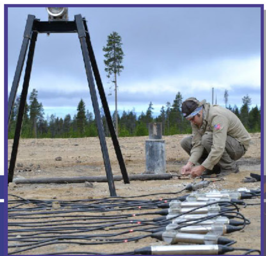

A Research Observatory for a Sustainable Future

Newberry Geothermal Energy

Establishment of the Frontier Observatory for Research in Geothermal Energy (FORGE) at Newberry Volcano, Oregon

Topical Report

May 23, 2016

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Acronyms and Abbreviations

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
BADGES	Building a Diverse Geothermal Energy Sector
BHTV	borehole televiewer
BLM	U.S. Bureau of Land Management
DEQ	(Oregon) Department of Environmental Quality
DNH	Davenport Newberry Holdings LLC
DOE	U.S. Department of Energy
DOGAMI	(Oregon) Department of Geology and Mineral Industries
EA	Environmental Assessment
EGS	enhanced geothermal system(s)
ES&H	Environmental, Safety and Health
FORGE	Frontier Observatory for Research in Geothermal Energy
ft	foot(feet)
GDP	Geothermal Drilling Permit
GDR	Geothermal Data Repository
gpm	gallons per minute
GSN	Geothermal Sundry Notice
GTO	(DOE's) Geothermal Technologies Office
HT	high-temperature
in.	inch(es)
InSAR	Interferometric Synthetic Aperture Radar
IP	intellectual property
ISMP	Induced Seismicity Mitigation Plan
km^2	square kilometer(s)
LiDAR	Light Detection And Ranging
m	meter(s)
mi^2	square mile(s)
MT	magnetotellurics
MW	megawatt(s)
NEPA	National Environmental Protection Act
NEGSD	Newberry Volcano Enhanced Geothermal Systems Demonstration
NETL	National Energy Technology Laboratory
NEWGEN	Newberry Geothermal Energy
NGDS	National Geothermal Data System
OSU	Oregon State University

PNNL	Pacific Northwest National Laboratory
R&D	research and development
s	second(s)
SOW	Statement of Work
SubTER	Subsurface Technology and Engineering Research, Development, and Demonstration
THMC	thermal-hydrological-mechanical-chemical
UO	University of Oregon
USFS	U.S. Forest Service
USGS-CVO	U.S. Geological Survey-Cascade Volcano Observatory

1.0 Summary

The Newberry Geothermal Energy (NEWGEN) Consortium proposes to establish and manage a Frontier Observatory for Research in Geothermal Energy (FORGE) for the U.S. Department of Energy (DOE) Geothermal Technologies Office (GTO) on the northwestern flank of the Newberry Volcano in Oregon. The Newberry Volcano possesses all of the physical attributes needed for the FORGE facility, which will be dedicated to research and development (R&D) of technologies needed to advance enhanced geothermal systems (EGS) to extract energy from hot, impermeable rock. Subsurface investigations have confirmed the existence of a large, high-temperature, very low-permeability geothermal resource at depths ranging from 1.7 to 2.25 km. The test site at the Newberry Volcano has already been the site of the Newberry Enhanced Geothermal Systems Demonstration (NEGSD), a partnership between AltaRock Energy, Inc. (AltaRock) and the DOE's Office of Energy Efficiency and Renewable Energy Geothermal Technologies Program (Award Number DE-EE0002777). Further research here will have long-lasting, positive economic benefits for Central Oregon, the Western United States, and beyond.

Vision

NEWGEN FORGE will build a pathway to large-scale economically sustainable green energy.

During Phase 1, NEWGEN formed a strong consortium of public agencies, universities, and private companies. The consortium was assembled to include leaders in geothermal energy development and partners with strong ties to technology commercialization to cover the entire value chain, an essential component for moving R&D results to market. During Phase 1, the NEWGEN team learned to work together, assembled a strong set of plans to move NEWGEN FORGE forward into the future, expanded the concept of the FORGE site to include three existing well pads (17, 16, and 29), and defined a rigorous set of activities that can be conducted simultaneously or sequentially during Phases 2C and 3. A comprehensive development plan was assembled for Phase 2 that leverages the existing infrastructure at the NEWGEN FORGE site so the EGS laboratory is operational and R&D projects can be implemented on the first day of Phase 3. NEWGEN updated the Environmental Information Synopsis and developed a robust plan for achieving compliance with the National Environmental Policy Act (NEPA) that strongly leverages previous experience and existing permits. A strong communications team was formed that continued previous NEGSD stakeholder involvement activities during Phase 1. Lastly, a robust R&D Implementation Plan was developed to support the establishment and management of FORGE.

A key activity during Phase 1 was to update the Conceptual Geologic Model, documenting a coherent and self-consistent understanding of the target reservoir depth, temperature profile, thermal conductivity, fluid chemistry, permeability and porosity, structure and lithology of the target formation, regional and in situ stress directions, extent of microseismicity, transmissivity, and impedance/injectivity. This process guided the thinking about where focus resources during the next phase of FORGE. A three-dimensional model was developed using the EarthVision™ software environment. Key parameters and their uncertainties were summarized. The Conceptual Geologic Model and update of the site characterization inventory demonstrate that Newberry Volcano is one of the most extensively characterized enhanced geothermal system (EGS) sites in the country, making it an ideal location for implementation of FORGE. Multiple terabytes of high-quality geologic, geophysical, geomechanical, and geochemical data were transferred to the Geothermal Data Repository (GDR).

Lessons learned are summarized for the Conceptual Geologic Model update, environmental constraints (or benefits from our existing environmental compliance documents and permits), and our ability to leverage the existing infrastructure.

2.0 Introduction

The NEWGEN Consortium proposes to establish and manage a FORGE for DOE- GTO) on the northwestern flank of the Newberry Volcano in Oregon (Figure 1). The Newberry Volcano possesses all of the physical attributes needed for the FORGE facility. Subsurface investigations have confirmed the existence of a large, high-temperature, very low-permeability geothermal resource at depths ranging from 1.7 to 2.25 km.

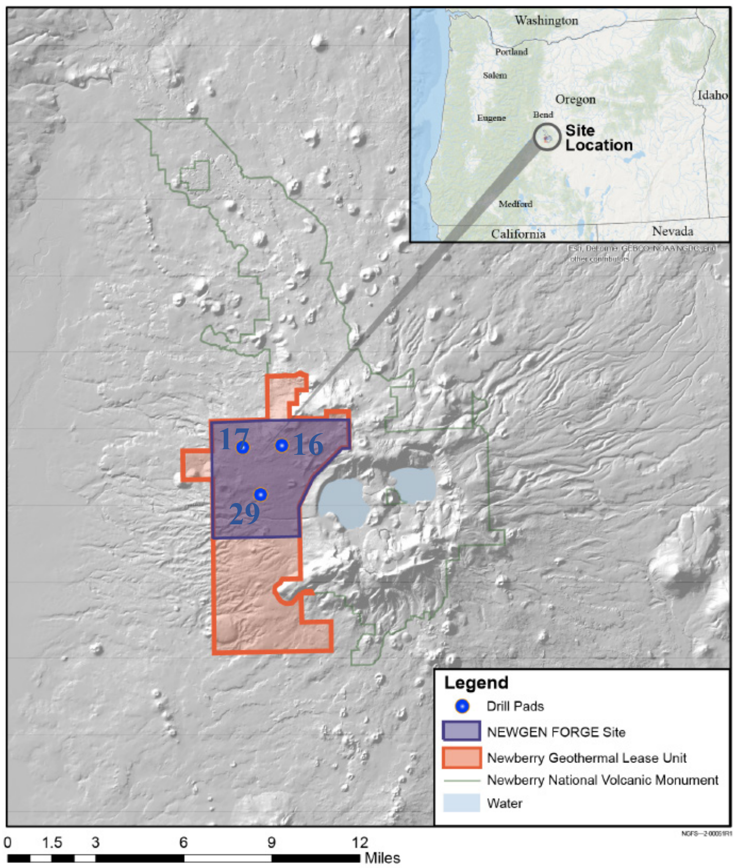

Figure 1. Location map for the proposed NEWGEN FORGE site, showing the Newberry National Volcanic Monument and geothermal leases. Blue dots with identification numbers correspond to the three pads selected for FORGE. Well NWG 46-16 is located on Pad 16 and Well NWG 55-29 is located on Pad 29.

NEWGEN FORGE will be dedicated to R&D of the technologies needed to advance EGS to extract energy from hot, impermeable rock. NEWGEN will implement FORGE via a public-private collaboration between Pacific Northwest National Laboratory (PNNL), AltaRock, General Electric Global Research (GE-GR), Oregon State University (OSU), and Statoil—bringing together world-class scientific knowledge, technical and industrial expertise, and community resources to meet DOE goals for the project and enable commercial energy production in the United States. These core consortium members are supported in the execution of FORGE by a group of committed science and technology providers composed of Blade Energy, Inc. (Blade), Cornell University, Lawrence Livermore National Laboratory (LLNL), Paulsson, Inc., Stanford University, University of Oregon (UO), and U.S. Geological Survey (USGS)-Cascade Volcano Observatory (CVO). NEWGEN offers a unique combination of assets for R&D of technologies. The test site at the Newberry Volcano has already been the site of the NEGSD project led by AltaRock and monitored by OSU. Further research here will have long-lasting, positive economic benefits for Central Oregon, the Western United States, and beyond. NEWGEN will develop rigorous and reproducible methodologies to help develop cost-competitive EGS power within the United States and reach the goal of 4% of electricity produced from this source by 2025. Technologies tested and developed at the NEWGEN FORGE site will be widely applicable across the country and worldwide.

FORGE is being implemented in three phases. Phase 1 (Planning) included technical and logistical tasks that demonstrated the NEWGEN FORGE site's exceptional suitability for meeting DOE's goals and the NEWGEN team's full commitment and capability for implementing Phases 2 and 3, as evidenced by the detailed teaming agreement attached to the Phase 2 Project Management Plan (PMP). NEWGEN is proposing a very well-characterized site, comprehensive infrastructure, and a research agenda that are ideally suited for accomplishing FORGE goals and objectives. Infrastructure and instrumentation at the NEWGEN FORGE site includes two existing deep geothermal wells, two planned geothermal wells, and a planned deep monitoring horizontal well for high-resolution imaging of the fracture network (seismicity, electrical resistivity methods), which will capture a higher-fidelity picture of EGS creation and evolution than prior demonstrations. The NEWGEN FORGE site has three existing pads, including one where EGS stimulation has already been performed, uniquely allowing all phases of FORGE—characterization, reservoir development, reservoir enhancement and maintenance, and operations—to be addressed simultaneously. The reservoir beneath two of the pads has already been characterized by deep wells, allowing technologies and tools for different phases of the EGS lifecycle to be tested in a controlled and well-characterized environment. In addition, innovative real-time data collection systems are already onsite. High-quality, graded dirt forest roads provide vehicle access to all three well pads and each of the monitoring station locations. Road access is granted under a U.S. Forest Service (USFS) Road Use Permit, which will be renewed and revised during Phase 2 of the project. Access to the site will be managed year-round with planned and budgeted snow removal during winter months.

