. geothermal industry economic and market demands
4. International perspectives on geothermal development
5. All facets of geothermal science, engineering, and technology disciplines
6. Areas outside traditional geothermal realms.

Each member will serve a minimum 2-year term. Initial appointments will be staggered over 2- and 3-year terms to establish a natural rotation among the members as the nature of FORGE evolves. The STAT will be composed of people primarily from outside the SRGC. These members represent all the technical members of the SMT, and, as a result, all STAT and SMT activities will be fully integrated. GTO will provide four (or more) STAT members. Because development of geothermal technologies is an international effort, special emphasis will be placed on recruiting international members who can offer different perspectives and current knowledge on the state of the geothermal industry. An extensive web-based communications system will enable most STAT activities to be performed virtually.

The STAT will be formed at the beginning of Phase 2C.

5.3 STAT Schedule, Meetings, and Report

The STAT will meet in person a minimum of once per year at CAES in conjunction with the annual Snake River Geothermal Workshop and in a virtual environment at least monthly. The annual Snake River Geothermal Workshop will be modeled after the Gordon Research Conference series, where week-long meetings will be used to present the current state of FORGE and other active EGS operations and to identify additional follow-on research topics.

The STAT will be invited to the meeting and work with the SMT to develop a consensus for the following year's R&D activities based on the information discussed and presented. For the purposes of holding a meeting of the STAT, a quorum shall exist when a minimum of 10 members are in attendance. The purposes of the onsite meetings are to review progress, give feedback to the SRGC leadership, and form the vision for the following year's research and FOA. Special meetings may be called to address critical, time-sensitive operational issues that arise during field operations.

A report of the meeting will be provided to the SMT and GTO within 4 weeks. The STAT's annual report will be included in the SRGC annual project reports and posted on the SRGC website (snakerivergeothermal.org).

6. APPROACH TO RESEARCH AND DEVELOPMENT MANAGEMENT

The SRGC has established an optimal organizational structure that will facilitate the performance of tasks and achievement of the objectives described in the FORGE *Statement of Work* (Shelton-Davis et al., 2016) within the timeframe specified, ensuring a cost-effective and timely establishment of FORGE while leveraging leading experts and visionaries into the STAT to drive EGS innovation.

Drawing upon the experience of SRGC members' efforts in operating user facilities and advancing technologies, we have defined a management approach that addresses essential elements for FORGE, which include:

1. Identify the most urgent technology issues and high-risk, high-reward R&D opportunities
2. Assess the complete geothermal development life cycle
3. Select the most appropriate point(s) of intervention, including economic, political, environmental, and market conditions
4. Identify the most direct path to commercialization at the outset.

This R&D-through-commercialization concept requires the SRGC to have the best-in-class research capability with the flexibility to meet and solve complex challenges; industry partners willing to become involved and work as a team; and flexible, proactive management to encourage synergy, cohesion, and free thinking within the team. Use of a portfolio planning approach that is based on an end-state of technology commercialization is critical, because this approach will tend to expose technology gaps that FORGE will need to address through annual FOA solicitations.

The following sections show how we plan to drive technical and managerial innovation; deliver effective site management and operations; and communicate among ourselves and with the geothermal community, the DOE, and the public at large.

The application of technology readiness levels (TRLs) will be more dominant as the project moves from the early stage research to the late operational stages of Phase 3. Activities will become more mature and TRLs more rigorous to ensure success during Phase 3. Based on our experience using the performance science approach, we anticipate that the typical TRLs of the FORGE project will increase as the R&D program moves technologies toward commercialization.

6.1 SRGC Structure for R&D Management

The SRGC organization is designed to support and enable a robust R&D enterprise for FORGE users by having a solid internal base of technical expertise coupled with extensive operational support and the communications infrastructure to broadcast FORGE successes. The SRGC views the FORGE project as the central element of GTO's EGS strategy for the next decade, and, as such, activities at the FORGE site will be closely coupled with GTO priorities.

We have defined the formation and role of the STAT and how it becomes the foundation for R&D innovation. However, in order for SRGC members and the STAT to work effectively on the more strategic elements of R&D management, it will be necessary for them to maintain continual awareness of the state of technology, research needs, technology gaps, and nontechnical externalities that might affect a developing EGS industry. The SRGC will enable this awareness by collecting, archiving, and linking relevant information on our website (snakerivergeothermal.org) and through our workshops and regular meetings. SRGC STAT members will be responsible for monitoring this website and keeping themselves current with the latest information at all times.

Our top-level structure is shown on Figure 9. The sections that follow describe the key leadership and operational structure we propose for FORGE. At the highest level, the SMT has the ultimate responsibility for the success of FORGE. We have defined three key teams to support the SMT in this mission: (1) the Outreach Team, 2) the Operations Team, and 3) The Technical Opportunity Team (TOT). Each team is described below.

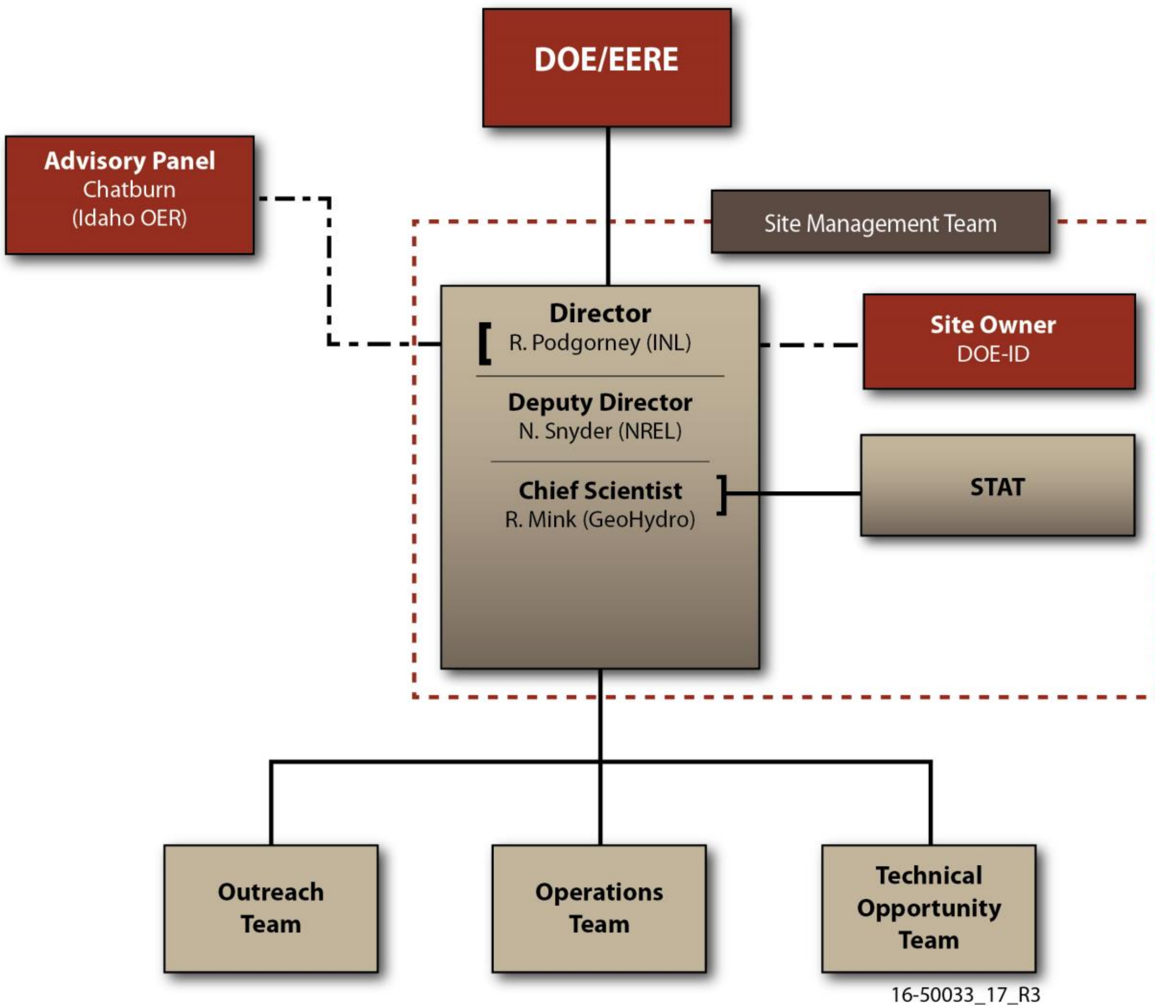

Figure 9. Leadership and operational areas organization chart.

