Clean, domestic, ubiquitous, renewable, baseload energy

Geothermal Technologies Program

Multi-Year Research, Development and Demonstration Plan

2009-2015 with program activities to 2025

Draft

GTP

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Cover Photo is Calpine's Sonoma Geothermal Plant at The Geysers field in Northern California

This page was intentionally left blank.

Foreword

Geothermal energy is the heat from the Earth. Resources of geothermal energy range in depth and quality from the heat in shallow ground, to hot water and hot rock found a few miles beneath the Earth's surface, and even deeper, to the extremely high temperatures of molten rock called magma at even greater depths.

Geothermal energy is a domestic resource that can be used to generate electricity in a clean, reliable, and sustainable manner. Geothermal power plants have almost no carbon footprint, require no purchase of fuel and are not subject to fuel price volatility or supply changes from global energy markets. The current and continued development and application of new, advanced geothermal technologies will enable geothermal energy to become a major component of the United States energy supply portfolio.

According to the Geothermal Energy Association, the United States has approximately 2,930 MWe of installed geothermal capacity and approximately 2,900 MWe of planned capacity from geothermal power plants under development. In 2007, geothermal energy accounted for 4 percent of renewable energy-based electricity consumption in the United States, including large hydropower. That same year, geothermal energy generated 14,885 GWh of electricity.

The results of a DOE sponsored study released in January 2007, "The Future of Geothermal Energy," led to renewed interest in an advanced technology known as Enhanced Geothermal Systems (EGS). EGS are both enhanced and engineered reservoirs created to produce energy from geothermal resources deficient in economical amounts of water and/or permeability. A panel of 18 independent experts, led by the Massachusetts Institute of Technology (MIT), examined the potential of geothermal energy to meet the future energy needs of the United States. The panel concluded that EGS is capable of providing at least ten percent (i.e., 100,000 MWe) of the nation's future electric power needs (approximately 100 quadrillion Btus). In the 2008 Annual Energy Outlook, the Energy Information Administration estimated that 103.5 quadrillion Btus (Quads) were used in 2008 and that 118 Quads will be needed by 2030. In September 2008, the U.S. Geological Survey (USGS) released a resource assessment of the western United States and estimated the EGS generation potential at 517,800 MWe.

By 2015, the U.S. Department of Energy, Office of Energy Efficiency and Renewable, Geothermal Technologies Program, in partnership with geothermal energy developers, plans to demonstrate that EGS is technically feasible. This Multi-Year Research, Development, and Demonstration Plan describes in detail the Geothermal Technologies Program activities for the next seven years, and projects the longer-term RD&D activities. This detailed Program Plan will incorporate Program progress and findings on a regular basis.

Geothermal technology developer evaluation of this Program Plan is essential. We welcome the opportunity to receive your comments and look forward to working with you on this critical energy initiative.

Sincerely,

Ed Wall, Program Manager, U.S. Department of Energy, Geothermal Technologies Program

This page was intentionally left blank.

Table of Contents

Table of Contents

Table of Contents

Executive Summary

Geothermal resources are available across the United States at varying depths, providing a ubiquitous buried treasure of domestic renewable energy. Approximately 3 GWe of hydrothermal geothermal energy is available in the western United States, but theoretically, geothermal sources are available across the United States. The key to being able to use geothermal energy is to find a way to enhance geothermal systems lacking key natural characteristics. Natural geothermal systems depend on three factors to produce energy: heat, water, and permeability. While heat is present virtually everywhere at depth, water and permeability are less abundant.

Geothermal technology is an attractive renewable resource because it can provide a constant source of renewable baseload electricity. While the sun and wind offer a large potential source of renewable energy that varies over time, geothermal technology is uninterruptible and can provide a stable baseload form of energy while diversifying the nation's renewable portfolio.

Geothermal energy has low environmental risk and impact. When used with a closed-loop binary power plant, geothermal systems emit zero greenhouse gas emissions and have a near zero environmental risk or impact.

Geothermal energy is ubiquitous, constant, clean, domestic, and renewable.

Geothermal energy also has the potential to make a significant contribution to energy independence. The resource size and domestic distribution, coupled with technology advancements in Enhanced Geothermal Systems (EGS) will help reduce national dependence on hydrocarbons for electricity generation and free these critical resources for other uses. As such, geothermal energy will supplement the domestic renewable energy portfolio.

The most critical near-term Program activity is demonstration of Enhanced Geothermal Systems. The program has identified a key decision point for determining if EGS is technically feasible by 2015. During 2006 EGS workshops, geothermal industry representatives agreed that initial EGS demonstrations should occur where data already exists indicating a favorable target for potential EGS development and electricity production. Accessibility to the grid, cooperative industry partner(s) with available land, and a favorable environmental setting are all critical for site selection.

Three steps will be important in pursuing EGS demonstrations goals:

- Validating the applicability of existing technologies.
- Establishing a broad knowledge base covering existing technologies.
- Thoroughly documenting the lessons learned to minimize duplicative efforts.

This Multi-Year Research, Development, and Demonstration (MYRD&D) Program Plan is only the first step in a new program strategy. Lessons learned will inform Program decision-making and research and development planning to insure that system demonstrations are of the greatest possible value to industry stakeholders engaged in EGS commercialization. As more analyses are performed and the Systems Demonstrations projects progress, project data will inform future research and development activities.

This page was intentionally left blank.

1.0 Introduction

Prior to the research efforts of the U.S. Department of Energy (DOE) Geothermal Technologies Program (GTP), no commercial geothermal power from the predominant liquid-dominated hydrothermal resources was generated in the United States. Today, the United States is the world leader in online capacity of geothermal energy and electric power generation. According to 2005 state energy data, geothermal energy provided 16,010 GWh of electricity, with a total installed capacity of 2,850.9 MWe.[1]

Current Federal funding of geothermal research and development is authorized by statute to support the U.S. geothermal industry in providing diverse and secure domestic energy supply options. This support also helps the industry maintain a technical edge in world energy markets, thereby enhancing exports of U.S. goods and services and U.S. job growth.

According to a MIT- led panel, many of the key technical requirements to make EGS feasible over a vast area of the country have been met, and the remaining goals are within reach, although certain technical barriers still need to be overcome. According to MIT, DOE and industry will have to invest between $800 million and $1 billion over 15 years to encourage deployment of 100,000 MWe of capacity.

Current efforts on Enhanced Geothermal Systems (EGS) include continued RD&D on: zonal isolation; downhole pumps; fracture characterization; image fluid flow; tracers and tracer interpretation; high-temperature logging tools and sensors and stimulation prediction models.

These efforts build on the technical research base developed over the last two decades.

EGS Demonstrations focus on reservoir pre-stimulation, stimulation, and long-term data collection and monitoring.

Initial DOE Program efforts focused on EGS will also improve existing geothermal technology development occurring in or near existing hydrothermal fields.

Following detailed analysis and technology development, GTP will estimate EGS power production costs and establish cost targets specific to EGS after 2015 when technical feasibility has been established. The Program's EGS cost targets will vary per geographical region.

EGS barriers, goals, objectives, and technical targets will be validated with detailed engineering analysis of the EGS reservoir and its wells. Figure 1.1 provides an overview of the Geothermal Technologies Program research, development, and demonstration timeframe required for technical feasibility and market entry.