3.0 Overview of Phase 1 Activities

During Phase 1, the initial three project partners—PNNL, AltaRock, and OSU—conducted a thorough gap analysis of competencies and capabilities needed in order to meet DOE's goals for FORGE. The core consortium was expanded to five members, adding the considerable strengths of GE-GR and Statoil to the management and development of NEWGEN FORGE. An extended consortium was then assembled to include leaders in geothermal energy development and partners with strong ties to technology commercialization to cover the entire value chain, an essential component for moving R&D results to market. The extended consortium includes Blade, the USGS-CVO, Cornell University, LLNL, Paulsson Inc., Stanford University, and the UO. During Phase 1, the NEWGEN team learned to work together, assembled a strong set of plans for implementation of FORGE at the NEWGEN site, and completed the following activities:

- evaluated and updated the Conceptual Geologic Model based on analysis of more than 40 years of site characterization data at Newberry Volcano, confirming the superior suitability of the NEWGEN site as the FORGE laboratory, and providing important guidance for future characterization and monitoring activities at the site;
- expanded the concept of NEWGEN FORGE site to include three pads (Pads 17, 16, and 29) and defined a rigorous sequence of activities that could take place at different pads simultaneously or sequentially during Phases 2C and 3;
- updated the plan for achieving NEPA compliance based on previous experience and plans for updating existing permits during Phase 2A for NEWGEN FORGE operations;

- evaluated the considerable amount of existing infrastructure at the NEWGEN FORGE site and developed a plan for Phase 2 to fully develop infrastructure (including options for power generation at the site) so the NEWGEN EGS laboratory is operational and R&D projects can begin on the first day of Phase 3;
- formed a strong communications team that has continued extensive stakeholder engagement activities during Phase 1, and has summarized lessons learned from their various outreach efforts.

3.1 Conceptual Geologic Model and Supporting Data

During Phase 1, the NEWGEN team developed a robust Conceptual Geologic Model (main results presented in Section 4.1 and described in detail in Appendix A) that demonstrates the proposed FORGE site at Newberry Volcano. In particular, the site

- has ideal temperature profiles at suitable depths, validated by measurements in four deep (~3 km) wells;
- meets the requirements for low permeability and absence of hydrothermal activity within the site;
- has an enormous reservoir of heat with 2.4 GW potential (representing 40 percent of Oregon's total electricity consumption for 30 years);
- builds on 40+ years of intensive characterization; and
- has reduced geological uncertainties based on existing wells and a known seismic response to injection based on more than 4 years of microseismicity data.

Geologic exploration and discovery data collected over the past 40 years from the Newberry Volcano and the surrounding region were assembled to update the Site Characterization Data Inventory (Appendix D), uploaded to DOE's GDR (Appendix B), and integrated into the Conceptual Geologic Model (Appendix A).

The Conceptual Geologic Model for the NEWGEN FORGE site provides a unified framework which identifies the target reservoir units, constrains their spatial extent, and characterizes properties of relevance to EGS. In the conceptual model, the temperature profile within the target reservoir units is constrained by borehole equilibrium temperature measurements from deep wells, backed by thermal conductivity measurements of rock cores and cuttings, diffusive heat flow models, and coupled thermal-hydrological-mechanical-chemical (THMC) models that make use of constraints on porosity and permeability obtained from measured well data, bulk permeability data, and injectivity test data. Additional constraints on porosity and permeability were inferred from seismic and magnetotellurics (MT) models. Fluid content at the NEWGEN FORGE site is limited to a shallow aquifer or aquifers that extends to depths of 150 to 300 m below ground surface, beneath which increasing alteration of the volcanic minerals to clays, zeolites, and other moderate temperature minerals decreases permeability substantially to form a thick low-permeability zone, as observed in cores, well logs, mud logs, and low electrical resistivity values. Structural characteristics have been defined by decades of geologic studies as well as by recent high-resolution LiDAR (Light Detection And Ranging) mapping, by seismic tomographic and waveform modeling, and by MT and gravity inversions. The site lithology and petrology have been defined by cores, well and mud logs, and surface sampling, and geophysical models provide a basis for interpolating between well-ties. The stress regime has been evaluated by regional seismic focal mechanism studies, by interpretation of faults and volcanic features aligned along structural controls, borehole breakouts, and the NEGSD stimulations. The Conceptual Geologic Model provides a dynamic, rather than static, view of conditions in and surrounding the NEWGEN FORGE site. As a FORGE Phase 1 deliverable, the model is intended to demonstrate the suitability of the site based on the extensive characterization performed to date, but it also highlights areas of greater and lesser uncertainty, providing guidance for additional characterization work needed during Phase 2 of the FORGE project.

The Newberry Volcano is one of the most extensively characterized EGS sites in the country, making it an ideal location for implementation of FORGE. Multiple terabytes of high-quality geologic, geophysical, geomechanical, and geochemical data were transferred to the GDR and are now associated, through keywords, to the FORGE effort and specifically to NEWGEN.

3.2 Environmental Information and Permitting

During Phase 1, NEWGEN generated an Environmental Information Synopsis (Appendix C) to outline the permitting needs for FORGE Phases 2A and 2B. NEWGEN FORGE will build on an extensive suite of existing permits and protocols implemented under the NEGSD project to secure new and/or updated permits for FORGE activities. A strong foundation of environmental documentation, prior analysis, and data collection create a foundation for ensuring environmental compliance is achieved throughout all phases of FORGE. NEWGEN member AltaRock[1] is the geothermal leaseholder and has experience and established relationships with the USFS and the U.S. Bureau of Land Management (BLM) in managing the site in a way that avoids or minimizes environmental impacts. This experience will help obtain the necessary regulatory approvals, including compliance with the NEPA in the time frame required.

In Appendix E, the NEWGEN team presents a robust Updated Permitting Inventory to support the establishment and management of FORGE at the Newberry Volcano in Oregon. A full set of permits, which exists for previous geothermal exploration and an EGS demonstration project at the site, is being updated for NEWGEN. The NEWGEN Permitting Inventory supports the FORGE goal to “accelerate breakthroughs” in EGS. The permitting inventory for NEWGEN will be updated by populating it with all existing data assembled during Phase 1 that support the Environmental Information Synopsis and the ability to meet NEPA compliance requirements. Other permitting/regulatory compliance requirements needed by the end of Phase 2B will be reflected in the Environmental Information Volume, which will include another update of the Permitting Inventory of Appendix E.

3.3 FORGE Implementation Plans

During Phase 1, NEWGEN developed plans to address data dissemination and intellectual property (IP) considerations (Appendix F), communications and outreach (Appendix G), an update of stakeholder engagement (Appendix H), sample and core curation (Appendix I), mitigation of induced seismicity (Appendix J), and environmental, safety and health (ES&H) management (Appendix K).

NEWGEN developed an integrated Data Dissemination and IP Plan (Appendix F) to support implementation of FORGE. Under this plan, NEWGEN will promote rapid dissemination of technical data to the geothermal community using GDR (Figure 2). NEWGEN FORGE data dissemination efforts will be executed by a technical team that has extensive experience with operating DOE user facilities, including the Atmospheric Radiation Measurement Climate Research Facility and the William R. Wiley Environmental Molecular Sciences Laboratory. NEWGEN also brings experience with the National Science Foundation’s EarthScope MT program, which is a part of the Incorporated Research Institutions for Seismology Data Management Center; and with the General Electric (GE) Field Vantage™ solution to streamline real-time data and information sharing. Using this experience, NEWGEN will leverage existing strategies, processes, procedures, methods, and implementing mechanisms needed to ensure effective management and dissemination of FORGE data.

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[1] Davenport Newberry Holdings, LLC (DNH) is the leaseholder and AltaRock is the majority owner of DNH and is an authorized agent managing and undertaking activities on behalf of DNH.

The IP plan includes methods for identifying, assigning, and managing IP that is developed during the sustained site characterization efforts, operational and technical support of R&D proposals, as well as the IP generated during the execution of R&D activities. Managing licensing and IP opportunities is a responsibility of the Commercialization Directorate (see PMP Section 1.4.5). Patentable inventions and copyrightable software are expected to result from these activities. Inventions would be relevant to the creation of a geothermal reservoir and measurement or characterization of such reservoirs or the processes involved in generating the reservoir. Copyrightable software could include data processing or integration tools related to data acquired from FORGE measurements, geological model improvements, and EGS simulation, optimization, or prediction tools.

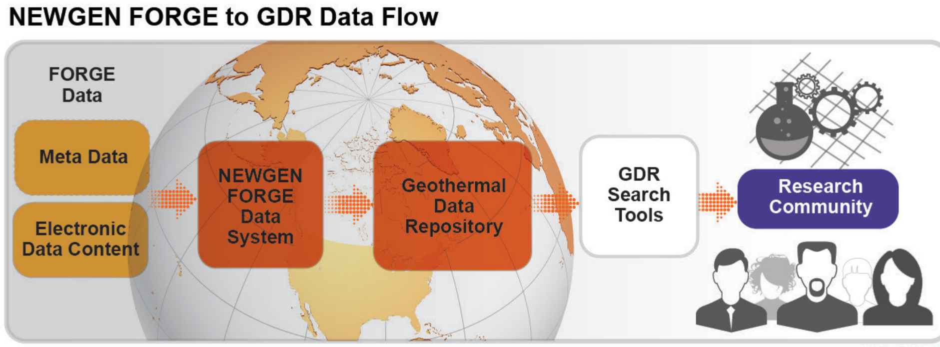

Figure 2. NEWGEN FORGE capabilities help streamline the generation and transfer of data assets to the GDR.

During Phase 1, NEWGEN developed a robust Communications and Outreach (C&O) Plan (Appendix G) to support FORGE. NEWGEN will drive active involvement in FORGE by the subsurface and geothermal communities to support the development, testing, and improvement of EGS technologies. By building awareness of FORGE through the C&O Plan, NEWGEN will inspire a wide variety of scientists and engineers to propose innovative research to gain a fundamental understanding of the key mechanisms controlling EGS success at the NEWGEN FORGE site. Simultaneously, communications efforts will increase public literacy in EGS and meet DOE reporting requirements. NEWGEN will employ cross-channel outreach methods to inform stakeholders and key audiences, including subsurface and geothermal scientists and engineers, industry, local communities and governments, educational institutions, and the science-attentive public (see Figure 3). NEWGEN will employ a combination of traditional outreach strategies and mechanisms (e.g., press outreach, conferences and tradeshows, in-person meetings) and new-media techniques (e.g., social media, search engine optimization, and mobile applications). Through these efforts, NEWGEN will establish EGS as a safe, sustainable source of renewable energy worthy of continued investment, research, and scientific pursuit.

AltaRock has developed excellent working relationships with the local community, as well as state and federal stakeholders. During Phase 1, the NEWGEN team conducted extensive outreach efforts to secure strong stakeholder commitment and the support necessary for FORGE (Appendix H). A key element of this effort was to work with stakeholders to ensure they understand the dramatic difference in scale, focus, and research objectives between the previous EGS demonstration at Newberry Volcano and the NEWGEN FORGE project. Key attributes of the NEWGEN FORGE site that have enabled this level of outreach are its proximity to urban areas and its ease of site access without security restrictions that limit public outreach and site tours. During Phase 1, several local and regional stakeholders toured the site and learned about the scientific and social benefits of NEWGEN FORGE. In addition, NEWGEN staff hosted or attended more than 40 meetings during Phase 1 to discuss the merits of the NEWGEN FORGE project with local, state, and national stakeholders. These wide-ranging stakeholder engagement activities have resulted in an unprecedented level of support for the project, as is evidenced by numerous letters of support included as part of the Phase 2 renewal application.