6.1.1 Site Management Team

The SMT is composed of the SRGC leadership and management team (LMT), which is composed of the SRGC director, deputy director, and chief scientist; the site owner (i.e., a DOE-ID representative); and the

STAT. The SMT, in coordination with GTO leadership, will provide the final guidance and direction for FORGE. The SMT ensures the consideration of all aspects of the SRGC, EERE, and GTO's broad range of activities and goals in its decision-making processes. A significant feature of the SMT is its combination of its members' scientific, engineering, economic, educational, and managerial credentials.

Dr. Robert Podgorney, the SRGC director, principle researcher, and an employee of the lead organization (INL), leads the SMT and has full authority and accountability for all aspects of FORGE operations. He has significant administrative, educational, and leadership experience combined with broad scientific credentials and experience in policy matters. The director coordinates the establishment of connections, collaborations, and communication across SRGC and monitors the integrative activities, and he leads the Outreach Team.

The SRGC deputy director, Neil Snyder, assists the director and assumes the director's duties and responsibilities during the director's absence; the deputy director also leads the Operations Team for SRGC. The deputy director has technical and management skills that are complementary to those of the director and has 9 years of experience supporting multiple EERE programs in managing its technical portfolios.

Dr. Roy Mink is the SRGC chief scientist and is an established authority in the technical subject matter of the SRGC. He provides expert guidance on its research projects and overall technical program, and he supports the director and deputy director in any tasks required. The chief scientist will also interact closely with the STAT.

The role of the SGRC will change as each phase of FORGE progresses. Phase 1 has been a paper exercise only, Phase 2 will begin the transition to field work for data-collection and site development, and Phase 3 will be fully focused on R&D activities and supporting operations.

The SRGC will be responsible for developing procedures that ensure DOE participation in the decision process and include regular status meetings with GTO management. The SRGC will coordinate with other federally funded projects related to subsurface research to prevent overlap and duplication while promoting collaborative R&D that could benefit FORGE.

6.1.2 Technical Opportunity Team

The TOT will be chaired by SRGC scientist Travis McLing and composed of representatives from all of the FORGE focus areas. These members represent all of the technical activities of FORGE, and, as a result, all technical and operational activities will be fully integrated. Figure 10 shows the organization of the TOT and SRGC focus areas.

The role of the TOT is to coordinate SRGC technical planning and execution efforts and evaluate all technical activities planned or proposed for FORGE from entities both inside and outside the SRGC. The TOT chair has the authority to call others, such as operations, finance, education, outreach, and environmental personnel, into the decision process to address the nontechnical issues of proposed research and ensure the activity is meeting the overall goals of FORGE.

A process will be established for using world-class researchers to assist in the evaluation of research being conducted or evaluation of activities being proposed by either internal or external researchers. Peer evaluations developed under this process will be forwarded to the TOT for review and recommendation, and the TOT will then make recommendations to the SRGC director and chief scientist.

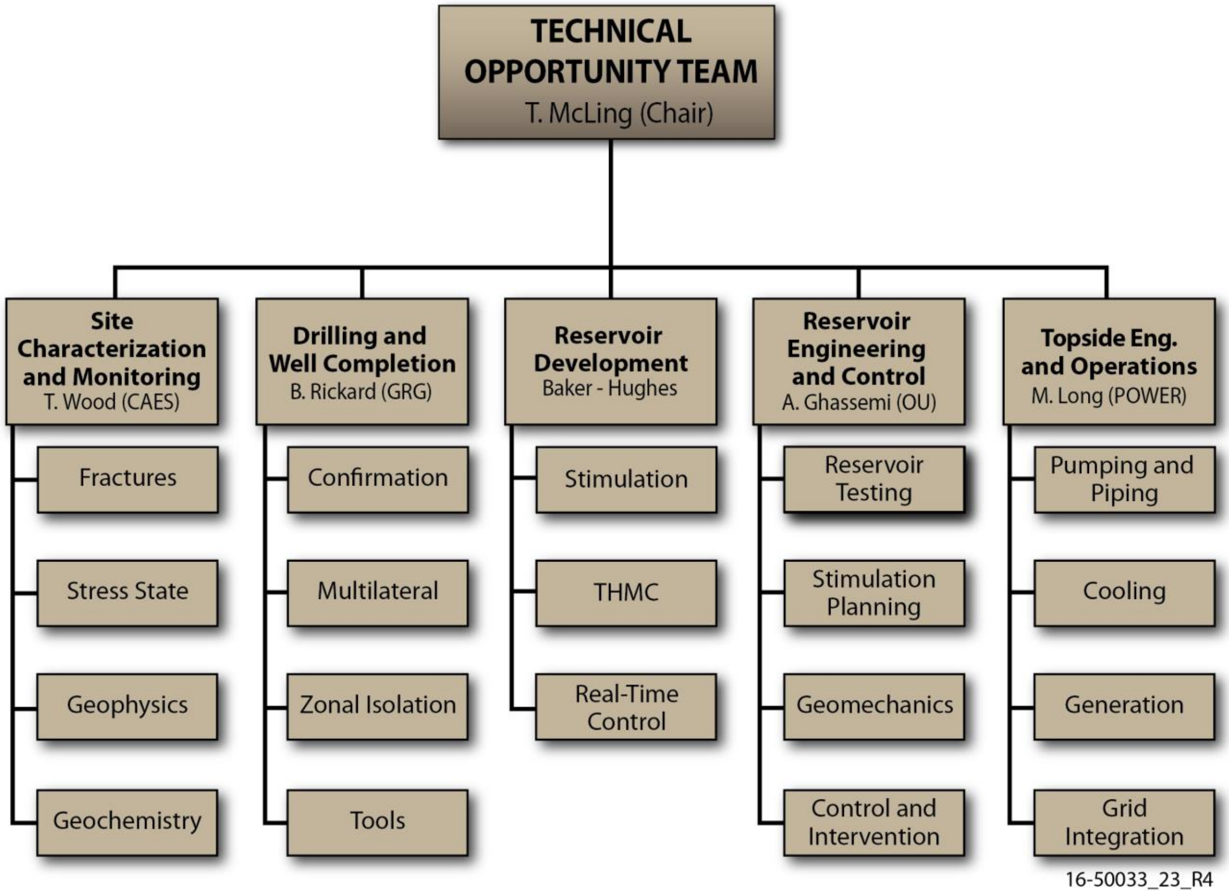

Figure 10. TOT and focus areas organization chart. Note that the boxes under each focus area represent functional areas, where SRGC expects collaboration with FORGE users and SRGC members.

Focus area leads have the responsibility of leading research in their focus area and for integration across the SRGC. They will lead the scientific and engineering areas of the SRGC, manage its scientific priorities, and serve on the TOT. The focus area leads are co-responsible with the SRGC director and chief scientist for integrating activities vertically and horizontally across the SRGC.

Table 5 identifies the focus area leads associated with each focus area and their affiliation.

Table 5. Focus areas, the respective lead of the area, and their affiliation.