1 http://www.geo-energy.org/publications/reports/Geothermal_Production_and_Development_Update_January_16_2008.pdf

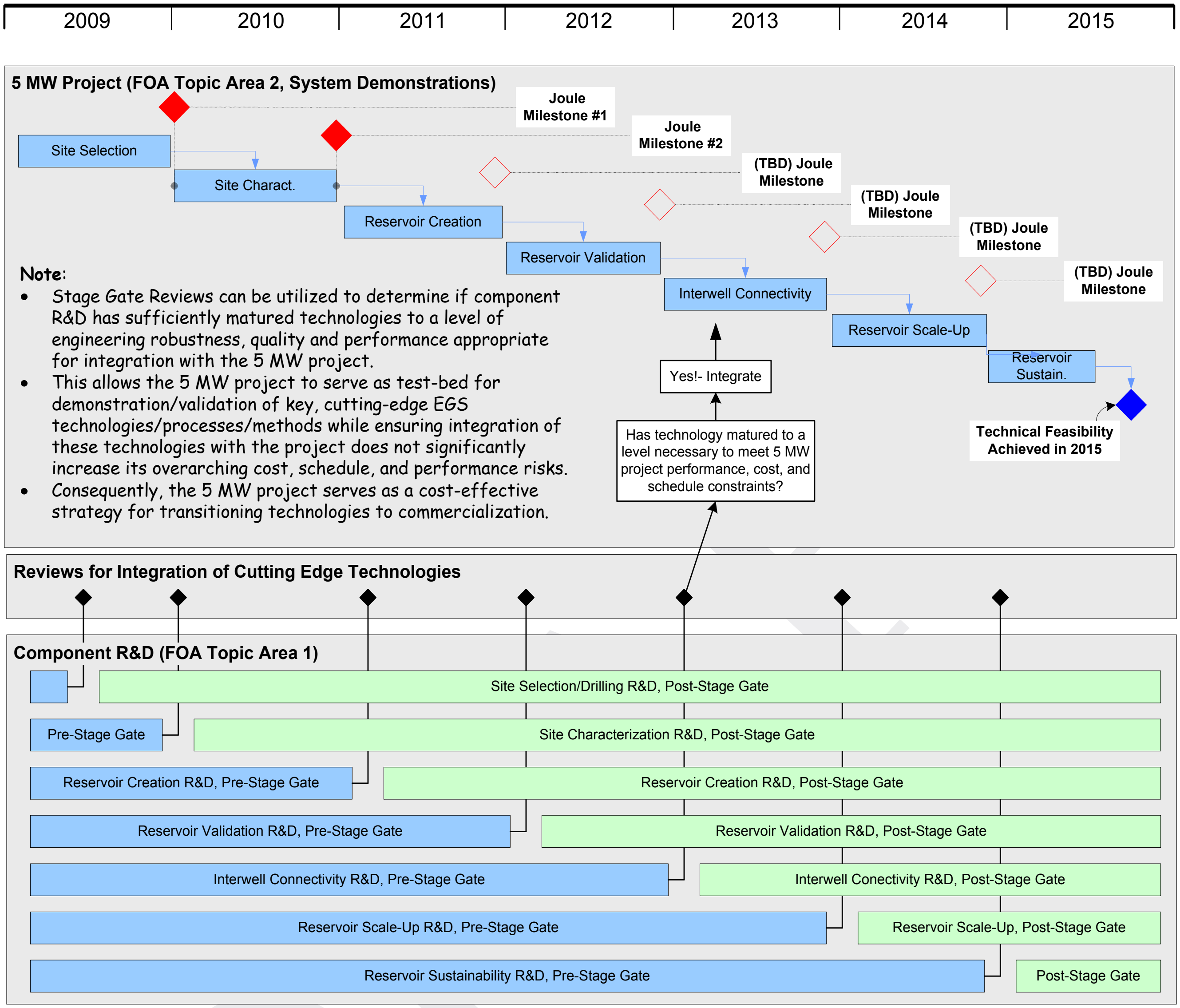


Figure 1.1. Overview of the System Demonstrations and Program R&D Activities

1.1 Background

Commercial geothermal electric power production in the United States began in 1960. In 1970, the Geothermal Steam Act was passed granting the U.S. Department of the Interior responsibility for geothermal resource management. The first Federal sponsorship of geothermal energy research and development (R&D) began the following year with funding from the Atomic Energy Commission and the National Science Foundation. A national commitment was also made to geothermal R&D when the Geothermal Energy Research, Development, and Demonstration Act of 1974 (PL 93-438) passed. In January 1975, the Energy Research and Development Administration took responsibility for the Federal R&D. This responsibility was then passed to the DOE in 1977.

The U.S. geothermal power industry boomed through the end of the 1970s and into the 1980s.

Program exploratory RD&D included cost-shared activities with industry which provided the initial identification of many currently producing geothermal fields. DOE cost-shared exploration drilling programs resulted in development of at least eight currently producing U.S. geothermal fields, briefly described at the end of this section in Table 1.1.

In the 1990s, the increased entry of independent power producers led to industry consolidation as the large oil companies and utilities that once dominated domestic geothermal energy development joined forces with the competition. The 1990s also yielded an increased focus on international markets, the effects of which can be seen decades later as the geothermal industry now represents a more global pool of information and resources. Since 2000, the industry has benefited from renewed interest in domestic development due to reduced production costs for conventional geothermal resources, increased domestic power prices, and incentives such as state Renewable Portfolio Standards (RPS) and Federal production tax credits (PTC).

Tens of thousands of wells are drilled onshore in the United States each year, the vast majority of which belong to the oil and gas industry. Fewer than one hundred are geothermal wells. While almost all of the tools and techniques used in geothermal drilling are derived from the oil and gas (O&G) industry, the small market share gives O&G little incentive to develop or market geothermal-specific products. Only recently did deep gas drilling recently begin to encounter formations above 350°F.

The Geothermal Technologies Program can, however, claim contribution to certain successes. The GTP has played a significant role in the development of technologies enabling more effective operation and management of resources under development. Examples of program achievements include:

Enhanced Geothermal Systems (EGS) Explained

The geothermal reservoir and its wells comprise an EGS system - Naturally heated, but impermeable rock (1) is fractured to create the reservoir, enabling water to flow through production wells (2) as one leg of a circulation loop, passing through a heat exchanger at the surface where power is generated (3), and returning to the reservoir through injection wells (4).