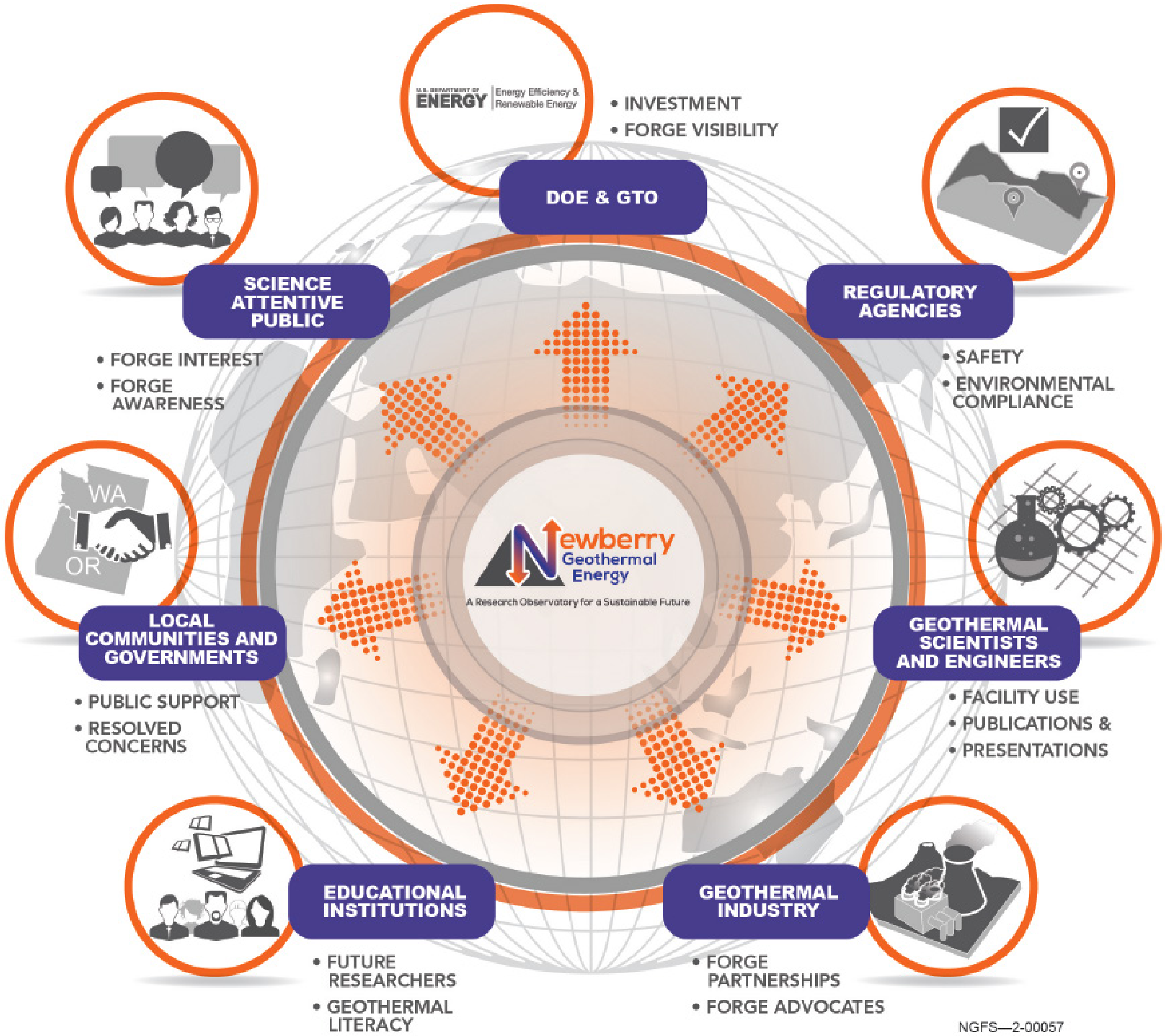

Figure 3. The NEWGEN communications team will employ a variety of cross-channel outreach methods to influence key targets and achieve FORGE goals.

Figure 4. NEWGEN FORGE site stakeholders and regulators.

During Phase 1, NEWGEN developed a comprehensive Sample and Core Curation Plan (Appendix I) to support the NEWGEN FORGE site. The Sample and Core Curation Plan provides mechanisms for sample handling and characterization, cataloging and discovery of the physical samples, and accessing sample metadata through web services. The curation process includes the physical samples, capture of metadata in a digital format, and development of searchable schema through the NEWGEN FORGE Data Management Platform Metadata Association Tool described in Appendix F. The Sample and Core Curation Plan includes a strategy for permanent sample and core storage and preservation beyond the life of NEWGEN FORGE that builds on extensive experience and an existing Geological Sample Repository at OSU in Corvallis, Oregon. This facility, in combination with the NEWGEN Sample and Core Curation Plan, will ensure access for use of the samples and cores by FORGE performers of R&D activities.

During Phase 1, NEWGEN updated the Induced Seismicity Mitigation Plan (ISMP) associated with the NEGSD. The ISMP developed for NEGSD (hereafter referred to as the 2011 ISMP) was being developed at the same time as the Protocol for Induced Seismicity Associated with Enhanced Geothermal Systems that is now required for all EGS projects. Hence, a complete ISMP has already been developed for the NEWGEN FORGE site. In the Phase 1 NEWGEN ISMP (Appendix J), results of the NEGSD were incorporated into seven steps of the Protocol for Induced Seismicity Associated with Enhanced Geothermal Systems. Further effort during FORGE Phase 2 will be conducted to finalize the NEWGEN ISMP for FORGE. Due to the breadth of previous efforts during the NEGSD related to monitoring and analysis of induced seismicity, finalizing the ISMP will be an expedient effort. Furthermore, the final ISMP will be among the most robust and well-supported of such documents in the world.

Safeguarding the health of personnel and the environment is the highest priority of NEWGEN FORGE and the core consortium members. The NEWGEN ES&H Plan (Appendix K) developed during Phase 1 addresses this priority and contains the ES&H policies and procedures associated with operating the proposed FORGE site at Newberry Volcano in Oregon.

During Phase 1, NEWGEN developed a robust R&D Implementation Plan (Appendix L) to support the establishment and management of FORGE. The R&D Implementation Plan provides the technical vision for effectively planning and managing a process for solicitation, review, selection, execution, and supervision of the technologies that will be evaluated at the site. A Science and Technology Analysis Team will establish formal procedures to ensure that selected technologies directly support the objectives of the GTO, and that the process for selecting and evaluating proposals for research is fair, logical, competitive, and consistent with DOE and federal guidelines and regulations.

The NEWGEN FORGE site will be dedicated to the subsurface scientific and engineering community for developing, testing, and improving new technologies and techniques to gain a fundamental understanding of the key mechanisms controlling EGS success—in particular, how to initiate, control, image, and sustain fracture networks in basement rock formations using different stimulation technologies and techniques. This critical knowledge will be used to design and test a methodology for developing large-scale, economically sustainable heat-exchange systems, thereby paving the way for a rigorous and reproducible approach that will reduce industry development risk.

NEWGEN envisions FORGE as an international research center for EGS, where R&D teams, selected after a competitive and rigorous selection process, will find the infrastructure they need to succeed. NEWGEN will provide the facilities; test wells and materials; logistics; permitting; ES&H support; physical sample processing; cyber-infrastructure; outreach and engagement; and management structures necessary to execute research at the NEWGEN FORGE site. This includes the efficient operation and competitive distribution of FORGE resources, as well as the archiving, preservation, and dissemination of the data and knowledge gained.

During Phase 1, NEWGEN established an R&D strategy to incorporate the best input from scientific and geothermal industry to define the most critical science and technology areas for targeted innovation under the FORGE project. In particular, following the 2013 GTO roadmap for strategic development of EGS the NEWGEN FORGE will promote and implement R&D in four main categories, as follows:

- **Better Characterization**
  - *In situ* stress measurements
  - Near-well fracture mapping
  - Reflection seismology in crystalline rocks (fracture zone mapping and targeting)
  - Tracers and active seismic sources (fracture zone mapping)
  - Electromagnetic and ground deformation sensing (fluid infiltration monitoring)

- **Better Drilling**
  - Technologies to assure wellbore integrity
  - High-temperature (HT) steerable hard-rock drill bits
  - Multilaterals/microholes
- **Better Stimulation**
  - Technologies to fracture rock and maintain permeability that use less water and non-toxic chemicals
  - HT proppants, and HT non-toxic degrading materials to place proppants
- **More Efficient and Sustainable Power Production**
  - HT pumps
  - Flexible binary power plants
  - Controlling temperature break-through, short circuit repair
  - Re-drills, re-stimulation.

Results from activities in these four R&D categories will contribute to the ultimate goal of NEWGEN FORGE R&D efforts to design and test methodologies for large-scale economically sustainable heat-exchange systems, resulting in an approach to EGS development that reduces risk for the geothermal industry and utilities.

Annual solicitations will be conducted to award 10 to 20 subcontracts for research and technology testing in characterization, drilling, stimulation and reservoir creation, and efficient and sustainable power production. This R&D Implementation Plan outlines a 5-year strategy that focuses initially on characterization and testing that takes advantage of the existing infrastructure, followed by testing of new stimulation and re-stimulation methods, and finally testing of methods to sustain reservoir integrity and produce power. Processes are defined to maintain the integrity of the proposal process, manage potential conflicts of interest, ensure that proposed work meets ES&H requirements, and provide triage support for the proposal process. Site infrastructure will provide the necessary site characterization and monitoring for implementing R&D projects.

The geothermal community will be engaged through annual workshops conducted in Bend to review NEWGEN FORGE progress and engage the community in the next annual solicitation. Information will be disseminated rapidly by providing data in near real time and issuing annual and topical reports on research progress.

Information gained at the NEWGEN FORGE site will be widely applicable across the Cascade Volcano chain, as well as other magmatically active areas across the Western United States, and more broadly throughout the entire Pacific Rim, including Alaska and Hawaii. Specifically, direct transfer of knowledge and technologies demonstrated at the NEGWEN FORGE site is an important element of communications and outreach (see Appendix G) and commercialization efforts.

4.0 Main Results and Lessons Learned

4.1 Conceptual Geologic Model

During FORGE Phase 1, the organization of four decades of site characterization data, the analysis and synthesis of these data sets, and the process of representing them in the form of a Conceptual Geologic Model has guided NEWGEN thinking about the strengths and weaknesses of the existing data sets and models that may exist, and how uncertainties in site characterization can be addressed during the next phase of the NEWGEN FORGE project. For example, the existing microgravity, resistivity, and seismic models for the NEWGEN FORGE site are consistent with the lithology determined from existing well logs and cores and indicate that at depths and temperatures within the site that are relevant to FORGE EGS there is no evidence of interconnected permeable pathways. This assertion comes with a caveat, however; the assembled geophysical data sets have finite spatial resolving power, which at present is on the order of one-to-several hundreds of meters in scale at the target depths of interest. By focusing future efforts on producing three- (and four-) dimensional (3D and 4D) images of subsurface geophysical parameters within the NEWGEN FORGE site at finer spatial scales, we can better identify baseline as well as induced changes in permeability and injected fluid flow fronts and circulation patterns.

The Conceptual Geologic Model shows a lithologic boundary at depths greater than those designated for FORGE EGS that bounds the area on its northern and western limit. Phase 2 site characterization is designed, in part, to better delineate these lithologic changes, their areal extents and depth ranges, and to provide a higher resolution view of changes in lithology, permeability, porosity, and temperature within the NEWGEN FORGE site.