Focus Area	Lead	Affiliation
Characterization	Tom Wood	CAES
Drilling the well design	William Rickard	GRG
Reservoir creation and development	Colleen Barton	Baker Hughes
Reservoir engineering	Ahmad Ghassemi	University of Oklahoma
Topside engineering	Mike Long	POWER Engineers

6.1.3 Operations Team

The Operations Team will be led by the SRGC deputy director. He will be responsible for overseeing the operational management of SRGC, including coordination of financial and project management, reporting, field operations, data dissemination, R&D solicitations, quality assurance/quality control, training, and integrated safety and security management. The Operations Team lead is accountable to the director for effective support to ensure the science and engineering teams can focus on critical outcomes from DOE's investment. Figure 11 shows the Operations Team organization.

The FORGE FOM (Paul Smith) will be responsible for ES&H and coordination of all FORGE operational activities. The FOM approves and monitors execution of research safety plans for all FORGE site activities and assesses subcontractor financial and operations performance; additional details are provided in the FORGE *Environmental, Safety, and Health Plan* (Smith et al., 2016).

The project manager (Colleen Shelton-Davis) is responsible for reporting on programmatic and financial status and subcontracting through procurement for construction or operations. She works closely with the finance representative (Marcia Lindsay) to develop budgets, schedules, and financial status.

The Data Management Team will be led by Jon Weers, the SRGC chief data officer, and will include the chief scientist, a data curator (to be hired), information technology professional (NREL staff), and the focus area leads. The primary objective of the Data Management Team will be to establish and maintain a robust data system enabled by the real-time data servers and a dedicated National Geothermal Data System hub. See the FORGE *Data Dissemination and Intellectual Property Plan* (Weers and Podgorney, 2016) for more details.

The lead of the INL Innovative Nuclear Energy Office (Greg Bala) will act as the FORGE R&D solicitation team lead. Planning for needed research, development, and deployment in Phase 3 will take place through a cooperative process involving the SMT, STAT, and EERE-GTO leadership. Once the research topics are identified and agreed upon, this independent, "firewalled" management group at INL will handle the solicitation in order to avoid any perceived or real conflicts of interest in awarding competitive funding.

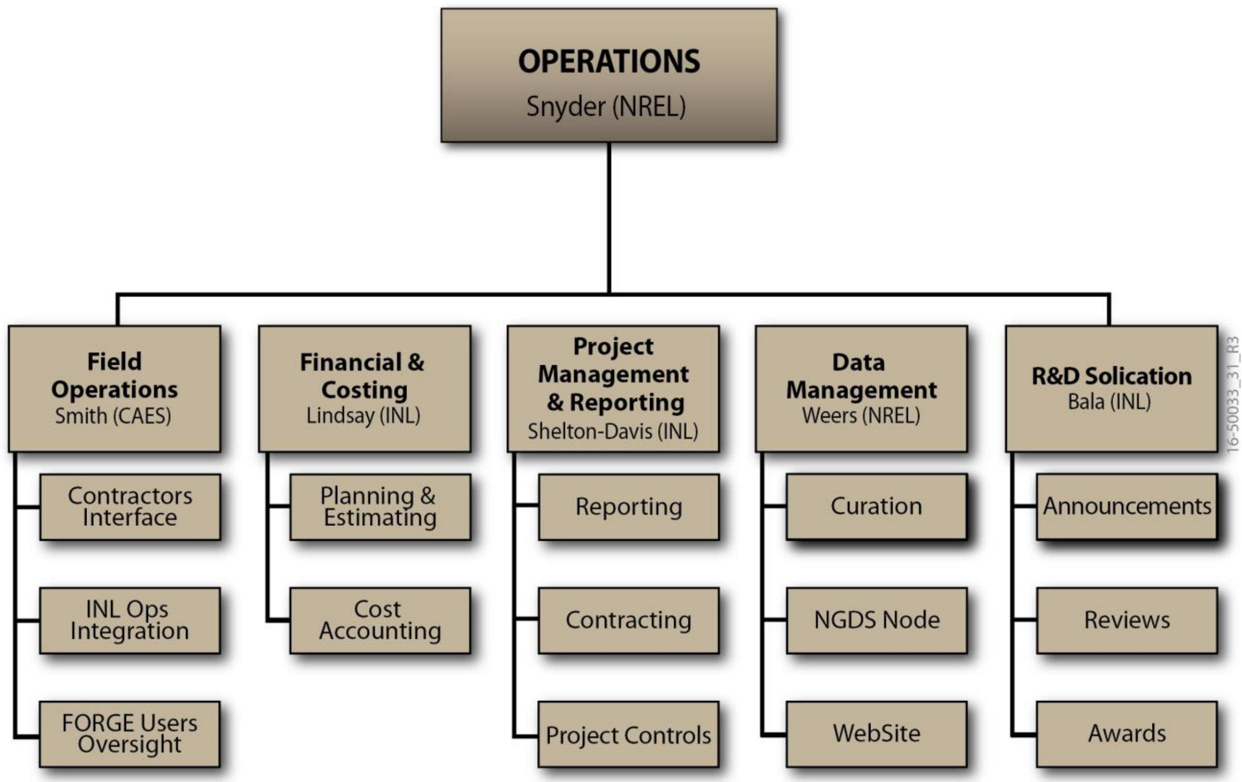

Figure 11. Operations Team organization chart.

6.1.4 Outreach Team

The Outreach Team will be led by the SRGC director. The goals of our outreach team are to educate, inform, and expand the support base for EGS and attract users to FORGE. The SRGC has been conducting public outreach activities related to FORGE and general geothermal development for more than 4 years and has built a strong support base locally. Simultaneously, we have been engaging a larger community using our website (snakerivergeothermal.org), social media, and outreach events.

Our communications and outreach approach includes static, dynamic, and multi-directional information exchanges with local community, regulatory, and government stakeholders. These exchanges are aided by traditional and nontraditional communications tools, such as our public website, a private content management web portal with access-only collaboration capabilities, social media outreach, media pitches, public tours, and methods to receive input from internal and external stakeholders.

The SRGC director will lead this team, because we feel outreach and education are paramount for the success of FORGE. Support will come from the SRGC communications lead (Julie Ulrich, CAES), the INL regional outreach and engagement manager (Stephanie Cook, INL), and an education coordinator (Don Roth, CAES).

6.2 SRGC Research and Development Activities

FORGE will be a collaborative technical learning facility, with strong emphasis on communication of activities and results to all interested parties; the only limitations on this will be by exceptions specified in intellectual property (IP) agreements. The SRGC staff, both resident and virtual, will be responsible for technical coordination, data gathering, and communications.

6.2.1 SRGC Team Activities

Planned SRGC R&D activities will be detailed in our Phase 2 project management plan and scope of work. We intend to execute the tasks necessary to make our vision for FORGE a reality using a combination of SRGC executed work and subcontracted and competitively solicited R&D. SRGC will comply with DOE's requirements for the number and dollar value of competitive R&D FOAs and subsequent awards to be issued each year.

6.2.2 Subcontracted Activities

The majority of FORGE R&D activities are envisioned to be conducted by specific awards to entities from academia, industry, and national laboratories, while SRGC will operate the site, plan and coordinate all activities, and provide technical oversight of the activities of the awardees. These external awards will be managed through INL subcontracting professionals and follow all applicable DOE guidelines and relevant DOE orders.

6.2.2.1 Contractual Obligations

Awardees will provide a detailed description of their proposed experimental activities, and a negotiated version of this description will be incorporated into their official scope of work. Because the FORGE site will be hosting numerous experiments, both serially and in parallel, within the same subsurface infrastructure, it will be critical that awardees adhere to their approved scope of work. Compliance with all FORGE operational and ES&H requirements will also be mandated in the award documents.