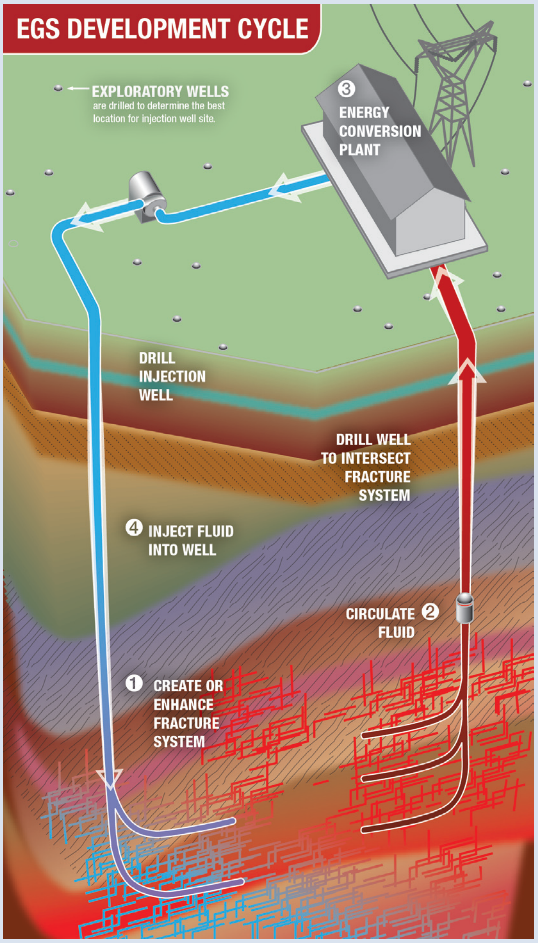


Figure 1.2. Enhanced Geothermal Systems

PDC Bits Program-funded research through Sandia National Laboratories (SNL) led to the development of, polycrystalline diamond compact (PDC) bits which dominate the oil and gas drilling industry. PDC bits made DOE's Top 100 Technologies list and have been a subject of GTP research since the late 1970s when oil and gas wells were primarily drilled with roller-cone bits. In 1977, General Electric introduced a new product, a synthetic bit material of diamond grains sintered with cobalt. Early field results of these nascent PDC bits were disappointing, but SNL conducted additional field tests and studies focused on rock/cutter interaction, diffusion bonding of the compact to the bit, and frictional heating of the cutters. This research catalyzed the growth of an estimated $1.9 billion industry, saving the oil and gas industry billions of dollars annually. PDC bits were then used to drill roughly 60 percent of world footage in 2006, reducing drilling costs from $500/ft to $300/ ft. Improvements in hard rock bit performance will be a critical cost factor in the next generation of anticipated deeper EGS drilling.

Diagnostics While Drilling: SNL also pursued use of continuous-transmission high-bandwidth downhole data to reduce the cost of geothermal drilling by providing a real-time report on drilling conditions, bit and tool performance, and imminent problems (known as Diagnostics While Drilling, or DWD). The driller can now use this information to change surface parameters (e.g., weight-on-bit, rotary speed, mud flow rate) with immediate feedback adding value to virtually every part of the drilling process.

Electronic Mud-Turbine Control System: Typical electronic components are only rated to withstand temperatures of up to 85°C (185°F), and are not suitable for use in geothermal environments. To address this issue, SNL designed an electronic mud-turbine control system based on SOI-SiC (Silicon-On-Insulator and Silicon Carbide) technology that can operate at an ambient temperature of 230ºC for hundreds, and up to, thousands of hours. This technology has yielded further developments in high-temperature electronics.

Geothermal Reservoir Modeling: DOE's sponsorship of geothermal reservoir modeling has had a major impact on the domestic and international community. The DOE-sponsored TOUGH codes are the most widely accepted software for geothermal reservoir modeling internationally, TOUGH codes have been used in over 300 installations in over 30 countries.

A complete list of more recently lauded program technologies can be found in Table 1.2 which lists "R&D 100 Awards" received by DOE Program partners since 1999.

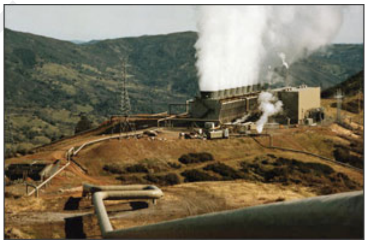
Site Name	Location	Technology Description	Well Depth (meters)	Temperature (Celsius)	Resource Type
Mammoth-Pacific Geothermal Power Plants	Eastern front of the Sierra Nevada Range - Mono County, CA	Two hydrothermal binary power plants generate enough power for approximately 40 MWe.	150-750	150º-175º	 Hydrothermal Binary
Coso Navy 1 Navy 2	Coso Junction, California	Double flash plants 90 MWe each. More than 273 MWe sold.	400-3200	245º-300º	 Hydrothermal Flash
The Geysers Geothermal Area	North of San Francisco, California	The world's largest dry-steam geothermal steam field hosts 22 power plants with capacities ranging from 20 to 120 MWe, producing a net total of over 750 MWe.	650-3350	240º-250º	 Hydrothermal Dry Steam
Hawaii Geothermal Area - Puna Geothermal Venture	South of Hilo on the Big Island, Hawaii	A hybrid-single flash/binary plant 35 MWe.	1400-2500	220º-350º	 Hydrothermal Flash/Binary
Honey Lake Geothermal Area	Lassen County, California and Washoe County, Nevada	Two binary plants, one 30 MWe and one 2 MWe, and one 1 MWe hybrid geothermal project actively producing electrical power.	300-1750	110º-120º	 Hydrothermal Binary

Table 1.1. DOE-Sponsored U.S. Geothermal Fields

Table 1.1. DOE-Sponsored U.S. Geothermal Fields					
Site Name	**Location**	**Technology Description**	**Well Depth (meters)**	**Temperature (º Celsius)**	**Resource Type**
Steamboat Springs Geothermal	Nevada	Six geothermal plants, five binary and one single flash plant totally 100 MWe.	185-1200	215º-240º	 Hydrothermal Binary
Utah Geothermal Power Plants	Milford and Beaver, Utah	Consists of three generating plants: the 23 MWe single flash Roosevelt Hot Springs facility, located near Milford, UT, and one 6.5 MWe binary plant and one 6.5 MWe dry steam plant at Cove Fort Station, located north of Beaver, Utah.	260-2230	138º-267º	 Hydrothermal Flash/Binary

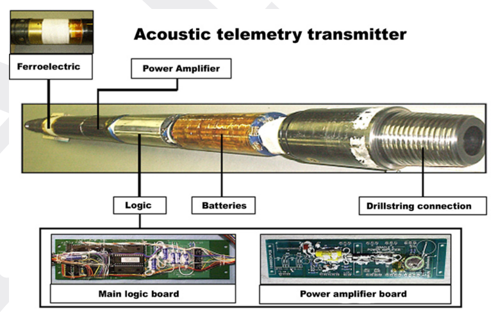
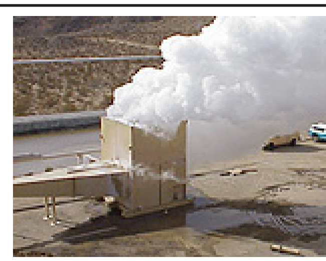
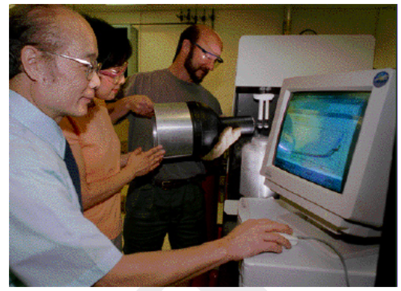
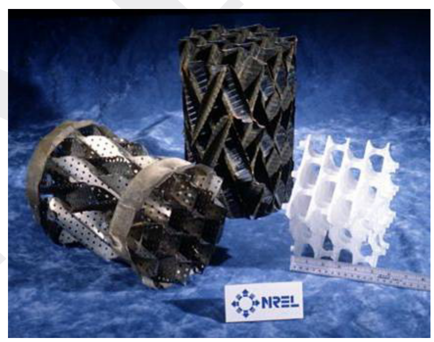
Table 1.2. Geothermal Technology R&D Awards	
Award Description	**Technology**
Low-Temperature Power Conversion (R&D 100, FY 2007): Chena Hot Springs Resort in Alaska is the site of the lowest temperature geothermal resource (165°F) ever used for commercial energy conversion. In previous systems the lowest temperature geothermal resource used for commercial energy conversion was 208°F.	
Solid-State High-Temperature Battery (R&D 100, FY 2006): This solid-state fluoride ion battery has nearly the energy density of competing lithium sulfuryl chloride batteries. Unlike lithium batteries, this battery consists of non-toxic fluoride and is neither explosive nor permeable.	
Acoustic Telemetry (R&D 100, FY 2003): This technology for monitoring downhole drilling conditions, developed in cooperation with industry, transmits data as sound waves that travel through the drill pipe. It has a high data rate (20+ baud) and operates with standard drill pipe or tubing in any kind of fluid. SNL licensed this tool to Extreme Engineering, resulting in an unqualified commercial success.	
Low Emission Atmospheric Monitoring Separator (R&D 100, FY 2003): This technology uses internal baffles and diverters to reduce the amount of carryover emitted during well flow testing, providing a single system for cleaning steam of polluting solids, liquids, and gases.	
CurraLon Coating System (R&D 100, FY 2002): A commercialized Polyphenylene Sulfide (PPS) coating technology for inexpensively reducing fouling in geothermal plant components, developed in cooperation with industry, resists corrosion at high temperatures, transfers heat well, and repairs itself when damaged.	