During Phase 1, the NEWGEN Core Consortium decided to include Well NWG 46-16 in future characterization and recomplete the well for R&D, in order to maximize the impact of drilling funds. Drilling and completion of the upper 4600 ft of NWG 46-16 cost $5.1 M and took 52 days in 2008. During an attempt to air-lift the well with the rig on the hole on October 26, 2008, a blockage formed near the casing shoe (1444 m [4736 ft]). The well was reamed out with a bit on November 4, 2008, but a dummy tool (gauge ring) attempted on December 8, 2008, only reached 1528 m (5012 ft). Given the large CO_2 flows observed in 2013, it is possible that the blockage encountered in 2008 is gone. Well logging is proposed during Phase 2B to evaluate the suitability of NWG 46-16 for Phase 2C and 3 plans. A Go/No-Go decision to proceed with coring and recompletion of NWG 46-16 during Phase 2C will be made during Phase 2B. A No-Go at NWG 46-16 would lead to evaluation of deep well drilling at any of the three pads. Pads 17 and 29 are available for future R&D work, although drilling a deep well at either of these pads is considered a backup plan at this time.

4.1.1 Phase 1 Model

The Conceptual Geologic Model for the NEWGEN FORGE site (Figure 5) provides a unified framework in which to identify the target reservoir units, to constrain their spatial extent, and to characterize properties of relevance to EGS. Achieving a coherent view of conditions within the target reservoir units has involved synthesizing and co-registering multiple data sets including surface geological and geophysical data, and subsurface well data with complementary sensitivity to one or more parameters of interest. The data sets and methodologies used to interpret them are described in detail in Appendix A, Section A.2. Here, the key sources of constraints on the specified EGS parameters are summarized.

The temperature profile within the target reservoir unit is constrained by equilibrium temperature measurements from deep wells backed by thermal conductivity measurements of rock cores and cuttings, diffusive heat flow models, and coupled THMC models that make use of constraints on porosity and permeability obtained from measured well data, bulk permeability data, and injectivity test data. Additional constraints on porosity and permeability also can be inferred from seismic and MT models. Fluid content at the NEWGEN FORGE site is limited to a shallow aquifer that extends to depths of 300 m below ground surface, beneath which increasing clay content decreases permeability substantially to form a basal aquiclude, as observed in cores, well logs, and mud logs. Structural characteristics have been defined by decades of geologic studies as well as by recent high-resolution LiDAR mapping, by seismic tomographic and waveform modeling, and by MT and gravity inversions. The site lithology and petrology have been defined by cores, well and mud logs, and surface sampling, and geophysical models provide a basis for interpolating between well-ties. The stress regime has been evaluated by regional and local seismic focal mechanism studies, by interpretation of faults and volcanic features aligned along structural controls, and by borehole breakouts.

At NWG 55-29, the full span of FORGE target temperatures of 175°C–225°C is reached at depths from 1472 m–1892 m. This depth range is contained in a basaltic andesite-basalt unit bounded on the bottom by a welded lithic tuff, considered to be John Day Formation. At NWG 46-16 (the northeast NEWGEN FORGE pad), the full FORGE target temperature range is projected to be reached at depths from 1752 m–2182 m. This depth range contains rhyolites, dacites, and andesitic basalts. At Pad 17, 2 km west of NWG 46-16, there are no deep temperature measurements—interpolation of the conductive profile at the bottom of a shallow borehole predicts the FORGE target temperature range to be from 1600 m to 2000 m. The N-NE profile connecting NWG 55-29 to NWG 46-16 defines the western edge of measured deep downhole temperatures. To the west of this line, other observations have to be taken into account. Examination of the NEWGEN 3D MT study results show no significant lateral variations in electrical resistivity at depths of 1400–2500 m below the surface of the NEWGEN FORGE site. Variations in resistivity would be expected if a significant quantity of interconnected interstitial fluids or secondary reaction products were contained within the rock matrix, or if there were strong temperature anomalies or significant compositional transitions. The NEWGEN gravity inversion performed during Phase 1 confirms the presence of an anomalous denser body under the three pads. Moreover, the fit of Frone et al.'s (2014) model to observed temperatures at the other well sites on the west flank provides confidence that the conductive heat flow regime holds throughout that area.

On thermal grounds, the target formation volume is therefore contained within depths of ~1472 m (shallowest at NWG 55-29) to ~2682 (deepest at well Pad 17), providing the full FORGE temperature range of 175°C–225°C. The thermally defined target formation volume spans (but is not limited to) the full ~37 km^2 (≃9400 acres) of the NEWGEN FORGE. Taking an average value of 435 m of formation volume thickness, and the NEWGEN FORGE surface area of 37 km^2, the total target formation volume is 16 km^3.

The Conceptual Geologic Model is intended to be a dynamic summary of conditions in and surrounding the NEWGEN FORGE site. As a FORGE Phase 1 deliverable, the model is intended to demonstrate the suitability of the site based on the characterization undertaken to date, but it also highlights areas of greater and lesser uncertainty, providing guidance for additional characterization work during Phase 2 of the FORGE project. As part of subsequent phases, fully coupled multi-physics/chemistry models will be developed for ongoing characterization and, ultimately, development of EGS process control methodologies.

4.1.2 Model Assemblage and Visualization

During FORGE Phase 1, NEWGEN assembled a considerable volume and diversity of site characterization information that is available at Newberry Volcano. From these data, NEWGEN has developed a coherent and self-consistent understanding of the target reservoir depth, temperature profile, thermal conductivity, fluid chemistry, permeability and porosity, structure and lithology of the target formation, regional and in situ stress directions, extent of microseismicity, transmissivity, and impedance/injectivity measurements. NEWGEN used EarthVision™ a software suite for 3D model building, analysis, and interpretation suitable for developing maps and cross sections, reservoir characterization, incorporating well-ties, and providing volumetric visualization and analysis—to assimilate and co-register the diverse data for the site.

The initial EarthVision reference models for Newberry Volcano were constructed as part of the National Energy Technology Laboratory (NETL)/OSU/Zonge project to monitor the NEGSD effort at NWG 55-29 (Mark-Moser et al. 2016), independent of the current FORGE effort. The EarthVision models provided by that project team were further refined by NEWGEN for FORGE Phase 1 using new content, particularly results from new 3D gravity and MT inversions. Section A4 in Appendix A describes in detail the construction of the EarthVision models and provides additional visualizations (Figure 5). Figure 6 displays the major units identified from geophysical signatures: the intrusive bodies and the caldera ring fractures, which coincide with mapped surface ring faults, extended here to a maximum depth of ~3 km and with a lateral thickness to match seismic tomography (Beachly et al. 2012). On the western flank the electrically conductive zone beneath the ring fault in the OSU 3D MT model is represented. The gravity high on the western flank (Waibel et al. 2015, and Appendix A) coincides with the tomographically inferred intrusive zone. The isosurface of 5.5 km/s P-wave velocity in red is inferred to correspond to the zone of increased rock competence.

Figure 7 displays the results of this project's 3D gravity inversion with the locations of the 2014 deep NEGSD stimulation seismic events superimposed. The top-most density layer has been removed to better reveal the seismic event locations.

Note that the cluster of microseisms from the 2014 NEGSD stimulation at NWG 55-29 appears to conform approximately to the boundary of the West Flank Intrusive. This is also seen in the gravity inversion (Appendix A – Section A.2.9). The West Flank Intrusive's northern and eastern boundaries approximately overlap the region of higher resistivity at depth beneath the western flank, as delineated by the OSU 3D resistivity model (Appendix A, Section A.2.8). While the spatial resolving power of both MT and gravity methods will be lower toward and inside of the caldera because of the sparser sampling there, stations to the immediate east of the FORGE site are sufficient to delineate the eastern boundary of both density and resistivity anomalies; consequently this boundary of the West Flank Intrusive is not taken to be an artifact of station coverage, but a deep structural boundary.

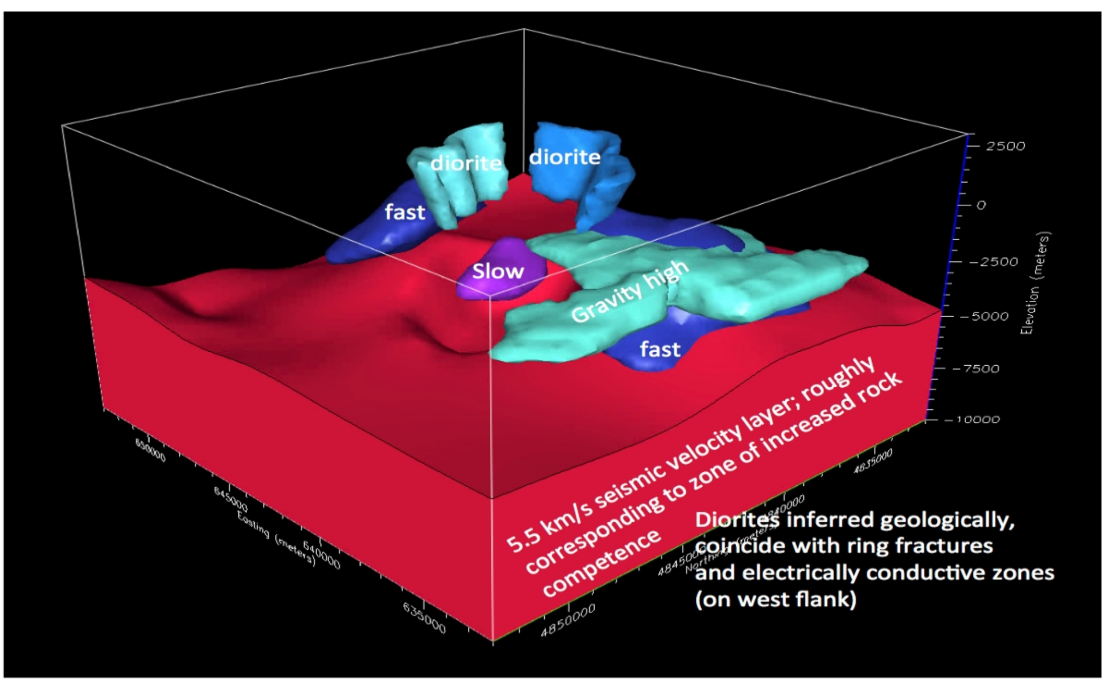

Figure 5. Representative geophysical data layers displayed in EarthVision viewed from the northwest looking toward the southeast (western flank/NEWGEN FORGE site on right-hand side).