6.2.2.2 Rights/Protection of Intellectual Property

Awardees may have IP that must be protected before, during, and/or after their activities at the FORGE site. We will develop appropriate legal documentation that clearly spells out the rights and responsibilities of SRGC and awardees, and completed IP provisions will be formally incorporated into the awardee's subcontract. Onsite information technology systems needed to support an awardee's activities will be configured for protection of moderate-level data in accordance with DOE requirements. A limited amount of locked physical storage will be built into the site infrastructure, and a designated area will be established for temporary siting of additional locked storage in cargo containers. Temporary security barriers will be provided, as needed, should an awardee's operational activities need to be isolated from other personnel at the site. SRGC staff members who have the potential to have access to IP will sign nondisclosure agreements.

6.2.2.3 Publication of R&D Results

The general expectation is that all R&D results will be openly published unless protected by IP agreements. We plan to include guidance in awardees' contracts, so that in most instances, at a minimum, one peer-reviewed journal publication will be required from each project. Where appropriate, SRGC members may seek to be co-authors on publications from external award recipients.

6.3 FORGE Research and Development Solicitations (FOAs)

Planning for needed R&D in Phase 3 will take place through a cooperative process involving the SMT, focus area leads, STAT, and EERE-GTO leadership. The first step each year will occur at an international forum at CAES, modeled after the Gordon Research Conference series. These annual events will explore the current status of EGS research and identify emerging ideas and research needs. Immediately following the forum, the collective FORGE management team will discuss the current status of FORGE and other active EGS operations, identify additional and follow-on research topics, and develop a consensus for the following years R&D activities.

Once the research topics are identified and agreed upon, an independent, "firewalled" management group at the INL will handle the solicitation in order to avoid any perceived or real conflicts of interest in awarding competitive funding. While a portion of the Phase 3 R&D will have to be managed and accomplished by the SRGC itself, it is anticipated that in some instances SRGC members will be assigned to successful external proposals that will do work at the FORGE laboratory; an organizational conflict-of-interest policy will be established and enforced to preclude any actual or perceived improper relationships (see Section 9).

6.3.1 Annual Solicitations Approach and Planning

As previously stated, the annual R&D solicitation will be developed jointly through a cooperative process involving the SMT, STAT, and EERE-GTO leadership. This solicitation is a key area where the STAT will provide leadership and guidance. FORGE must support a spectrum of projects funded for short- (1 year), medium- (2 to 3 years), and long-term (3+ years) periods, but all must be coordinated and reviewed annually. The SRGC will be responsible for basic FORGE site development and maintenance and for ensuring that funded projects are compatible with all other operations and do not put at risk the work of others or the subsequent operation of the FORGE site. At least 50% of our annual R&D budget will be made available to external users through FOAs.

We will use STAT meetings for planning and prioritizing FORGE R&D projects on an ongoing basis and for dealing with any conflicts between projects as they arise.

6.3.2 Solicitation Management

R&D solicitation activities will be managed using a proprietary INL database system that "firewalls" the FORGE management team from the submittal and review process. The database is a proprietary, custom-developed application that can be used for the entire application, review, and reporting life cycle. The system has two main functions: (1) accept and review applications and (2) enable administrators to use existing data to find qualified technical peer reviewers.

Enabling administrative functions of the database system include using existing data to search for qualified technical peer reviewers, executing reviewer assignments, managing applications and reviews, and providing robust data export tools for analysis.

The database is managed through individual account access. Individual users set up accounts, and then administrators assign security privileges. Therefore, individuals have access only to applications, quarterly reports they have created, and any reviews assigned to them by an administrator.

The database system is currently used by the Innovative Nuclear Research Integration Office to manage more than 1,100 applications each year that require in excess of 4,500 peer and relevancy reviews. Specifically, the system is being used for applications received in support of the DOE Nuclear Energy University Program funding allocation (R&D, infrastructure, and student support), competitive Nuclear Energy Enabling Technology crosscut funding (including equipment acquisitions by national laboratories), NUSF access/access with R&D support, and (new this year) competitive R&D sponsored by the DOE Office of Environmental Management. The system is also being used to mediate the review processes for DOE request–for-information calls, support of other DOE Office of Nuclear Energy (DOE-NE) FOAs, DOE-NE program reviews, selection of reviewers for DOE-NE scoped Small Business Innovation Research solicitations, the newly announced Gateway for Accelerated Innovation in Nuclear, and the 2016 Technology Commercialization Fund call for proposals by the DOE Office of Technology Transitions.

Since 2009, the database has logged $434.8 million in funding awarded to 110 schools in 40 states and the District of Columbia. The database also has logged and archived tens of thousands of applications and reviews for export and later retrieval.

6.3.3 Assurance of Alignment with GTO Research and Development Objectives

As defined in our vision for developing topics for R&D solicitation, we plan to include GTO in the planning and vetting process. We will also use any EGS program planning documentation produced by GTO as a formal input to the annual planning process.

6.3.4 Communication of FORGE Opportunities for Research and Development

As discussed in the FORGE *Communications and Outreach Plan* (Ulrich and Podgorney, 2016), communications of FORGE R&D opportunities will be through numerous channels, primarily through our website (snakerivergeothermal.org) and the social media channels of SRGC members. In addition, traditional methods for communication of funding opportunities, such as EERE-Exchange, will be used. Additional methods either requested by GTO or required by statute will also be used as appropriate.

7. FORGE SITE OPERATIONS MANAGEMENT

To manage rapid deployment of new technologies and long-term innovation, SRGC will combine traditional project management (frequent reporting, quantitative performance measures, regular go/no-go or refocus decisions) with the best practices of creative and innovative organizations and other large, multi-disciplinary programs managed by SRGC partners, such as NREL's National Wind Technology Center or INL's Advanced Test Reactor NUSF.

7.1 Evaluation Procedure for Testing Technologies

The purpose of FORGE is to advance the development of EGS technologies through field testing. FORGE will be open to researchers from academia, industry, and national laboratories. Competing demands for access will need to be balanced against available time and DOE priorities. Also, the engineered subsurface structure of the FORGE site will need to be developed and maintained in a way that ensures support of DOE goals over the 5-year life of the site. A structured process for managing decision-making about proposed projects will be described in this section; an overview of the process is shown in Figure 12.

The decision-making framework with respect to experiments and tests to be conducted at FORGE must balance the potential risk of an experiment on the FORGE infrastructure (such as losing the functionality of a well) with the potential reward that the risk offers and how experiments conducted today may impact our opportunities for future tests. With these concerns in mind, we have developed a decision-making framework for evaluating all potential FORGE activities.

Evaluation of the risk of most FORGE activities will take place in the planning stages and will be considered among the SMT-TOT-STAT-GTO during the annual work and FOA planning activities. However, as responses to funding opportunities are evaluated and awarded, their impact to FORGE must be considered. Also, because FORGE is being built as an asset for industry to test methods, tools, and materials, we expect to receive unsolicited requests for access to the FORGE laboratory. Figure 12 shows the decision logic for evaluation of the suitability of experiments at FORGE.

While not all teams are shown in Figure 12, the process involves many of the groups identified earlier on the SRGC organization charts, as they all interact in the operation of FORGE. The project selection process begins with a user making a request to access FORGE.

All FORGE access requests will be routed through the SRGC LMT for initial screening and vetting. This vetting is important, because it will protect funded projects from scientific encroachment (e.g., protects the projects funded from duplicative efforts) and will ensure that proposed projects meet the objectives of FORGE. Requests that are deemed to be valid and within the scope of FORGE will be forwarded to the TOT chair for detailed technical evaluation at the next regularly scheduled TOT meeting to ensure there are no conflicting activities planned or schedule/access constraints. If the work puts key FORGE infrastructure or attributes at risk, the request will be sent to the field operations manager for a safety review and scheduling. If significant risks are present, the request will be elevated to the next SRGC LMT meeting for discussion.