Table 1.2. Geothermal Technology R&D Awards	
Award Description	**Technology**
Silica Recovery from Brine (R&D 100, FY 2001): This commercial silica extraction process improved the economics of geothermal brine processing.	
ThermaLoc CaP Cement (R&D 100, FY 2000): This commercialized CO_2-resistant cement for geothermal wells may extend well life from less than one year to 20 years in acidic environments.	
Advanced Direct Contact Condenser (R&D 100, FY 1999): This energy conversion technology developed for the geothermal industry can also reduce emissions from many fossil-fueled (coal and natural gas) power plants, improve the efficiency of food processing, and any other industrial process in which steam is condensed.	

1.2 U.S. Geothermal Potential

Historically, geothermal power plants have been built under "ideal" conditions for energy production where heat is close to the surface, the host rock is permeable and porous, and the ground has fluid saturation and recharge rates. The relative scarcity of such ideal hydrothermal sites has been a barrier to widespread geothermal energy use. Since subsurface heat with the potential to produce electrical energy does exist underneath the entire United States, geothermal energy has the potential to provide clean, affordable energy which will diversify our national energy portfolio and increase energy security.

An economically successful geothermal system for electricity production requires three things: heat, fluid and permeability. Geothermal potential in any given area falls into a continuum of potential based at least partially on these three elements. A graphic depiction of geothermal potential as it corresponds to site selection is shown in Figure 1.3. In general, geothermal plants have been developed in locations where all three of these elements exist naturally in appropriate. These ideal areas are known as “hydrothermal” reservoirs. Hydrothermal reservoirs include basin, range and intermountain systems associated with deep groundwater circulation, very high heat flow, and no volcanic activity.

The regions where such ideal conditions exist are relatively limited, especially since active faulting scenarios must be coupled with high temperature gradients and economically drillable depths. Despite great potential for regional impact, limited capacity precludes these associated hydrothermal resources from being a major national energy portfolio component.

			Heat a	Fluid b	Permeability c	Solutions d
	Hydrothermal Reservoirs	1	Acceptable	Acceptable	Acceptable	NONE NEEDED
Engineered Geothermal Systems Technology Application	Enhanced Hydrothermal Reservoirs	2	Too Low	Acceptable	Acceptable	Develop/Use Low T Energy Conversion Technology; or Drill Deeper
		3	Acceptable	Too Low	Acceptable	Re-injection and/or injection of external water source
		4	Acceptable	Acceptable	Too Low	Fracture/Stimulate Rock Formation
	Engineered Geothermal Reservoirs	5	Acceptable	Too Low	Too Low	Introduce Working Fluid AND Fracture/Stimulate Formation
		6	Acceptable	Too Low	Too High	Seal Fractures
		7	Too High	Too Low	Too Low	Create High T working tools, Introduce Working Fluid, AND Fracture/Stimulate Formation
		8	Too Low	Too Low	Too Low	Develop Low T Conversion Technology, Introduce Working Fluid, AND Fracture/Stimulate Formation

Figure 1.3. Potential Site Characterizations

Site Characterization Terms for Figure 1.3

Hydrothermal Reservoirs: Areas with ample heat, fluid, and permeability for geothermal power generation.

Enhanced Hydrothermal Reservoirs: Areas with hydrothermal power generation potential that requires enhancement of one of the three elements to be productive and/or economically viable. In some areas with low heat or low (or decreasing) fluid supply, solutions exist to mitigate these issues. In other areas with ample heat and fluid, but low formation permeability, development and application of EGS technologies will increase power generation capacity.

Engineered Geothermal Reservoirs: Areas with two or more of the required elements for geothermal power production. Creation of new geothermal systems in these locations will require engineering of the required elements. Creation of significant, accessible, and sustainable surface areas/volumes for mining the heat from regions of the universally present naturally heated rock at depth is the distinguishing promise/challenge of Engineered Geothermal Systems.

Locations where all three of the required elements are present, but one element is weak are depicted in rows two through four of Figure 1.3. An explanation of methods to overcome these barriers follows.

- **Low Temperature:** Since recently developed low temperature hydrothermal sites have shown success using low temperature energy conversion methods, temperature is no longer the barrier it used to be.

- **Low Fluid Supply:** As part of normal operations, geothermal power plants will re-inject the produced fluid into the formation to replenish the reservoir fluid volume. If there is significant loss in the system or low fluid in the reservoir to begin with, it is possible to inject an external water source into the formation to replenish the fluid volume. As an example, at the Geysers in California, treated wastewater from two communities is pumped underground to augment steam production.

- **Low Permeability:** Wells drilled within hydrothermal systems may have "skin damage" from drilling mud, or may not have the interconnectivity required to access the total natural resource because of permeability barriers. These may be related to compartmentalization of the reservoir by faults or lithology.

It may be possible to use conventional well stimulation technology to enhance the permeability of the rock formation to increase productivity, thereby also increasing the capacity of the existing hydrothermal plant. Though formation stimulation has been widely used in oil and gas well field applications, the application of this technology to geothermal energy development has not yet been satisfactorily demonstrated.

Despite low permeability, enhancing currently identified hydrothermal locations with high heat and fluid is ideal for developing and testing rock fracture and stimulation technologies because the wells have been drilled, the site and formation, characterized and the power plant constructed.

Figure 1.4 depicts with a gray halo, geothermal growth potential which could be achieved by enhancing existing hydrothermal locations. The DOE-sponsored geothermal fields named in Table 1.1 fall into this category of geothermal energy producers with additional potential. Figure 1.4 includes current, proposed, and potential hydrothermal locations.

Once successfully demonstrated, the stimulation and fracture application can be further adapted to additional locations with low-quality elements. Some of these types of locations are depicted in the bottom four rows of Figure 1.3.

Although the technical evolution to EGS from hydrothermal geothermal production exists on a continuum, there is a fundamental technology divide separating the approaches. The former relies on engineering the reservoir to add water, permeability or both. EGS technology mines heat by creating new heat exchange surface area and reservoirs in the hot rock of the Earth's shallow crust.

The strategy for realizing geothermal potential nationwide will be to first target areas with only two elements missing. The ultimate goal is to develop geothermal energy in environments where all three elements are less than ideal..