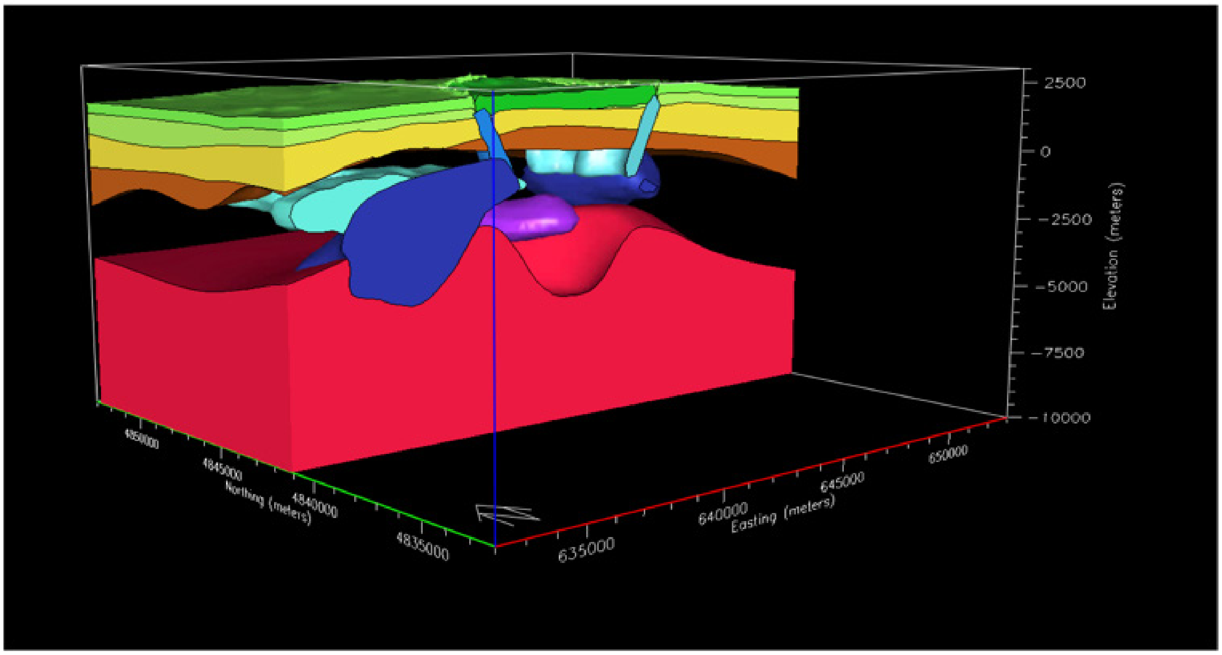

Figure 6. Perspective view of major geophysically detected units with the zone of increased chlorite and epidote removed to show internal units.

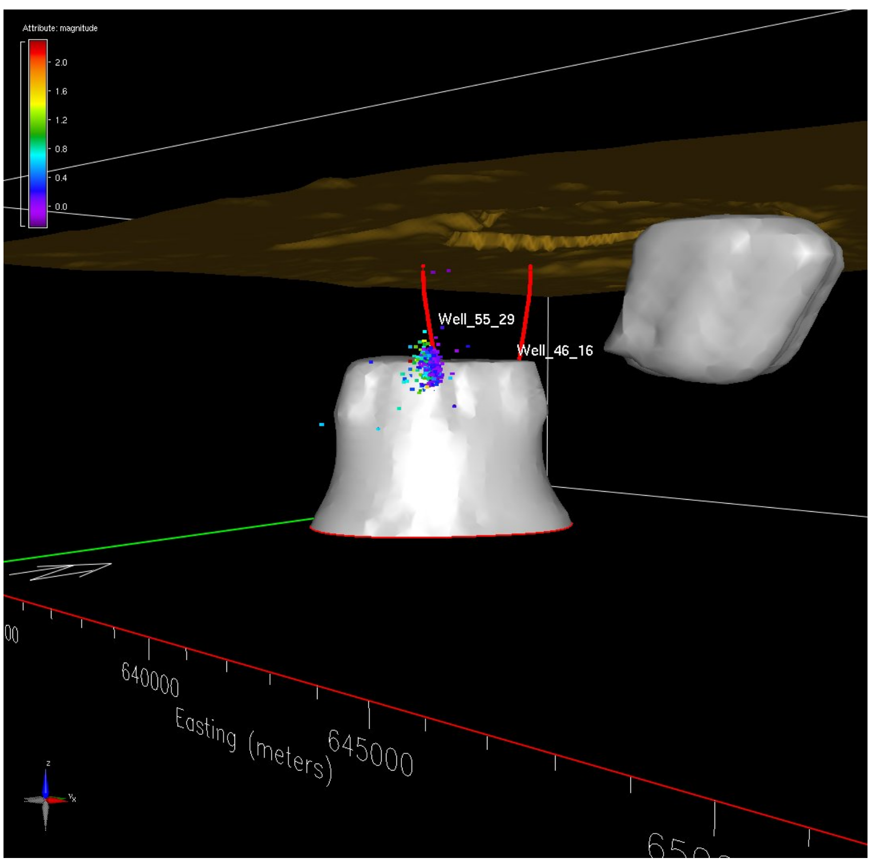

Figure 7. Close-up of the gravity model of the NEWGEN FORGE site showing Wells NGW55-29 and NGW 46-16 with the cluster of microseisms from the 2014 NEGSD stimulation.

At the current FORGE Phase I stage, the EarthVision model is conceptual, i.e., qualitative rather than quantitative, in line with the FORGE Phase 1 goal of developing a Conceptual Geologic Model. Therefore, the visualizations provided above represent conceptual data layers rather than rigidly constrained geologic layers. They are interpretations based on the current state of knowledge. Most importantly, the visualizations do not display the uncertainties in the various parameters. On the contrary, in the absence of constraining information the assumption in the visualizations displayed below is that layer horizons are continuous, and extend to the outer boundaries of the model in the horizontal direction.

Qualitative, quantitative, and/or probabilistic uncertainties in the parameters of relevance are described in detail in Appendix A, Section A.5. The temperature range and depths of the target reservoir units, their spatial extent, and their main properties have low uncertainity. During the proposed Phase 2 of the FORGE project, the EarthVision model will continue to be developed as new data sets are acquired and parameter uncertainties are refined so the conceptual aspects of the geologic model will be transformed into quantitative ones; those uncertainties will propagate into the EarthVision visualizations as well.

4.1.3 Suitability of the NEWGEN FORGE Site to Support GTO/FORGE Goals and Objectives

In summary, the NEWGEN FORGE site presents all of the characteristics necessary for multiple successful EGS R&D projects to be developed within the short time frame of the FORGE project:

- **Conductive temperature gradient** – NWG 55-29 is characterized by an equilibrated conductive temperature gradient of 109–128°C/km (6°F–7°F/100 ft) from the surface casing at 338 m (1108 ft) to total depth. NWG 46-16 is characterized by an equilibrated conductive temperature gradient of 112°C/km (6.2°F /100 ft) between 700 (2295 ft) and 1300 m (4265 ft).
- **High temperatures at relatively shallow depths** – At NWG 55-29, the full span of FORGE target temperatures of 175–225°C is reached at depths from 1472 m to 1892 m. At NWG 46-16, the full FORGE target temperature range is projected to be reached at depths from 1752 m to 2182 m. Similar conditions are expected within 3 km of the well, as evidenced by thermal models and by geophysical methods showing the continuity of geological features under the NEWGEN FORGE site.
- **Large thermal anomaly** – Four deep exploration wells drilled on the northwestern flank of Newberry Volcano, including NWG 55-29 and NWG 46-16, indicate that the NEWGEN project area lies within a large thermal anomaly (21 km^2, 8 mi^2) sufficient for many more wells than the two planned for the FORGE project.
- **Low permeability** – Where intersected by exploration wells, the natural reservoir permeability is very low, as evidenced by the lack of production flow. Studies of core from GEO N-2, just above the NEWGEN depths at NWG 55-29, indicate strong competent rock with very low permeability and porosity.
- **Low well injectivity** – NEGSD stimulation injection tests were performed on NWG 55-29 at various different peak flow rates and wellhead injection pressures. These pre-stimulation tests indicated injectivity of about 0.144 L/s/bar, which is more than an order of magnitude lower than needed for an EGS injection well. Post-stimulation injectivity reached 0.02 (L/s)/bar. The injectivities measured in Wells CE 86-21 and CE 23-22, in the northeast corner of the NEWGEN FORGE site, were, respectively, 0.04 (L/s)/bar and 0.05 (L/s)/bar. The low measured natural injectivity means that the water injected will be efficiently focused on generating new permeability, and that any injectivity improvement will be straightforward to measure.
- **Reservoir integrity** – The lithologies of the site, as indicated by NWG 55-29, GEO N-2, and NWG 46-16, include a wide variety of volcanic, volcaniclastic, and hypabyssal units, ranging from ash

flows and debris flows, to silicic domes, mafic flows, and mafic and felsic dikes. Borehole televiewer (BHTV) images of NWG 55-29 did not reveal any irregularities in the boreholes that would indicate weak zones.

- **No evidence of past or current natural hydrothermal systems** – Mineralogical alteration in the well predominantly reflects diagenetic overprinting by thermal contact metamorphism, with very minor and localized hydrothermal alteration associated with past fluid flow in fractures and joints. No mineralogical evidence of a significant hydrothermal system is observed in the drill cuttings from this well. X-ray diffraction analysis of drill cuttings and core indicates good correlation between modern temperatures and the borehole mineral assemblage.

4.2 NEPA and Other Permitting/Regulatory Constraints

NEWGEN will take advantage of excellent working relationships with the regulatory agencies to build on existing permits and protocols from the NESGD project to gain NEPA approval and secure other regulatory documents for FORGE activities. AltaRock has experience and established relationships with the USFS and BLM in managing the site in a way that avoids or minimizes environmental impacts. OSU has separately permitted a wide footprint of the NEWGEN FORGE area for noninvasive ground-based geophysical monitoring during the NESGD project. This NEWGEN team experience will help obtain the necessary regulatory approvals, including compliance with NEPA, in the time frame required.

The abundance of environmental information about the NEWGEN site simplify and will expedite permitting and preparation of NEPA documentation because much of the environmental impact assessment work has already been completed. Phase 2 and 3 activities will require a suite of permits as noted in Appendices C and E. No significant federal actions planned for Phase 2 should warrant an Environmental Impact Statement, and based on precedence it is probable that the lead federal agency will proceed with an EA. The primary environmental issues of concern for Phase 2 appear to be expansion of the site infrastructure to support further characterization and additional well drilling. Prior environmental documentation addressed issues of this nature and concluded there was no significant environmental impact. Expansion to Phase 3 may require additional NEPA review depending on decisions regarding site expansion and the range of R&D and associated environmental risk. The additional data from site characterization in Phase 2 combined with the existing environmental data on the NEWGEN site will significantly support the completion of any NEPA review required for Phase 3.

Four Environmental Assessments (EAs) have been completed at the NEWGEN site within the past 8 years for geothermal exploration and leasing activities. In addition, an Environmental Impact Statement for vegetation management was recently prepared by the USFS in the immediate project area. The NEWGEN team will draw heavily from these studies, which describe the existing environmental conditions at the site in great detail. The team will also draw from its recent experience permitting the NEGSD project to identify potential environmental impacts and areas of concern with regulators and local stakeholders. NEWGEN will leverage the strong working relationship its team members have established and maintained with the responsible federal and state agencies and will work closely with them during Phase 2A to scope any potential environmental impacts and develop a strategy for NEPA compliance during Phase 2B.

During Phase 2B, the NEWGEN team will work with federal agencies (BLM, USFS) to achieve NEPA compliance and secure all necessary permits for Phases 2C and 3 of the FORGE project. The NEWGEN FORGE site is located entirely on National Forest Service lands as part of the Deschutes National Forest managed by the USFS. The majority of NEWGEN FORGE activities will take place on federal geothermal leases administered by the BLM. Therefore, BLM will be the lead agency and the USFS and DOE will be cooperating agencies for the preparation of any NEPA documents.