If the original request is not related to existing SRGC or FORGE FOA-related activities and comes from outside the normal FORGE user community, the SRGC LMT chair will screen the request, as described above. For requests that do not interfere with FORGE or put its assets at risk, the same evaluation and scheduling process will be followed, and the work will be allowed to proceed.

All requests to access FORGE will be tracked and reported to the SMT and GTO.

7.2 Technical Oversight

The overall management structure of SRGC is described in the FORGE *Project Management Plan* (Podgorney, 2016). The subset of that structure that will be directly involved in the technical oversight of R&D is described in this section.

- ***Leadership and Management Team (LMT)***

  The LMT is composed of the senior leadership of the SRGC, namely the director, deputy director, and chief scientist. The LMT is a key component of the SMT and will work in coordination with DOE-GTO leadership and the STAT to provide guidance for FORGE projects and milestones. This guidance includes assurance that FORGE is a *dedicated site where scientists and engineers can develop, test, and accelerate breakthroughs in EGS R&D.*

Figure 12. Technical/operational decision-making flow chart.

- ***Field Operations Manager (FOM)***

  The FOM is responsible for ensuring effective execution of the FORGE field activities. He is responsible for the assigned schedule and given specifications, and he prepares these schedules and monitors the work progress against the task schedule. He makes sure that the execution targets are achieved while adhering to the FORGE *Environmental, Safety, and Health Plan* (Smith et al., 2016). The FOM oversees the operations and provides support and guidance to the entire FORGE team, with the aim of achieving operational excellence through meeting performance metrics (milestones). The FOM utilizes the TOT and focus area leads as resources to see that project objectives are aligned with the stated mission of the FORGE project. The FOM reports directly to the FORGE operations manager, ensuring that all issues and concerns relating to field operations are addressed in a timely manner.

- ***Technical Opportunity Team (TOT)***

  The TOT provides scientific and technical evaluation and expertise to the FORGE leadership regarding suitability of projects that have requested to conduct studies at FORGE. The TOT is composed of a chair, who is knowledgeable of both the technical and operational constraints, and of the focus area leads, who are SMEs for the range of scientific, engineering, and operations areas that fall within the FORGE mission. The TOT's role is to ensure the technical feasibility and interoperability of proposed R&D projects. Projects that are recommended by the TOT are routed directly to the FOM for a path forward to deployment. Projects that are not recommended for deployment at FORGE are routed back to the SRGC LMT with details regarding the technical concerns and potential risks.

- ***Focus Area Leads***

  Focus area leads have the responsibility of leading research in their area of expertise and for integration of their focus area across the SRGC. The focus area leads will lead the scientific and engineering areas of the SRGC, manage the scientific priorities of the area, and serve on the TOT. The focus area leads have the responsibility to determine the suitability of proposed projects that fall under their technical expertise and request access to FORGE. Direct technical oversight will be handled by the FOM, and the focus area leads' technical oversight will be captured in project vetting and evaluation of results.

- ***Science Technology Analysis Team (STAT)***

  The STAT is responsible for the injection of innovation into FORGE and for providing insight into the development and management of the FORGE R&D. From a technical oversight role, the STAT will not directly oversee individual projects on a day-to-day basis but will focus on advancing the FORGE objectives as a whole. The STAT will provide technical oversight to SRGC's overall operation of FORGE and the associated R&D programs.

- ***DOE***

  DOE participation in the management of FORGE R&D activities will be through the STAT and SMT and through the terms of the contractual agreement for the FORGE award.

7.3 Environmental, Safety, and Health Interface

Maintaining a unified ES&H plan across a multi-institutional program of this kind is a considerable challenge, especially given the magnitude of the operations-based field engineering components of FORGE. A central ES&H function for the activities taking place at the FORGE laboratory will be required.

ES&H compliance for activities at the FORGE site will be managed and overseen by the FOM and supporting staff; activities performed elsewhere will be the responsibility of the host institution(s). We will enforce a work plan review and approval, known as a "readiness review," before work begins at FORGE. The readiness review will be based on the Integrated Safety Management System program used at INL. A readiness review ensures that appropriate ES&H hazards are identified and that corresponding mitigations are included in the work plan and are properly budgeted. Readiness reviews will be coordinated by the FOM.

8. ANNUAL OPERATING PLAN DEVELOPMENT

Development of annual operating plans for FORGE will require a significant amount of planning and coordination. We have developed a management system and operational teams to accomplish FORGE goals and execute experimental plans. To accommodate what we expect to be a significant amount of simultaneous experiments, some of which may take months or years to complete, we will operate FORGE using a model that is a hybrid of a standard user facility, where experiments or beamtime can be reserved, and focused "campaigns," where multiple teams and projects will access the site and conduct research simultaneously during an effort lasting several months.

8.1 SRGC/GTO Agreement on 5-Year R&D Framework for Phase 3

The SRGC will develop an agreement with GTO that will provide an overall framework for FORGE operations over the project's lifetime. This framework will be updated annually.

It will be critical for SRGC and GTO to work from a common frame of reference to establish goals, a technology baseline, metrics of various kinds, and a program-completion strategy for FORGE. Both parties will need to provide all relevant data for discussion. As discussed in Section 6, planning for Phase 3 R&D will take place through a cooperative process involving the SMT, STAT, focus area leads, and EERE-GTO leadership. Modeled after the Gordon Research Conference series, these week-long annual meetings will be used to present the current status of FORGE and other active EGS operations, identify additional and follow-on research topics, and develop a consensus for the following years' R&D activities.

At the initial planning meeting, we intend to present our vision to GTO and the STAT as a starting point for development of the 5-year framework. Harmonization of SRGC and GTO visions at the very beginning is critical to successful framework development. Following this, a detailed summary of each plan year will be developed, with more details on the first 1 to 2 years.

Due to the geographic distribution of various stakeholders, many of these activities will be conducted virtually, but key annual face-to-face meetings will be conducted at CAES.

8.2 Phase 3, Year 1 Research and Development Goals

The FORGE EGS baseline described above will form the basis for initial R&D goal setting. The purpose of the R&D goals will be to provide specific guidance for the SRGC in carrying out FORGE operations in general over the lifetime of the project, as well as in specific detail for operations during the first year. Sharing of FORGE project information with all members of the geothermal community is a key ongoing priority, so communication of these frameworks and goals will be part of this activity.

The first year of operation will include a considerable amount of learning for all involved, but it will be particularly important in that environment to establish concrete and measurable goals. From a practical sense, SRGC will need to execute, or directly subcontract, as necessary, FORGE subsurface infrastructure development work scope in Year 1 of Phase 3, while at the same time complying with DOE requirements for issuing FOAs. This SRGC work will include all well drilling, characterization, and other activities detailed in the scope of work.

8.3 Phase 3, Years 2–5 R&D Goal Planning

The state of EGS technology is expected to evolve rapidly, and, as such, it will be necessary to revisit FORGE EGS baseline and R&D goals on an annual basis. Updating the FORGE EGS baseline annually will be essential to the development of timely and relevant goals. This will be a critical step in injecting innovation into FORGE research and operations and is a critical point where the STAT will provide analysis, feedback, and vision for annual and out year research plans.

The same basic processes described for initial goal setting will be followed on an annual basis, although it is anticipated that annual updates will not be as resource-intensive as the initial activity.

Based on our experience with SRGC member user facilities, we anticipate that the typical TRLs of FORGE projects will increase over time as the EGS program makes progress in moving toward its goals of developing commercially viable technologies. Figure 13 illustrates a notional example of TRL progression over time. Assessing the state of EGS technology will be a critical part of annual goal setting and of adjusting priorities with the end state of commercial viability as a central focus.