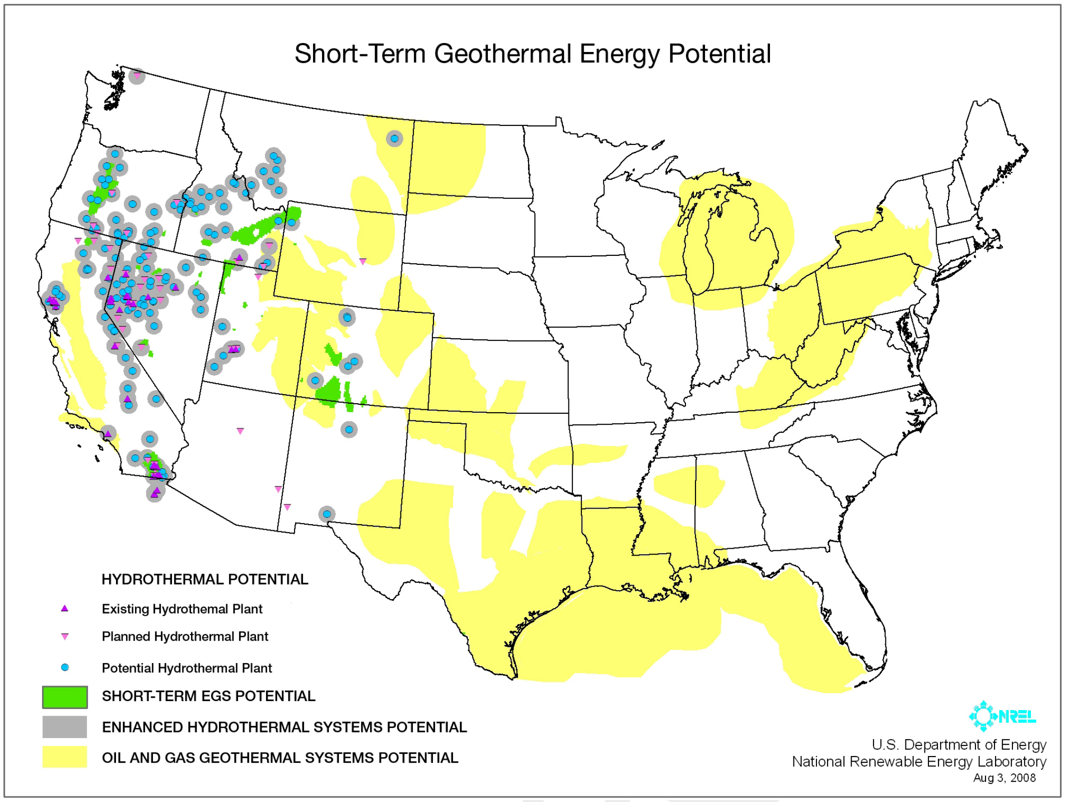


Figure 1.4. Short-Term Geothermal Energy Production Potential[2]

1.3 Market Potential

As a baseload renewable energy source, geothermal energy competes with conventional sources like coal and nuclear power in the bulk power market. Electricity generated from geothermal energy also competes with other renewable energies in green power markets.
Although geothermal energy is currently only a small contributor to the national electricity generation portfolio, it has the potential to become a significant part of a diversified portfolio that includes other sources of renewable energy.

According to the conclusions of the MIT-led panel in January 2007, EGS has the potential to become a major supplier of primary energy for United States. Current technology barriers hinder EGS as an immediate contributor to the national energy landscape, but the panel concluded that with EGS baseload generation potential, 100 GWe of capacity could be generated by 2050. Figure 1.5 shows the estimated EGS resource base for the United States.

2 http://www.eia.doe.gov/oil_gas/rpd/topfields.pdf; SMU heat contour maps.

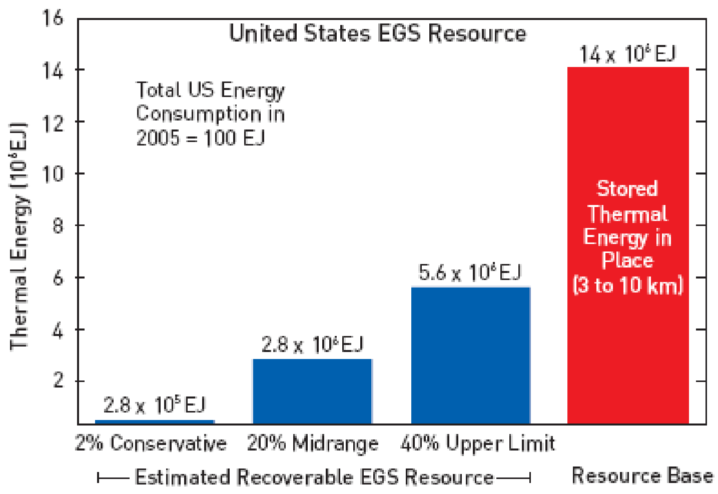


Figure 1.5. U.S. EGS Resource[3]

In addition to the 2007 MIT study, several other recent reports and events have also highlighted the renewed interest and desire for investing in geothermal technologies, including:

- A 2007 U.S. Geothermal Energy Market Report, published by Glitnir Bank, stating that the sales of geothermal powered electricity could increase six-fold from $1.8 billion to $11.0 billion.[4]
- Investment by private equity firms of more than $400 million[5] in geothermal energy, in 2007.
- Large institutional investments: Investors who formerly shied away from geothermal technologies, are now part of the $9.8 billion invested in current expansion and are expected to continue with the $22 billion required over the next ten years.[6]
- $3 billion invested in disclosed deals in the geothermal industry, in 2007– resulting in a 183 percent increase from 2006.[7] Nearly half of the new investment is being spent in the United States.
- Significant attendance at a recent geothermal energy workshop: The Geothermal Energy Association hosted the Geothermal Development and Finance Workshop. This sold out workshop included geothermal industry experts, geothermal government officials, and financial experts interested in geothermal energy investments.
- Strategic industry academia partnerships: In conjunction with Southern Methodist University (SMU), Google plans to spend $500,000 to leverage core capabilities in development of resource maps of known geothermal areas in the western United States.

Other tangible evidence suggests an increase in geothermal development: the U.S. Bureau of Land Management (BLM) has recently increased the number of land leases for geothermal development ten fold. From 2001 to 2007, BLM processed 291 land leases for geothermal development, compared

3 "The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century," Massachusetts Institute of Technology, 2007.
4 Glitnir Bank. "United States – Geothermal Energy: Market Report". September 2007.
5 Ibid
6 Ibid
7 Ibid

to only 25 from 1996 to 2001.[8] BLM continues to conduct open leasing nomination and competitive lease sales for geothermal resources throughout the year including in Washington and Oregon, which previously were not considered viable for geothermal production. Additionally, Federal lands allocated as right of ways for transmission could share locations with geothermal.

1.3.1 Geothermal Energy Potential

Geothermal energy potential exists beneath the entire United States. The short-term targets for implementing the technology developed during the course of this plan are at locations near currently producing hydrothermal plants, or "known" sites, which allow for reduced risk. Reservoir enhancement technologies will be tested in areas of known hydrothermal activity as a first step in development of the technology for greenfield EGS. In many of these locations, low-productivity wells already exist on the outskirts of producing well fields. Adaptation of fracturing technology from the oil and gas industry at these sites may allow these wells to increase the capacity of nearby power plants.

There is also short-term potential for development of oil and gas geothermal systems projects in existing well fields. As shown in Figure 1.4, the yellow "Oil & Gas Geothermal Systems Potential" areas on the map outline the 100 volumetrically largest U.S. oil and gas fields, as defined on the Energy Information Administration (EIA) website.[9] The orange "Short-Term EGS Potential" areas on the map outline the area where the temperature is 180°C or greater at depths of 3,500 meters or less, as defined by Southern Methodist University (SMU) heat contour maps. This MYRD&D Plan will focus on development of geothermal energy at depths where temperatures are between 180 and 250°C until tools are developed that can sustain higher temperatures for long periods of time.

In addition to known hydrothermal sites, the geothermal energy industry is seeking to utilize abandoned oil and gas wells and even oil and gas wells where water is produced as waste. This "waste" water is hot in many locations and has the potential to be used for electricity production. Figure 1.4 also shows the location of the major oil and gas basins in the United States that would have the potential for this kind of "Oil & Gas Geothermal System."