Although the exact pathway for the NEPA process is uncertain, NEWGEN foresees that the BLM, as they have in the past, will elect to prepare an EA and the NEWGEN team will work with the BLM to conduct this analysis,[2] building on three previous successful EAs conducted at the site. Based on previous experience with the NEGSD project, likely issues of concern, such as potential induced seismicity and water-quality impacts, will be similar to those that were successfully dealt with in the past. NEWGEN expects the USFS will permit proposed geophysical surveys described in the Statement of Work through a special use permit and NEPA compliance will be met through the use of a categorical exclusion during Phase 2B. Permits for geophysical surveys have been permitted this way in the past to Davenport Newberry Holdings (DNH) and the OSU/NETL 4D EGS monitoring project.

The NEWGEN team will work with federal and state regulatory authorities to secure the required operating permits for Phases 2C and 3. The project already has an extensive list of existing operating permits (detailed in Appendix E) that may be used going forward. New permits will be required after NEPA compliance is secured. The anticipated new permits include the following:

- BLM – Approval of proposed exploration and operations plan and regulation of the project in a phased approach through the use of Geothermal Drilling Permits (GDPs) for drilling new wells and Geothermal Sundry Notices (GSNs) for modifications to existing wells.
- USFS – A special use permit from the USFS for the geophysical surveys and equipment installation proposed during Phase 2B, making use of a categorical exclusion for these activities under NEPA. The current road use permit will be modified to cover new locations for expanding the survey areas.
- Oregon Department of Geology and Mineral Industries (DOGAMI) – DOGAMI drilling permits for new wells and modification permits for new stimulations. Well NWG 55-29 is currently permitted by DOGAMI and any changes to that well will need to be approved by DOGAMI.

NEWGEN has an underground injection control permit with the Oregon Department of Environmental Quality (DEQ) for the existing geothermal wells. These permits are still valid and may be used for the NEWGEN FORGE.

4.3 Environment, Safety and Health

ES&H considerations will be integrated into planning and executing all work on the NEWGEN FORGE project, creating a strong safety and environmental compliance culture (Figure 5) to minimize accidents and incidents. The ES&H Plan for the NEWGEN FORGE developed during Phase 1 builds on policies and procedures that were successfully implemented for both the DOE-sponsored NEGSD and the Integrated Field Research Challenge project for the DOE Office of Science at the Hanford Site. Both of these projects were executed with outstanding safety and environmental compliance records. Elements of an integrated safety management system are incorporated into the NEWGEN approach to ES&H. The NEWGEN team's experience with these previous efforts demonstrates the value of using engineering solutions and industry-developed programs like Stop Work Authority and Job Safety Analysis to mitigate risks to people and the environment.

[2] The ultimate decision about how to meet NEPA compliance will be determined by the federal agencies (BLM, USFS) once they have reviewed the proposed action and completed the environmental analysis. What is stated here is simply our best estimate at this time.

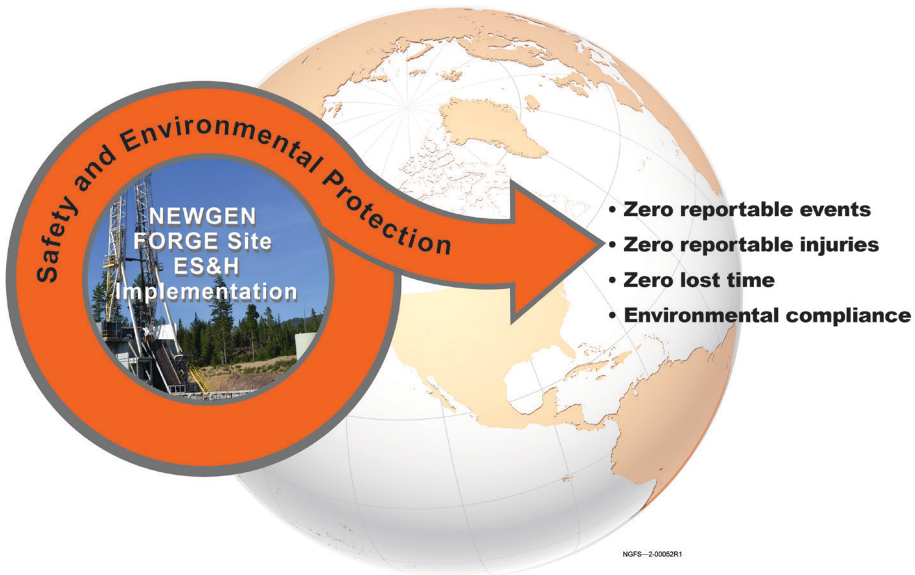

Figure 8. NEWGEN safety and environmental protection.

4.4 Induced Seismicity Mitigation Plan

The NEGSD project led by AltaRock from 2011 through 2015, started with an ISMP (AltaRock 2011; hereafter the 2011 ISMP). NEWGEN updated that ISMP to develop the FORGE plan.

An EGS reservoir is created by injecting fluid at high pressure into a rock formation, which increases fracture permeability and generates seismic vibrations, or "induced seismicity," that can be detected by seismometers and used to map EGS reservoir growth. Most induced seismic events have a magnitude less than 2.0 and are not felt at the surface. However, some EGS projects have generated events large enough to be felt and have caused minor damage. Thus, it is critical that EGS projects follow procedures to evaluate, monitor, and mitigate the risk of felt or potentially damaging induced seismicity.

The 2011 ISMP was updated to incorporate 1) a better theoretical and empirical understanding of induced seismicity from geothermal, wastewater, and oil and gas hydraulic fracturing worldwide; 2) a better understanding of the seismic response of the NEWGEN FORGE site to hydraulic stimulation; and 3) stimulation activities at the NEWGEN FORGE site that will be operationally more varied than those of the NEGSD project, which focused on hydroshearing and zonal isolation involving treatments of thermally degradable zonal isolation materials.

During Phase 1, the 2011 ISMP and the results of the NEGSD project were incorporated into seven steps of the Protocol for Induced Seismicity Associated with Enhanced Geothermal Systems. During Phase 2, the preliminary NEWGEN ISMP will be finalized for implementation during Phase 3. Because of the NEWGEN team's previous monitoring and analysis of induced seismicity during the NEGSD project, finalizing the ISMP will require far less effort than for other sites where previous EGS stimulations have not yet been performed. Furthermore, because the final NEWGEN ISMP will be based on a previous EGS stimulation, it is among the most robust and well-supported of such documents in the world.

Several findings were noted during the update of the 2011 ISMP for NEWGEN FORGE. First, geoscientists from AltaRock studied the history of injection-induced seismicity, starting with the Rocky Mountain Arsenal in 1967 and proceeding up through the Deep Heat Mining project in Basel, Switzerland. Some of the most relevant lessons learned from these projects are described in the 2011 ISMP, while details of AltaRock's analysis can be found in articles by Cladouhos et al. (2010, 2011). Second, the 2011 ISMP included a section on "Recent Injection-Induced Seismicity Theory." The theory of induced seismicity has progressed a great deal in the last 5 years; therefore, much of this section is now out of date. The NEWGEN team is dedicated to further advancing the theory related to induced seismicity and mitigation of risk. We anticipate that the NEWGEN FORGE site on the flank of Newberry Volcano will once again be at the cutting edge of induced seismicity R&D. Lastly, in writing the 2011 ISMP, AltaRock found that the audience—regulators from USFS, BLM, DOE, and local stakeholders—needed some education in seismology in order to understand the issues related to induced seismicity. Therefore, we wrote a primer on seismicity, which is also included in the preliminary NEWGEN ISMP as Section J.11.Lessons Learned During Phase 1 and Plans.

During Phase 1, the NEWGEN team was assembled and expanded from three to five members, adding the considerable strengths of GE-GR and Statoil to the management and development of FORGE. NEWGEN built an expanded consortium to provide great technical breadth and depth, including Blade, the USGS-CVO, Cornell University, LLNL, Paulsson, Inc., Stanford University, and the UO. The team learned to work together and assembled a strong set of plans to move NEWGEN FORGE forward into the future.

4.5 Environmental Constraints and Risks

As described in the results section, NEWGEN will take full advantage of the Consortium's experience and excellent working relationships with the regulatory agencies to build on existing permits and protocols from the NESGD project to gain NEPA approval and secure other regulatory documents for FORGE activities. NEWGEN team experience will help obtain the necessary regulatory approvals, including compliance with NEPA, in the time frame required.

During Phase 1, we identified the following lessons learned:

- NEWGEN can leverage the extensive permitting and environmental compliance activities that have already been carried out at Newberry Volcano as part of the NEGSD project and previous geothermal exploration efforts within the NEWGEN project area.
- Regulating agencies are familiar with EGS, the project area, and have been adaptable to changing situations based on the outcome of field activities.
- Groundwater monitoring before, during, and after stimulation showed no connection between the EGS reservoir at NWG 55-29 and the local groundwater system. The Groundwater Monitoring Plan developed for the NEGSD project can easily be modified for application to NEWGEN FORGE.
- The 2011 ISMP, which was successfully implemented during the NEGSD project with no seismic events exceeding predicted threshold magnitude values, forms a strong basis for NEWGEN seismic monitoring and seismic risk evaluation.
- Project risk for NEWGEN FORGE is reduced by the NEWGEN team having experience with previous stimulation campaigns at the site during the NEGSD project. Results from the previous stimulation efforts will inform future stimulation design and operating parameters to improve successful EGS reservoir practices at the NEWGEN FORGE site.

4.6 Techno-Economic Analysis and Infrastructure

NEWGEN will leverage the extensive existing infrastructure and permits from the NEGSD project for FORGE, reducing the need for future investments. The existing infrastructure that will be leveraged for NEWGEN FORGE includes:

- three existing well pads (Pads 17, 16, and 29) of ~$1.5M total value, each with ca 3.8 million liter sumps;
- two geothermal exploratory wells, NWG 55-29 and NWG 46-16, each with bottom-hole temperatures >225°C, of ~$15M total value;
- eight existing monitoring boreholes completed to depths up to 289 m that are or can be used for seismic monitoring at depth, two of which can also be used to sample and monitor shallow groundwater;
- graded dirt forest roads that provide vehicle access to all three well pads and all of the surface and borehole monitoring station locations;
- two water use permits with the State of Oregon (G-17031 and G-17032) that allow groundwater extraction at a rate up to 3000 L/min (800 gpm) each (water supply demand has never exceeded 2650 L/min [700 gpm] during the 4 years of the NEGSD project).

NEWGEN recognizes the importance of infrastructure to the success of FORGE and has planned to identify gaps in the currently available infrastructure and address those needs. This assessment achieved during Phase 2A will identify the limitations of existing infrastructure, the extent of any upgrades the existing infrastructure requires, and new infrastructure needed for FORGE Phase 3. Here are the main infrastructure categories/needs that were identified during Phase 1:

- *Year-round site access*. As part of the Phase 1 infrastructure assessment, NEWGEN evaluated the cost of maintaining access during the winter, which will vary considerably depending on weather severity. The team evaluated a range of conditions and estimated that site access using snow plows will range from $50,000 to $150,000 per winter, a very manageable infrastructure cost that is more than offset by the value of the existing infrastructure at the site.
- *Site power*. The NEWGEN FORGE site is off-grid, but generators can easily supply the continuous needs of the planned facilities, including buildings and instruments. Contractors for drilling and stimulation, with demands of 2–4 MW will bring large generators that are included in the cost of those tasks. An infrastructure evaluation task planned during Phase 2 will evaluate different options for site power, including diesel generators, liquefied natural gas generators, running distribution power lines from the local electric cooperative, solar panels and storage batteries, and pilot-scale geothermal production on an EGS couplet on Pad 29. AltaRock has already been in contact with the local utility, Mid-state Electric Cooperative, about running distribution and transmission power lines to the site.
- *Site design*. Having three existing pads at the NEWGEN site for development of FORGE, including one at which EGS stimulation has already been performed, provides a distinct advantage for DOE-GTO. The three pads will allow all phases of FORGE—characterization, reservoir development, reservoir enhancement and maintenance, and operations—to be conducted simultaneously.
- *Facilities*. Temporary buildings will be used on the NEWGEN site. The building types may include office space with computer facilities, laboratory space with a wet lab and electronic repair shop, housing for up to five people, and storage containers for drilling and logging equipment. The exact needs for each of the three pads will be evaluated during Phase 2, but there is plenty of space on each pad to accommodate needed facilities.