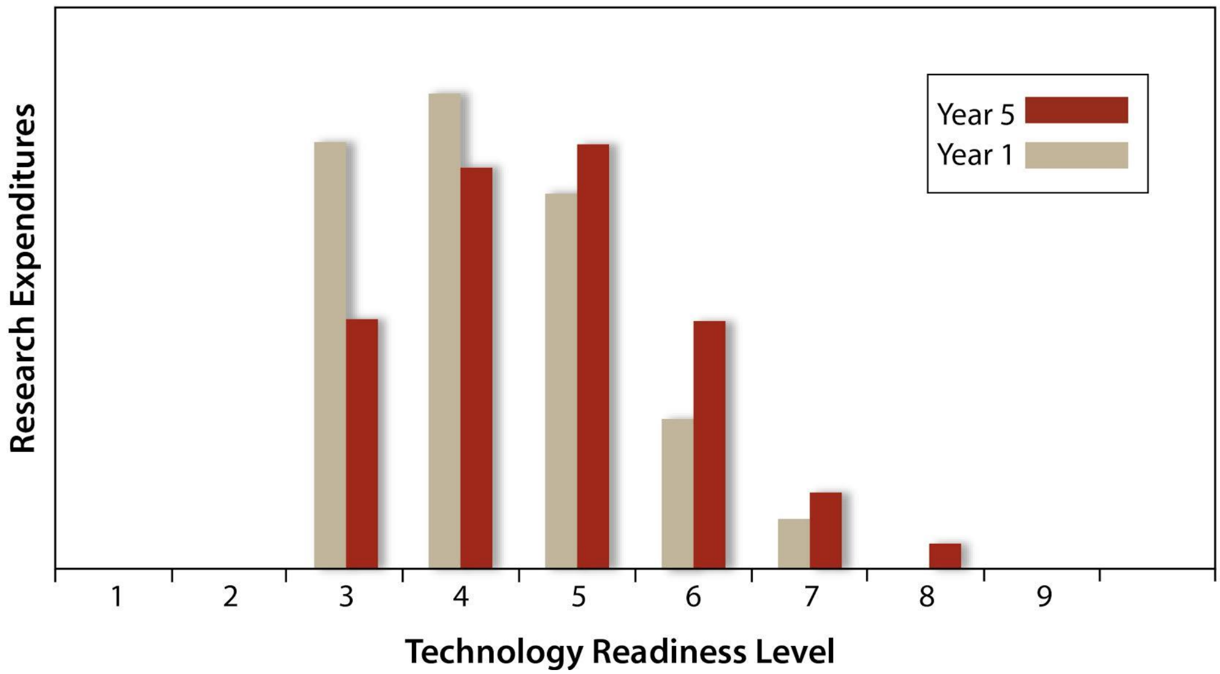

Figure 13. Example of TRL transitioning expected during Phase 3 of FORGE operations.

8.4 Communication to the Geothermal Community

It is critical that the geothermal community remain apprised of all the details of FORGE operations, including the annual goals. Baseline and goals documents will be posted on the SRGC website (snakerivergeothermal.org) and communicated in other ways, as outlined in the FORGE *Communications and Outreach Plan (Ulrich and Podgorney, 2016).*

Papers will be authored by SRGC members for the annual Geothermal Resources Council and Stanford Geothermal Workshop meetings, and the SRGC will work with GTO to try to optimize FORGE visibility within the agendas of those meetings.

The SRGC communication guidelines are designed to meet several needs by providing transparency in matters of management, governance, and science; providing accessibility to vital information; ensuring expeditious sharing among all participants; providing powerful tools for collaboration; protecting patentable subject matter and confidential information; and segmenting information for restricted access internally, where necessary, to meet the requirements of nondisclosure agreements.

8.5 Unified Web Presence

SRGC has developed a model for a unified web presence using a "one-stop shop" portal for all information and has established the portal at snakerivergeothermal.org. The web portal is used for all aspects of FORGE: data, information, future R&D funding opportunities, and discussions. The website was created as a tool for communication, education, and outreach (Figure 14). It relies on four main systems:

- A content management system for publicly available content
- A collaboration environment for specialized and secured content sharing
- A live data server and dedicated/automated National Geothermal Data System node
- A firewalled database for Phase 3 proposal submission, review, and tracking.

The content management system is used to provide additional access-only collaboration capability for individual project needs. For this capability, we have created a team-only SharePoint site at forge.inl.gov, which is accessible from the external site. In this collaboration environment, users must have an administrator-provided login to access content. Individual security will be assigned using a graded approach, allowing some to have full access while others are restricted to certain portions of the collaboration environment. Capabilities available using the collaboration environment include internal collaboration tools, document sharing, document/record control, change notifications, and automated approval structures.

9. MANAGEMENT OF POTENTIAL CONFLICT OF INTEREST

The geothermal community is relatively small. As a result, finding entities that will support GTO in the management of FORGE, but are not in any way interested in using the FORGE laboratory for their own projects, is challenging. This situation necessitates that a strong conflict-of-interest plan be part of R&D management.

9.1 Initial Ground Rules

Certain SRGC individuals and/or roles will be involved in the definition of desirable projects, while there will also be business operations staff members who will be tasked with creating contractual relationships with FORGE users. Individuals who participate in these decision processes will not be allowed to propose work as users of FORGE. Organizations affiliated with SRGC that employ such individuals and desire to propose work at FORGE will be required to comply with the SRGC's formal conflict-of-interest identification and mitigation process.

9.2 Documentation of Individual and Organizational Affiliations/Potential Conflicts

The SRGC will establish a procedure and forms to describe the conflict-of-interest program, collect information on individual and organizational affiliations, determine real or perceived conflicts of interest, and develop mitigation strategies. These documents will be developed from existing, proven conflict-of-interest programs at INL and other partners, thus leveraging long experience in the DOE environment. All of these documents will be formally incorporated into contractual documents with FORGE users.