1.3.2 Electrical Energy Potential Future Development

In order to describe the benefits of this MYRD&D Plan and of the long-term goals of the Program, it is necessary to understand the current national state of the electrical energy market. Baseload geothermal energy has great potential to offset other baseload energy resources. The map in Figure 1.6 shows the current distribution of baseload energy in the United States by North American Electric Reliability Corporation (NERC).

8 The risks involved with geothermal energy development, which can be found at the following link: http://www1.eere.energy.gov/geothermal/pdfs/geothermal_risk_mitigation.pdf.

9 http://www.eia.doe.gov/oil_gas/rpd/topfields.pdf

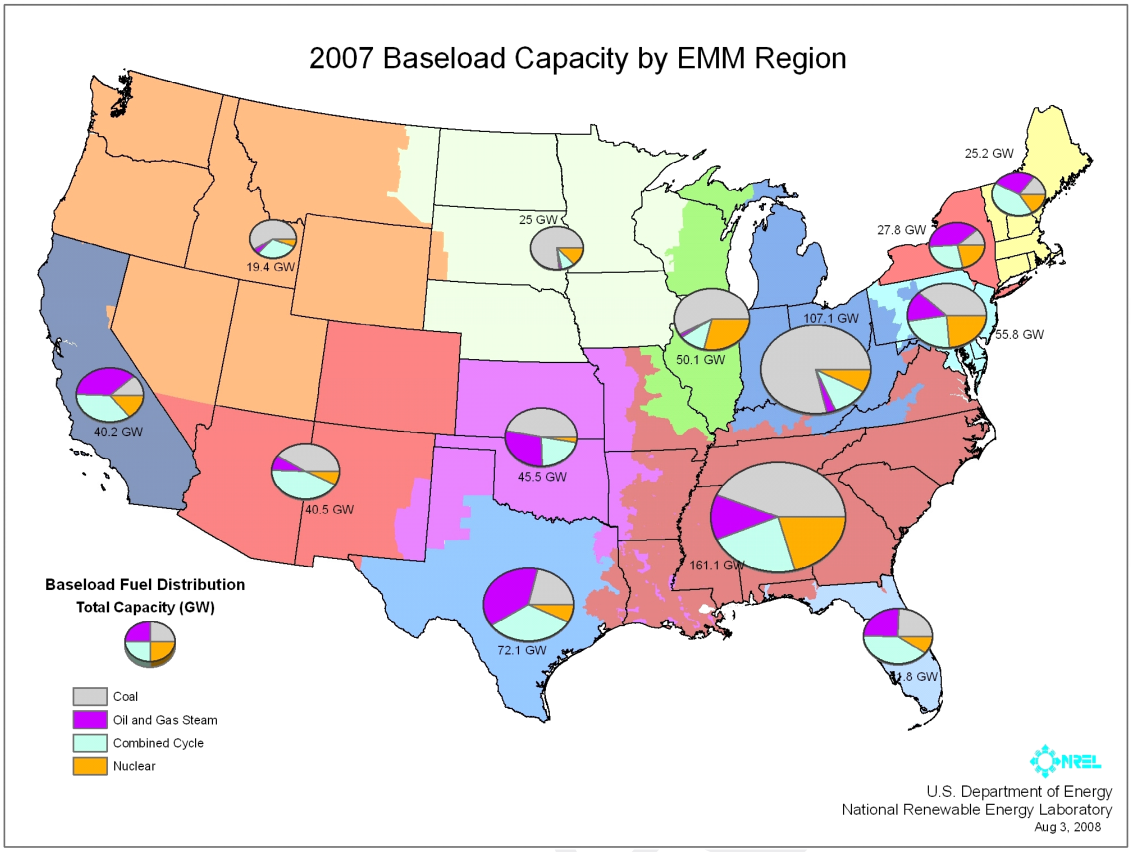


Figure 1.6. U.S. Baseload Energy Fuel Distribution

Most immediately, geothermal energy has the potential to offset coal, oil, and natural gas in the western United States. As the resource potential is better understood, the geographic distribution of geothermal potential will likely spread toward the eastern United States as well.

1.3.3 Heating Energy Potential

Though relatively small in potential, the U.S. heating energy market may be able to benefit from the generation of electricity from geothermal resources. According to the EIA, of the 107 million households in the United States, approximately 7.6 percent use oil as the main heating fuel. Figure 1.7 provides a map of the breakdown of heat energy in the United States. Comparing this map with the short-term geothermal energy potential map (Figure 1.4), geothermal electricity generation can potentially offset heat generation from natural gas and liquid fuels such as heating oil.

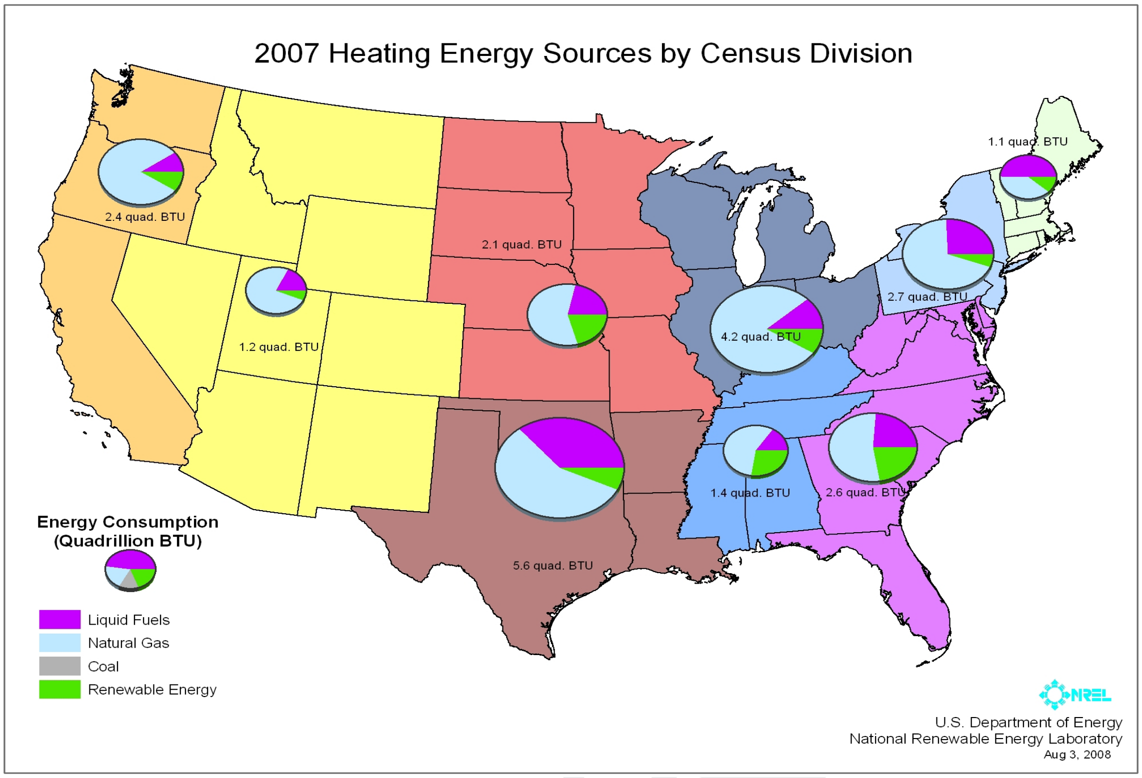


Figure 1.7. U.S. Heating Energy Fuel Distribution

According to the EIA, most heating oil use occurs from October through March. As shown in Figure 1.7 though it is used throughout the country, the central and eastern regions of the United States are most reliant on heating oil. Because homeowners may have to refill tanks as often as four or five times during the heating season, rising or spiking prices are a concern. Refiners are limited in the amount of heating oil they can produce to meet the demands of the winter heating season. When demand goes beyond the production of domestic refineries, heating oil is imported from foreign sources. Reduction in the reliance on foreign heating oil will allow for greater heating energy security in the United States.