- *Improvement of existing wells*. During Phase 1, preliminary plans for evaluating the existing wells and boreholes were developed. During Phase 2, NEWGEN will further evaluate and refine use of the wells and workover designs. NEWGEN will perform a technology review of geothermal well technology, including directional drilling, directional planning, casing and cements, and deep borehole monitoring design. Specific steps have been identified for making the best use of the existing wells, including NWG 55-29 and NWG 46-16, for characterization and a number of existing boreholes for temperature and geophysical characterization and monitoring activities.
- *Instrumentation*. Statoil, GE, PNNL, AltaRock, OSU, Paulsson, Inc., and Blade will perform a technology review of instrumentation used in geothermal wells including a gap analysis for downhole monitoring instruments and downhole pumps. NEWGEN will evaluate the GE Field Vantage technology for real-time data reporting.
- Expansion of the existing network of InSAR (Interferometric Synthetic Aperture Radar) corner reflectors as permanent ground deformation networks, as well as reoccupation and expansion of MT and gravity measurement stations throughout the NEWGEN site.

Table 1 gives a preliminary estimate of the total and net costs of the infrastructure that will be implemented for a small part in Phase 2C and mainly in Phase 3.

Table 1. Preliminary cost estimates to develop new or upgrade existing infrastructure.

	GROSS PROJECT COST	VALUE OF EXISTING INFRASTRUCTURE	NET PROJECT COST
Site Preparation (3 pads & water wells)	$2,500,000	$2,500,000	$0
Power and Surface Facilities	$3,000,000	$0	$3,000,000
R&D Infrastructure (monitoring wells, seismic network, fracture imaging, stimulation pumps, etc.)	$12,500,000	$3,000,000	$9,500,000
Injection and Production Wells	$36,300,000	$15,000,000	$21,300,000
TOTAL COST	**$54,300,000**	**$20,500,000**	**$33,800,000**

4.7 Stakeholder Involvement Activities

NEWGEN benefits from a long history of strong stakeholder engagement, cooperation, and participation with geothermal development companies and previous site operators through more than 40 years of intensive characterization and exploration at Oregon's Newberry Volcano. Since commencement of Phase 1 of the project, the NEWGEN team has been conducting extensive outreach efforts to secure strong stakeholder commitment and the support necessary to establish an EGS field laboratory at the proposed NEWGEN FORGE site. A key element of this effort has been working with stakeholders to ensure they understand the differences in scale, focus, and research objectives between the previous NEGSD project and the NEWGEN FORGE project.

Key attributes of the NEWGEN FORGE site that have enabled this level of outreach are its proximity to urban areas and its ease of site access without security restrictions that limit public outreach and site tours. During Phase 1, several local and regional stakeholders toured the site to learn about the scientific and social benefits of establishing the proposed FORGE at the NEWGEN site. In addition, NEWGEN staff have hosted or attended more than 40 meetings over the last 7 months to discuss the merits of the NEWGEN FORGE project with local, state, and national stakeholders. These wide-ranging stakeholder engagement activities have resulted in an unprecedented level of support for the project.

Key successful engagement activities from Phase 1 included the following:

- Project Kickoff Meeting at the USFS Deschutes National Forest Supervisor's Office in Bend, Oregon, on September 14, 2016. This meeting included early engagement of BLM, DOGAMI, the USFS, which will be particularly useful during the NEPA and permitting processes.
- Site visits by DOE, BLM, USFS, DOGAMI, Oregon and Federal Congressional representatives, local community leaders, regional universities, media, and international collaborators. These visits also initiated early engagement of the regulatory community, local stakeholders, and Congressional representatives to gain support for implementation of FORGE.
- More than 40 face-to-face meetings with local, regional, and national stakeholders were used to promote establishing FORGE at Newberry Volcano, answer questions, address concerns, and secure letters of support for the project.
- NEWGEN has discussed modifications needed for existing site permits, as well as any new NEPA permitting activities (e.g., EAs) with the BLM and USFS, to promote successful completion of FORGE Phase 2.
- The NEWGEN team established a website (NewberryGeothermal.com) and social media accounts (e.g., Facebook and Twitter). As of mid-April 2016, the website had over 630 views, 680 Facebook likes, and 250 Twitter followers, indicating interest in the project given its state of development. An informational video highlighting FORGE was developed and is hosted on YouTube with over 200 views, also indicating interest.
- The NEWGEN team developed and distributed a four-page brochure to the stakeholder community (local, regional, and national) and prospective NEWGEN FORGE partners. Feedback on the brochure has been positive.
- The NEWGEN team has begun discussing a potential FORGE Program task entitled Building a Diverse Geothermal Energy Sector (BADGES) to identify and nurture a cohort of talented and underrepresented undergraduate students who might not be aware of the career potential of the EGS sector, or of geothermal energy in general. Although not implemented during Phase 1, this effort will broaden the participation in FORGE.
- The Oregon Legislative Assembly unanimously passed House Joint Memorial 19, which urges the Secretary of Energy and the United States Congress to support selection of Newberry Volcano as the site for FORGE. This is an indication of success for our legislative outreach efforts.

The key to the success of the NEWGEN FORGE Phase 1 outreach program has been its proactive approach and transparency, which have allowed the NEWGEN team to build strong, positive relationships with various stakeholders based on a foundation of trust. This has been achieved through consistent contact, honest dialog, and open and objective discussions. Perhaps the best lesson learned from the local community was the need to communicate how the NEWGEN FORGE project is different from other research projects performed at Newberry Volcano, and particularly, the recent NEGSD project led by AltaRock. As an R&D field laboratory, the NEWGEN FORGE will enable researchers to demonstrate new and innovative technologies that are sure to include novel stimulation techniques and fluids. Previous stakeholder outreach efforts have shown that the composition of fluids and chemicals injected into the subsurface is one of the most polarizing issues among the various stakeholders. Therefore, significant effort was expended during Phase 1 to communicate the objective to demonstrate cutting-edge research, including permeability manipulation, at the NEWGEN FORGE site during Phase 3. This transparent approach to communication has enabled NEWGEN project team members to maintain their strong and trusted standing within the local community, and is positioning the project for success in future phases.

While the primary focus of Appendix H is a retrospective look at stakeholder engagement activities performed during Phase 1, it is anticipated that it will serve as a “living document” to track both the progress of NEWGEN FORGE communications and outreach (Appendix G) and the means by which each stakeholder has been engaged. Relevant lessons learned will continue to be captured and shared with the broad stakeholder and scientific communities.

5.0 Conclusion

NEWGEN FORGE has developed a set of robust plans to demonstrate transformational science and technology in EGS through research at a world-class field laboratory. We envision NEWGEN FORGE as an international research center for EGS with the infrastructure needed for success. Newberry Volcano has already been demonstrated to be extremely favorable for EGS technologies and is perfectly suited for FORGE based on its unique combination of natural attributes and existing infrastructure. The Conceptual Geologic Model builds on more than 40 years of intensive characterization work at the volcano (see Appendix A). Perhaps the greatest attribute of the site is the extensive infrastructure that is already in place, including three well pads with sumps, two deep geothermal wells, two water wells with corresponding water rights, a microseismic network, 8 boreholes (6 in. diameter, ~250 m deep), stimulation pumps, and a full set of permits that are already in place. This infrastructure, efficient operations, and competitive distribution of FORGE resources, as well as the dissemination of knowledge gained, will enable NEWGEN FORGE to meet GTO goals and objectives over the 5 years of FORGE operations.

NEWGEN’s robust strategy for accomplishing GTO’s science and technology objectives for FORGE during Phase 3 operations is summarized as follows and shown in Figure 9:

- Year 1 – Complete fracture network imaging testing and demonstration projects on NWG 55-29, which was previously drilled and stimulated; complete well design development followed by drilling and well completion technology demonstration and testing at NWG 46-16.
- Year 2 – Migrate successful laboratory demonstrations of technologies into field deployment; perform innovative stimulation projects, possibly at multiple depths in Well NWG 46-16; demonstrate innovative geophysical and geochemical monitoring and imaging techniques.
- Year 3 – Continue implementation of novel reservoir stimulation/re-stimulation technologies and methodologies (e.g., non-hydraulic, multi-zone, and simultaneous conduct stimulation of multiple wells); design and drill auxiliary well(s) for R&D complementary to the primary EGS wells.
- Year 4 – Design and drill a production well; conduct flow measurement experiments; initiate reservoir sustainability testing. Continue deployment of innovative geophysical and geochemical monitoring and imaging techniques.
- Year 5 – Characterize the reservoir(s) formed and demonstrate long-term reservoir sustainability techniques; perform testing and evaluation of innovative power generation technologies tailored to EGS resources.

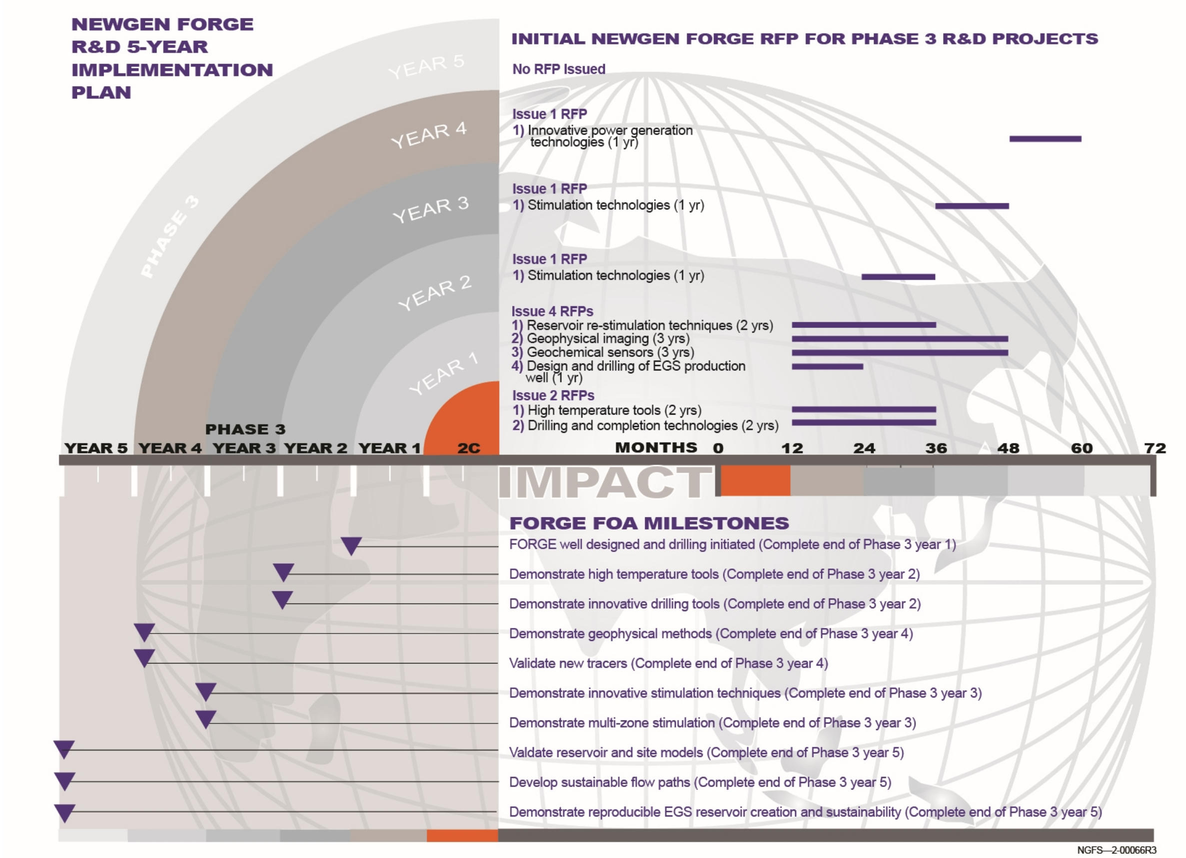

Figure 9. NEWGEN FORGE R&D Implementation Plan.