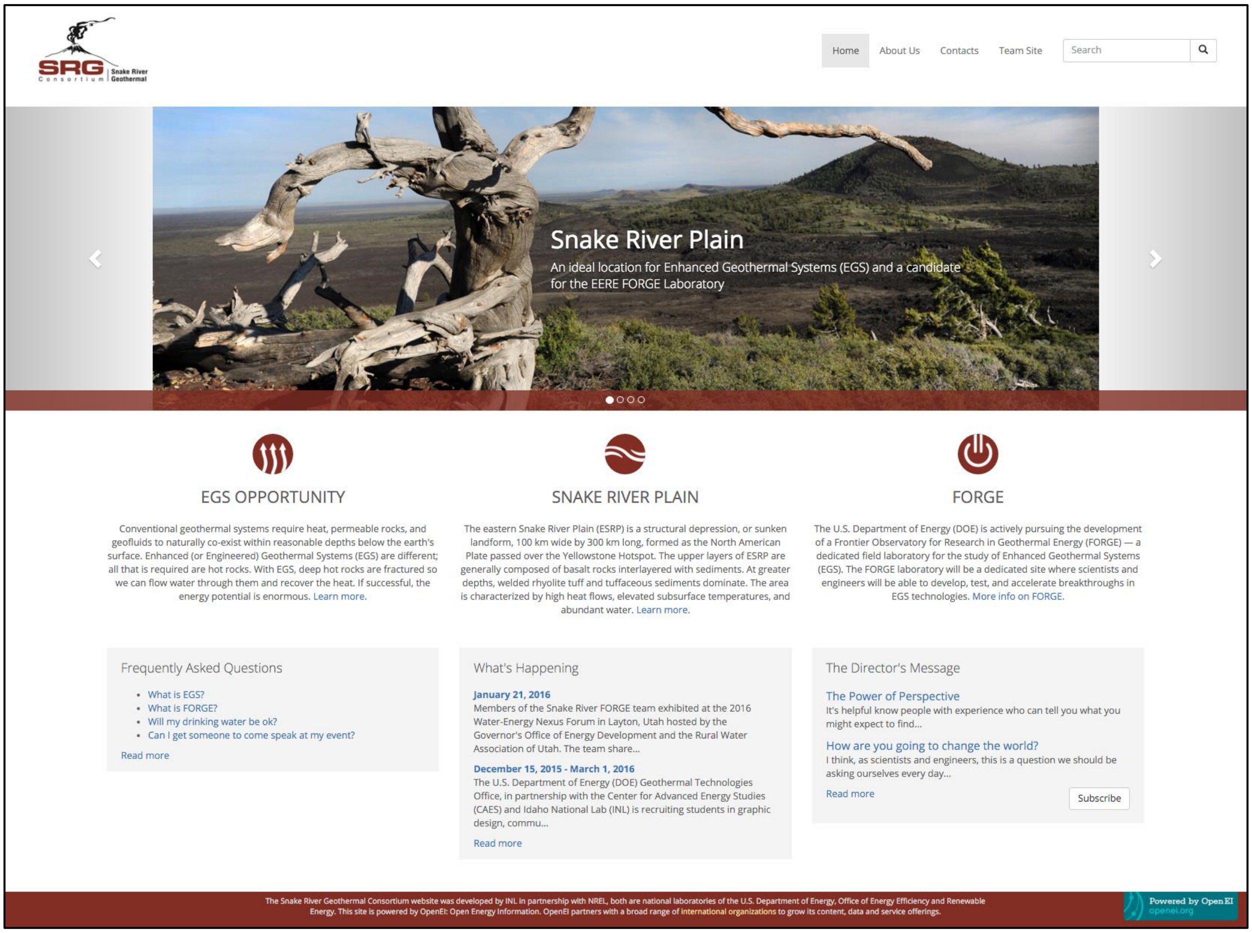

Figure 14. Image of snakerivergeothermal.org homepage.

9.3 Approaches to Mitigation of Perceived or Real Conflicts of Interest

The conflict-of-interest management process will be an ongoing effort, starting with initial user proposals and continuing through final closeout of user contracts. The SRGC will publish all relevant conflict-of-interest information in advertisement-of-opportunity documents. During contract negotiations, any potential issues will be brought to the surface, and the proposing user will be required to submit mitigation plans. Any issues that cannot be resolved between SRGC and the proposing user will be elevated to GTO for resolution.

The issue of perceived conflicts of interest may be more challenging than actual conflicts. Because of the small size of the geothermal community, complete organizational independence among parties affiliated with management of the FORGE site and parties affiliated with users may be difficult to achieve. The formal conflict-of-interest documentation described above will be designed to address legal requirements, but negative public perceptions can sometimes occur even when there is full legal compliance.

SRGC management will address this concern by providing comprehensive information on the project selection and procurement processes through its various media outlets in order to provide complete transparency. In the unlikely event that an actual conflict-of-interest situation arises during the execution of a user contract, the issues will be addressed quickly in accordance with contractual provisions, and information on the situation will be provided to the public to ensure full transparency.

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Appendix A

Lessons Learned from Past EGS Projects

Appendix A

Lessons Learned from Past EGS Projects

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
1974	1992	Fenton Hill	Baca Geothermal Field, New Mexico	• Stimulated zone was missed due to shift in stress field with depth. • Crystalline basement rocks can be hydraulically fractured to create reservoirs. • Open fracture networks persist over time. • Reservoir productivity goals were not achieved. • Flow rates and pressures were difficult to maintain. • Drilling cost was very high. • Microsiesmicity can be used to image reservoir creation. • Regional stress and preexisting fracture are implicated in reservoir creation. • Thermal power can be produced over extended periods from EGS reservoirs. • Long-term studies are important; funding needs to be reliable and consistent over time.
1977	1986	Falkenbert	Falkenberg, Germany	• Pre-existing naturally fractured networks can be stimulated by low pressure that is just above the critical pressure of shear failure (at shallow depths).
1977	2008	Geothermie-Pilotprojekt Bad Urach	Bad Urach, Germany	• This was one of the first EGS tests. • Development of down-hole heat exchanger was successful. • This was a collaborative cross border project between Germany and France; little information is known. • Great drilling difficulties were encountered; Urach 4 was not completed. • EGS project success is not guaranteed. Significant financial needs can lead to project delays or even abandonment.

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
				• An intense borehole measurement program was performed. • A novel down-hole heat exchanger was developed by massive hydraulic fracturing; the largest EGS worldwide was created; a long-term (4 months) hydraulic circulation test was performed; a thermal power of 11 MW was achieved.
1978	1986	LaMayet	La-Mayet-de-Montagne, France	• The best sampling of the seismic radiation field at that time was attained in a hot dry rock (HDR) field experiment. • Borehole packers were used to isolate several zones, so that a succession of stimulated zones was created. • The result was a large-scale fractured heat-exchange area with good connection between two boreholes. • Tiltmeters were successfully used to monitor the growth of fractures.
1983	Operating	Bruchsal	Bruchsal, Germany	• Many consider this not to be an EGS study operating power plant. • High salt content caused corrosion in piping. • Stress field was studied in depth.
1984	1992	United Downs Project	Rosemanowes, England	• This was the first major EGS project after Fenton Hill. • In this project, the major lesson learned is that natural fractures and engineered fracture are mostly unrelated. • Natural fractures are significantly more important to circulation compared to engineered fractures. • Prior to the study, deep basement rocks were assumed to be massive competent rocks. This study concluded that these rocks contain a significant population of open natural fractures and resulted in the abandonment of existing models for the hydraulic stimulation EGS concept.

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
1984	1995	Fjällbacka	Fjällbacka, Sweden	• The natural fractures system dictates the nature of the hydraulic fracturing. • Compressional regime resulted in a horizontal-oriented reservoir. • Observations were similar to those at Rosemanowes, England, where deep basement rock contains numerous open fractures.
1984	Continuing	Soultz-sous-Forêts (European consortia)	Soultz-sous-Forêts	• In EGS tests at the Soultz site, microseismic events generated in the reservoir during stimulation and circulation were large enough to be felt on the surface. • Near wellbore conditions are implicated in large a pressure drop across the heat fracture heat exchangers. • Stimulated fractures dominated the EGS reservoir. These fractures were part of the preexisting fracture network in the rock. • Soultz demonstrated that EGS reservoirs could continue to expand during circulation. Therefore, pressures need to be controlled during circulation. • Feed in tariff motivated the project.
1985	2002	Hijiori	Hijiori, Japan	• Water losses were high. • Scale is a significant issue. • EGS projects can extract geothermal energy from naturally fractured reservoirs. • Caldera stress fields present challenges to stress field - vertical orientation, and east-west strike of the seismic events are essentially coplanar with the caldera ring-fault structure. • Preexisting structure controls stimulation. • Despite HiJiori successes, HDR EGS is put on hold in Japan. • Future extension of the HDR usage will require a proper system design in each case. Overall system design will be a key component of the HDR future.

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
				• Down-hole and topside water geochemistry needs to be better understood. During heat exchanger circulation test, calcium carbonate and silica precipitated along the fluid pathway. Aragonite precipitation was an issue in cooling water due to super-saturation caused by the water used for cooling. • Projects should drill the injection well and stimulate so that the production well can encounter the stimulated zone. • The stimulation zone will increase in size (fractures will continue to propagate) as circulation time increases.
1989	2002	Ogachi	Ogachi, Japan	• New hydraulic fracturing technology was tested that was later used at Cooper Basin. • Financial problems stopped the project. • Water flow was short cut in the lower reservoir. • The cooldown was faster than expected due to short cutting; this also created a scaling problem in the production wells.
1989	Continuing	Altheim	Altheim, Austria	• This project uses an engineered working fluid to produce electricity through a low enthalpy Organic-Rankine-Cycle-Turbogenerator.
2000	2007	GeneSys Hannover	Horstberg and Hannover, Germany	• This was an in situ down-hole laboratory for developing techniques for the exploration of EGS. • Stimulation protocols: methods should be laid out individually depending on rock properties, stratigraphic conditions, structural setting and regional stress field, and self-propping potential. • The hydraulic-fracturing technique successfully applied in crystalline rocks for the creation of HDR systems will be used to create large-scale fractures. • Post-frac venting tests showed that at least one fracture that was created had high injectivity.