1.4 Program Vision and Mission

The new DOE Geothermal Technologies Program is committed to achieving EGS technology readiness by 2015. While GTP's vision and mission reflect the longer-term goal of cost competitive power production, demonstrating EGS technology readiness in the near-term is essential.

Vision

Geothermal energy will be a major source of clean, renewable domestic baseload electricity.

Mission

The Geothermal Technologies Program will conduct research, development and demonstration projects to establish Enhanced Geothermal Systems (EGS) as a major contributor for electricity generation.

Strategic Goal

The Geothermal Technologies Program will develop the technology base that creates and sustains commercial-scale EGS reservoirs.

Performance Goals

- 2015 – Demonstrate the ability to create an EGS reservoir capable of producing 5 MWe.

  __Demonstration Joule Targets__
  2009 - Determine actual pre-stimulation reservoir flow rate for a least one EGS field site.

  2010 - Select a design stimulation plan predicting an increased reservoir flow rate of 10 percent or at least 10 kg/second above EGS field site baseline.

- 2020 – Validate the ability to sustain an EGS reservoir capable of producing at least 5 MWe.

1.5 Key Activities

The Program is facilitating the research and technology developments needed to permit EGS to become a continuous baseload power source in the United States. The GTP collaborates with industry, academia, and national laboratories on several key activities. Table 1.3 describes the key program activities and current focus.

Table 1.3. Program Elements

Key Activity		Geothermal Technologies Program Focus
Research, Development, and Demonstration	Site Selection	Prioritization of sites for future EGS development and estimation of the size of the economic EGS resource; Development of low-risk, economical EGS site selection and characterization capabilities; Drilling, casing, and preparation of the wells for stimulation and production.
	Reservoir Characterization	Identification of preexisting subsurface formation characteristics in order to establish a baseline from which to measure the effectiveness of reservoir creation efforts.
	Reservoir Creation	Stimulation of the target formation by fracturing to create the subsurface heat exchanger component of the EGS.
	Reservoir Validation	Improvement of geophysical methods for downhole detection of fractures and water flow for validation of created EGS reservoirs.
	Interwell Connectivity	Accurate detection of reservoir characteristics including fluid pathways, dynamics, residence time, etc.
	Reservoir Scale Up	Optimization of use of wells and sidetracks to economically exploit EGS resources.
	Reservoir Sustainability	Management of EGS reservoirs for maintenance of reservoir lifetime and productivity.
	Energy Conversion	Development of more efficient energy conversion systems that maximize the power generated for sale from the produced fluids.
System Validation	System Demonstrations: • EGS • Coproduced fluids	Utilization of industry cost-shared projects at, and near producing geothermal fields in order to avoid the cost associated with surface development and to increase the immediacy of economic benefits.
	Technology Validation	Market transformation and commercialization of the tools and processes being developed in the research community.
Strategic Planning, Analysis, and R&D Integration	Strategic Planning and Analysis	Implementation of cross-cutting Program analysis aimed at assessing EGS development scenarios including market, risk, technology, climate change, and environmental impact.
	Systems Integration	Increased support to the Program in the achievement and verification of the capabilities required to reach technology readiness in 2015 effectively and at the minimum cost.
Institutional Barriers		Development of a national geothermal database, revolving fund for exploratory drilling, and workforce education initiative.
International Partnerships		Implementation of the International Partnership for Energy Development in Island Nations and International Partnership for Geothermal Technology Memorandums of Understanding

1.6 Scope of Multi-Year RD&D Plan

Under the guidance as outlined in this MYRD&D Plan, the Geothermal Technologies Program will conduct cost-shared technology research, development, and validation on Enhanced Geothermal Systems which will directly and concurrently support DOE's Strategic Plan ("2006 Strategic Plan, The Department of Energy" http://www.cfo.doe.gov/strategicplan/docs/trifold.pdf).

DOE's Strategic Plan identifies five Strategic Themes (one each for energy, nuclear, science, environment, and management) plus 16 Strategic Goals, four priorities, and nine operating principles. The Geothermal Technology Program directly supports the following goal:
Strategic Theme 1, *Energy Security*
Strategic Goal 1.1, *Energy Diversity:* Increase our energy options and reduce dependence on oil, thereby reducing vulnerability to disruptions and increasing the flexibility of the market to meet U.S. needs.
And concurrently supports:
Strategic Goal 1.2, *Environmental Impacts of Energy:* Improve the quality of the environment by reducing greenhouse gas emissions and environmental impacts to land, water, and air from energy production and use.
Strategic Theme 3, *Scientific Discovery and Innovation*
Strategic Goal 3.3, *Research Integration:* Integrate basic and applied research to accelerate innovation and to create transformational solutions for energy and other U.S. needs.
The Geothermal Technology Program has one GPRA Unit Program Goal which contributes to Strategic Goal 1.1
GPRA Unit Program Goal 1.1.05.00, *Geothermal Technology:* The GTP goal is to develop sustainable, cost-competitive, EGS technologies to enable utilization of our Nation's considerable geothermal energy resources.

As discussed in Section 1.4, this Program Plan has four primary performance goals, three of which are related to systems demonstrations. The primary near-term (2009-2015) focus on fracture creation, detection, and modeling technologies will help in achieving the Program objective to confirm the capability to create EGS reservoirs with acceptable technical parameters and risk. A 5 MWe demonstration is planned by 2015 and is one of the performance goals of this Plan. This performance goal is depicted in the top half of Figure 1.1. Additionally, there are two performance targets:

- **2009:** determine the actual pre-stimulation reservoir flow rate for a least one EGS field site; and
- **2010:** select a stimulation design plan predicting an increased reservoir flow rate of 10 percent or at least 10 kg/sec.

In parallel, the GTP will conduct more long-term R&D on surface and subsurface opportunities for systems cost reduction. Such savings will improve the technical viability and economics of EGS and enable EGS development across a broader range of thermal conditions and depth. This performance goal is depicted in the bottom half of Figure 1.1. The figure also shows how these technological developments will feed into the planned 5 MWe technology demonstration.

The GTP R&D priorities are focused on overcoming technology barriers that demonstrate the greatest potential to hinder the development of viable EGS at acceptable cost, risk, and timeframes. Consequently, the GTP does not focus on technologies that: have limited scope for technical improvement; are likely to have diminishing marginal returns on research investment; or are likely to be provided by the private sector without Federal intervention.

This page was intentionally left blank.

2.0 Program Benefits

This Multi-Year Research, Development, and Demonstration (MYRD&D) Plan is designed to show the program strategy for EGS development in non-ideal geothermal settings, allowing for more widespread use of EGS technology. As discussed in Section 1, there are two programmatic goals: in the long-term, to develop technologies for future EGS development, and in the short-term, to develop a 5 MWe geothermal project by 2015 for proof-of-principle demonstration. The benefits described in this section (and depicted in Figure 2.1 below) will relate to both the short-term goals of this Plan and the long-term goals envisioned by the MIT-led panel report, which suggests that 100 GW of geothermal electricity can be generated by 2050.