6.0 Compliance Matrix

MERIT REVIEW CRITERIA	
CRITERION 1: SITE SUITABILITY	
The quality, type, vintage and diversity of the information and data provided in the updated Site Characterization Data Inventory (included as an Appendix in the Phase 1 Topical Report to support the Conceptual Geologic Model)	Appendix A, Sections A.2, A.5; Appendix D, Sections D.3, D.4
Data integration into model: The Awardee’s thoroughness and statistical rigor in bounding the uncertainties of the Phase 1 geologic model with respect to the values and distribution of key subsurface data. This includes data such as target reservoir depth, temperature profile, thermal conductivity, fluid chemistry, permeability and porosity, structure and lithology of target formation, geophysical surveys, regional stresses, in-situ stress directions, expected volumetric extent, extent of micro seismicity, transmissivity, and impedance.	Appendix A, Sections A.4, A.5
Strength of candidate site: Suitability and overall merit of the FORGE site to meet GTO project goals and objectives. This is based on quality and content of the Phase 1 Conceptual Geologic Model, Topical Report and its associated appendices including data such as target reservoir depth, temperature profiles, thermal conductivity, fluid chemistry, permeability and porosity, structure and lithology of target formation, geophysical surveys, regional stresses, in-situ stress directions, expected volumetric extent, extent of micro seismicity, transmissivity, and impedance.	Appendix A, Sections A.2 through A.5

CRITERION 2: TECHNICAL APPROACH AND OPERATIONS PLAN	
The clarity and thoroughness of the SOW to demonstrate effective implementation and integration of operations plans developed during Phase 1, including effective integration of site-wide operation activities such as site preparation and infrastructure development with planning, solicitation, selection, and implementation of R&D technologies through all phases of the FORGE project	SOW, All Tasks; Appendix L, Sections L.5 through L.8
The quality and thoroughness of the Awardee's Phase 1 ISMP and the robustness of the Awardee's technical approach as outlined in the SOW for implementing this plan including the design, installation, and operation of a surface micro-seismic monitoring system and other systems for continuous monitoring at the surface to inform a completed probabilistic seismic hazard analysis	SOW, Tasks 2A-5, 2B-6, 2C-5; Appendix J
The quality of the Awardee's Phase 1 R&D Implementation Plan and the degree to which it and the technical approach as outlined in the SOW incorporate the broader scientific and research community into the planning, development and implementation of the overarching R&D strategy	SOW, Tasks 2C-10, 3-3, 3-12, 3-13, 3-14; Appendix L, Sections L.5, L.6
The robustness of the Awardee's technical approach to perform non-invasive site characterization as permitted by NEPA status (including, but not limited to: detailed geothermometry, ground water/fluid geochemistry, hyperspectral imaging, aeromagnetics, gravity survey, MT, InSAR, and tiltmeter surveys) to inform and improve the Site Geologic Model	SOW, Tasks 2A-7, 2B-7, 2B-8, 2C-4, 2C-5, 2C-6, 3-4 through 3-9; Appendix J, Section J.7, Appendix L, L.7
The clarity and thoroughness of the Awardee's approach for conducting a detailed assessment of infrastructure requirements to support FORGE activities, including the schedule and cost of upgrading existing or establishing new infrastructure, as well as long-term maintenance requirements such as power and transmission, fuel supplies, water supplies, pipelines, roads, and site communications including data transmission and handling	SOW, Tasks 2A-6, 2B-9, 2C-9, 3-7, 3-8, 3-9 ,3-11, 3-16; PMP Section 6.0 (same tasks); Topical Report, Section 4.3.1
CRITERION 3: PROJECT ORGANIZATION AND PROJECT MANAGEMENT PLAN	
The clarity, logic, and effectiveness of the project organization and site management team's structure, including sub-awardees, with respect to the roles and responsibilities and decision making authority of each team member and key personnel as delineated by task assignments discussed and/or illustrated with tables and charts	PMP Section 1.0
The clarity of the Project Schedule as it pertains to the logical sequencing and integration of all work elements (e.g., SOW tasks/subtasks) including R&D technology testing and evaluation, and maintenance of existing and/or new facilities, equipment, and infrastructure necessary to achieve the project goals	PMP Section 4.0
The reasonableness of the project's critical path milestones and decision point success criteria in terms of their ability to be measured and verified, and that they show progress toward achieving budget period and/or project goals	PMP Sections 3.0, 4.0, 5.0
The thoroughness of identified project risks, the appropriateness of their overall degree of risk rating (i.e., the Awardee has appropriately assigned risk potential and impact ratings to the identified risk), and the adequacy of the Awardee's risk mitigation strategies as outlined in the Risk Register tables of the PMP	PMP Section 2.0
The appropriateness of the proposed budget as it relates to all research and site operational activities provided in the SOW and PMP, and the degree to which the budget delineates costs for each sub-awardee	PMP Section 6.0; PMC 123.1; SF-424A

CRITERION 4: COMMUNICATIONS AND OUTREACH	
The quality and innovativeness of the proposed communications and outreach activities proposed in the SOW	SOW Tasks 2A-3, 2B-3, 2B-5, 2C-3, 3-3; Appendix G; Appendix H, Sections H.2, H.3
The frequency and diversity of outreach activities including geographic diversity (i.e. outreach and communication outside of the local community and the proposed site's state), as well as medium diversity (e.g. conferences, printed materials, social media)	Appendix G Section G.3; Appendix H, Sections H.2, H.3
Clarity and breadth of the Awardee's integrated approach to engage stakeholders, local communities and governments, and educational institutions (K-12 and higher education) outside the boundaries of FORGE activities, increase awareness and understanding of fundamentals of EGS technology, to communicate the research objectives of FORGE, and introduce the community to planned FORGE activities as detailed in the Phase 1 Communications and Outreach Plan and Stakeholder Engagement Status Update	Appendix G Section G.3; Appendix H, Sections H.2, H.3
The robustness of proposed Communications and Outreach Plan to leverage existing resources unique to the Prime Awardee or sub-awardees, and engage experienced outside scientific communications and public relation specialists/experts	Appendix G Section G.3; Appendix H, Sections H.2, H.3
CRITERION 5: DATA MANAGEMENT	
The accessibility, utility, innovation, and technical sufficiency of the Awardee's initial data system design and clear demonstration of the Awardee's capabilities to successfully implement this design, resulting in a fully operable, sustainable, National Geothermal Data System (NGDS)-compatible, FORGE Data System/Node that meets GTO objectives for data archival and accessibility	Appendix B, Section B.3; Appendix F Section F.3
The Awardee's level of commitment to facilitate live data-sharing (or in as close to real-time as possible) through the Geothermal Data Repository (GDR) and the NGDS regardless of its proprietary status, date collected, or funding source	SOW, Tasks 2A-6.3, 2A-7, 2B-9.3, 2C-8.3, 2C-9.3, 3-5.1; Appendix F Section F.3
Clear identification of and appropriate mitigation strategies for addressing intellectual property (IP) issues during Phase 2 and beyond in accordance with the Rights in Technical Data-Facility Provision (see Section VIII.P)	Appendix F Section F.4
The dDegree to which the Awardee outlines a reasonable, appropriate, and sustainable strategy for the curation and storage of all physical samples collected at FORGE in the Phase 1 Sample and Core Curation Plan and theadequacy of the Plan to equitably distribute samples to the community and researchers	Appendix I, Sections I.4, I.5
SPECIAL PURPOSE REVIEWS	
NEPA Evaluation:	
The degree to which the Awardee has adequately evaluated the level of foreseeable FORGE site operations and R&D Implementation actions as it pertains to their potential cumulative environmental, safety, health, and socioeconomic effects to be evaluated under NEPA	SOW Tasks 2A-4, 2B-4; Appendix C, Section C.4
The clarity and thoroughness of the Awardee's technical approach as outlined in the SOW for conducting environmental reviews as necessary, in order to ensure the FORGE site meets NEPA and other federal, state, and local regulations and permitting requirements	SOW Tasks 2A-4, 2B-4; Appendix C, Section C.4
Feasibility of meeting FORGE goals and objectives on schedule, given NEPA and permitting constraints as supported by the Phase 1 Environmental Information Synopsis and Updated Permitting Inventory (included as an Appendix in the Phase 1 Topical Report)	SOW Tasks 2A-4, 2B-4; Appendix C, Sections C.4, C.4.4; Appendix E, Sections E.2 through E.12

Thoroughness of the Awardee's approach in the SOW for implementing site safety management as outlined in the Phase 1 Environmental, Safety and Health (ES&H) Plan including procedures and protocols for hazards communication, emergency evacuation and response, and flow down requirements to subcontractors	SOW, All field-oriented tasks; Appendix K
Program Policy Factors	
The quantity and availability of Phase 1 project and site data that the Awardee committed to sharing with the broader community through the GDR, and ultimately the FORGE Data System/Node, regardless of its proprietary status, date collected, or funding source	Appendix B, Section B.3; Appendix F, Section F.3
The degree to which the proposed project, including proposed cost shares, optimizes the use of available DOE funding to achieve programmatic objectives	PMP, Section 6.0; PMC 123.1; SF-424A
Presence of risks (e.g., technical, geological, environmental) that cannot be mitigated and their associated impacts limiting the site's ability to meet GTO goals.	PMP Section 2.0
The results of the geologic model as related to the proximity of and likelihood of inadvertently creating a connection with an existing hydrothermal field	Appendix A, Sections A.2.7.3, A.2.10, A.5.1, A.5.2
The diversity of the sites geology with respect to GTO's existing EGS portfolio and broader applicability of the site's geologic setting for reproducibility	Appendix A, Sections A.2.3, A.4
The results of the Awardee's Phase 1 preliminary techno-economic assessment as discussed in the Phase 1 Topical Report	Topical Report, Section 4.3
The financial capacity and strength of team members who provide their proposed portion of project cost share	Appendix A in PMP; PMP Section 6.0; Cost Share Letters of Commitment
The extent to which the Awardee has already properly completed, solely of its own accord or from prior activity, any of the required or anticipated steps envisioned under NEPA review	Appendix C, Section C.2; Appendix E, Sections E.2 through E.12

7.0 References

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