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
				• This project demonstrates the benefits of stimulation in a sedimentary environment—large storage coefficient and preexisting permeability. • The concept of using a single borehole was not effective, because there was no connection between the injection zone and the production zone, so the production zone was not recharged and could not support long-term production. • Few microseismic events were detected during stimulation and circulation tests, especially compared to the large number of microseismic events generated and detected during stimulation in crystalline rock.
2000	Continuing	Groß-Schönebeck	Groß-Schönebeck, Germany	• This is an in situ down-hole laboratory for developing techniques for the exploration of EGS. • Stimulation protocols: methods should be laid out individually depending on rock properties, stratigraphic conditions, structural setting and regional stress field, and self-propping potential. • Combining proppants and gels and acidification is an effective stimulation technique in EGS.
2001	Continuing	Berlín	Berlín, Germany	• Lessons from this project have been particularly useful for induced seismicity. • Monitoring should continue for at least 6 months beyond the end of the project. • This project showed the ground shaking hazard caused by small-magnitude induced seismic events (Majer et al., 2007). • Conducting EGS in third-world countries where building standards are lax or not presentment represents a different problem than do similar projects in developed countries, as lower-magnitude events may cause significant damage.

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
2002	2012	Coso	Coso geothermal Field, Nevada	• Rose (2012) reports that a first stimulation at Well 34-9RD2 failed due to encountering a large natural fracture during redrilling. • Foulger et al. (2008) reported that the recompletion of Well 46A-19RD2 failed due to a well liner becoming stuck. The project was then abandoned.
2003	2013	Cooper Basin	Cooper Basin, Australia	• Geologic models are important to early project success. • Well control issues occurred even with oil and gas drilling technology. • Absence of complete chemical data resulted in casing failure (wrong grade of steel selected). • Project was abandon due to political issues. • A 0.7-km^3 reservoir was created. • EGS stimulation can create a large reservoir for heat exchange. • This project demonstrated that heat recovery based on the Desert Peak model is not sufficient for all EGS. Cooper Basin recovery may be as low as 4% due to short circuiting and low fluids. • It is important to distinguish between proof of concept and commercial demonstration. • Scale management is an issue (stibnite). • Cooper basin is under compressional stress.
2003	Continuing	Landau	Landau, Germany	• Geothermal operations have resulted in felt seismicity that threatens to shut the facility down. • Several centimeters of uplift were observed extending over a square-kilometer area around the Landau geothermal site. • A seismicity issue, water reinjection pressure, has been reduced to avoid induced seismicity, derating the power plant.

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
2004	Continuing	Unterhaching	Unterhaching, Germany	• This was the first geothermal project in Germany where increased heat supply resulting from reservoir stimulation resulted increased electrical generation. • This was also the first geothermal reservoir stimulation worldwide with private-sector insurance to monetize risk associated with deep wellbores. • District heating project associated with EGS operations. • There is still a fundamental lack of knowhow in the industry and engineering community.
2005	2009	Deep Heat Mining Project	Basel, Switzerland	• This location is in an area of high historic seismicity. • Induced seismicity resulted in the project being shut down. • Great care needs to be put into a competent seismicity plan. • Public is intolerant of felt earthquakes. • Conducting EGS stimulation in an area with historic earthquake history is in not advised. • "Only a combination of a series of measures will lead to effective mitigation of risks of induced seismicity as a prerequisite for obtaining trust of authorities, investors, insurances and hopefully public acceptance" (Meier et al 2015).
2005	2009	St. Gallen	St. Gallen, Switzerland	• Although felt earthquakes up to Magnitude 3.6 occurred, the development chose to continue with the project. However, public pressure due to seismicity and a lack of water resulted in cancelation of the project in 2014. • Induced seismicity resulted in the project being shut down. • Great care needs to be put into a competent seismicity plan.

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
				• The public is intolerant of felt earthquakes. • Conducting EGS stimulation in an area with historic earthquake history is in not advised.
2005	Continuing	Paralana Geothermal Energy Project	Flinders Rangers, Australia	• The natural fractures system dictates the nature of the hydraulic fracturing. • An advanced method was used to develop a down-hole heat exchanger (HEWI Heat Exchanger with insulator). • Oil and gas technology was utilized.
2007	Continuing	Insheim	Insheim, Germany	• Induced seismicity has been an issue. A side-leg concept for the injection well was designed and implemented to solve the problem. However, in 2013, another event of Magnitude 2.0 occurred during a pause in water circulation. • Several centimeters of uplift were observed extending over a square-kilometer area around the Landau geothermal site.
2008	2009	South Geysers	The Geysers, California	• Testing failed to reveal drilling issues caused by well bore instability sufficient to cancel the project. • Seismicity concerns also play a major role in project suspension.
2008	2015	Bradys	Bradys Hot Spring, Nevada	• Lessons learned from Desert Peak were used here. • Results and methodologies are transferable to other locations. • This project illustrated the importance of a strong integrated research team integration of tectonics, geology, petrology, rock mechanics, and stress regime. • Induced seismology management is critical.
2008	2015	Desert Peak	Desert Peak, Nevada	• Permeability in Well 27-15 increased to commercial levels. • Overall injectivity increased by 175 times. • Techniques are transferable to other locations.

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
				• Conceptual model for an EGS site is important. • Seismicity is consistent with regional stress field. • Stress strain data are crucial. • Achieve self-propping fractures is difficult without proppants. • Rock integrity is important. • Implementing the chemical treatment after achieving significant gains in permeability likely increased the effectiveness of the chemical treatment. • Enhanced seismic monitoring is useful. • Most of the stimulation occurred early in the project. • This project did not meet commercial operation goals. • Government industry collaborations are highly desirable.
2009	2015	Northwest Geysers	The Geysers California	• Microseismicity is useful in imaging a reservoir. • Corrosion is an ongoing issue. • Microseismic events are related to shear reactivation of preexisting fractures. • Stimulation was actively managed to “gently stimulate” thermal fracturing processes, minimizing induced seismicity. • Modeling exercises can reasonably predict the stimulation zone. • Shearing due to cold water injection was successful – increased injectivity. • Noncondensable phases and corrosion are issues. • Injection in Well PS-32 has increased reservoir pressure to levels observed in the 1980s.

Start Date	End Date	Project Name	Project Location	Key Lesson(s) Learned
2009	Continuing	Raft River	Raft River, Idaho	• Cold water stimulation resulted in dramatic increase permeability. • Accessing a larger volume of the target region is possible by taking advantage of the thermal stress alteration and associated fracturing. • Combining of multiple data sets microseismic, EMT, geochemical and tracer data production, pressure, are effective tools in characterizing EGS system stimulation volume and interconnectivity.
2009	Continuing	United Downs project	Redruth, England	• This project is currently on hold pending cost share.
2010	Continuing Research	Newberry Volcano	Newberry Volcano, Oregon	• Stimulation resulted in increased permeability. • Three zones of stimulation were achieved. • A limited reservoir was created. • Better resolution is needed for monitoring.
2010	Continuing	Eden Project	St. Austell, Cornwall England	• This project is stalled due to lack of funding.
2011	2012	Mauerstetten	Mauerstetten, Germany	• This is one of the few projects that ended up with better than expected flow rates. • Project goals included reducing the seismic footprint of EGS. • Results are transferable to other EGS studies in sedimentary rock. • Active public outreach was extended to all vested parties. Take public concerns seriously. • Dissemination of data occurred at near real time (webpage, conferences, publications, and workshops).
2012	2025?	Geostras	Strasburg, France; Kehl, Germany	• This is a collaborative cross-border project between Germany and France; little information is known.