Current	Short-term	Long-term
Currently producing geothermal plants take advantage of naturally occurring, shallow hydrothermal systems.	Development of fracturing technology and demonstration of such technology for development of Enhanced Hydrothermal Systems.	In the future, it may be possible to drill in temperatures up to 300°C, to depths of 10,000 meters, and to fracture solid-body, “hot, dry” rocks to create subsurface hydrothermal systems.

Figure 2.1. Spectrum showing how the short-term goals of this Plan relate to current technologies and to the future long-term goals of the Program.

2.1 Energy Diversity

As described in Section 1, geothermal electricity generation has the potential to offset natural gas, nuclear, and foreign oil as a supply of baseload energy in the electrical energy market. By increasing the availability of indigenous fuel in the United States, geothermal energy can improve our national ability to control our economic future and improve our national security.

2.1.1 Offset of Coal and Natural Gas

U.S. reliance on natural gas has been steadily increasing. Energy Information Administration (EIA) data shows that although the consumption of natural gas has remained relatively constant over the last 35 years, use of imported natural gas has gone from five percent of the total U.S. consumption in the early 70s up to 20 percent in 2007, as shown in Figure 2.2.

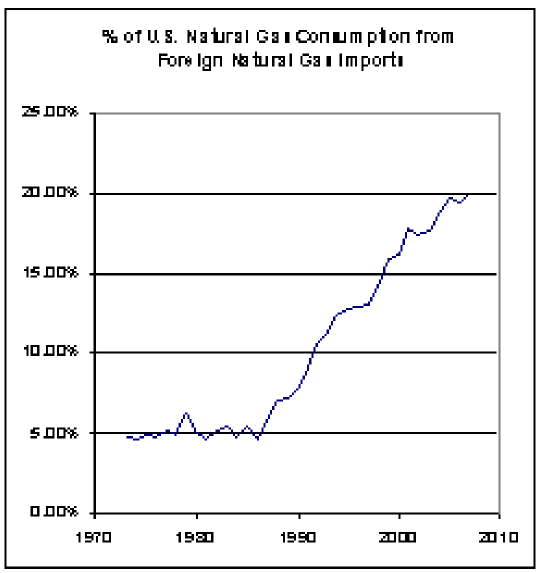
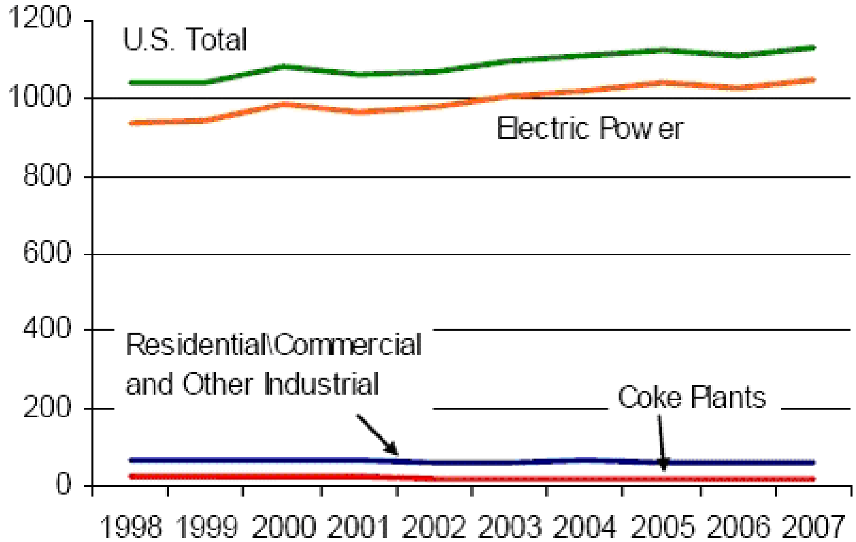


Figure 2.2. Data from EIA website[10]

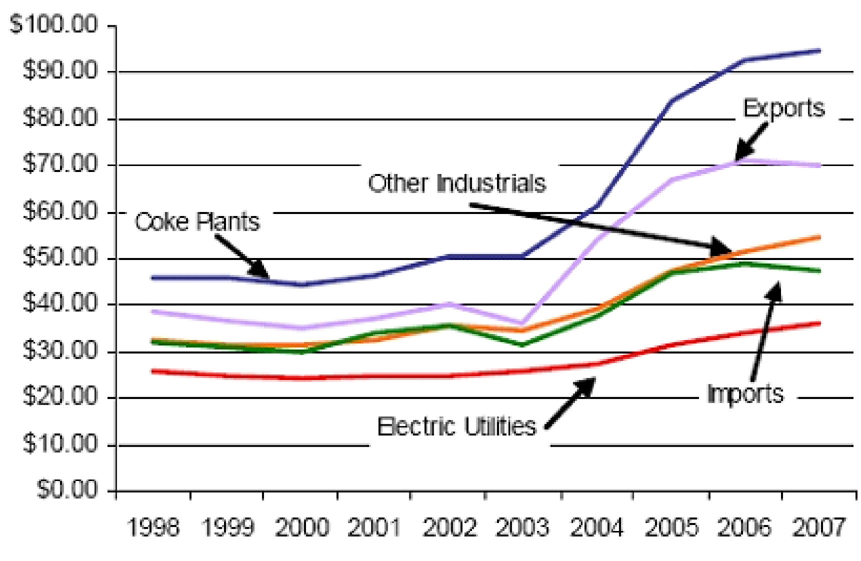
10 http://www.eia.doe.gov/emeu/international/gastrade.html, http://tonto.eia.doe.gov/dnav/ng/ng_move_impc_s1_a.htm

Although U.S. coal consumption has not seen the sharp increases that natural gas has seen, the price of coal has been on the rise. Coal prices at electric utilities increased for a seventh consecutive year, to $36.08 per short ton ($1.78 per million Btu). Price increases were even greater for industrial and coke plant use.



Source: Energy Information Administration, Monthly Energy Review, March 2008, DOE/EIA-0035(2008/03) (Washington, DC, March 2008).

Figure 2.3 Coal Consumption by Sector, 1998-2007 (Million Short Tons)



Source: Energy Information Administration, Quarterly Coal Report, October-December 2007, DOE/EIA-0121(2007/Q4) (Washington, DC, March 2008); Coal Industry Annual, DOE/EIA-0584, various issues; Annual Coal Report 2003, DOE/EIA-0584(2003), (Washington, DC, November 2004); Annual Coal Report 2005, DOE/EIA-0584(2005), (Washington, DC, November 2006) and Electric Power Monthly, March 2008, DOE/EIA-0226 (2008/03) (Washington, DC, March 2008).

Figure 2.4 Delivered Coal Prices, 1998-2007 Nominal Dollars per Short Ton

Because the "fuel" (e.g., hot rocks, water) is secured at the initiation of the project, geothermal electricity generation protects against unstable electricity prices. The resource (heat from the underground rocks) is secured through long-term leases with private, state, or Federal landowners, and the costs to create the heat exchanger prior to electricity generation and distribution are capitalized. This places the cost risk on the developer, and not the consumer. The acquisition of a long-term power purchase agreement from a utility further stabilizes the long-term electricity price and supports the financing and operational costs of a project.

Developing the tools necessary to make geothermal energy feasible and competitive in the electrical energy market will help diversify the portfolio of energy resources.

2.1.2 Offset of Nuclear

While nuclear power is not imported, the public perception of the dangers of nuclear power plants, combined with sky rocketing permitting and construction costs of nuclear power plants, makes geothermal energy an appealing alternative baseload energy resource. Additionally, long-term disposal of extremely radioactive spent fuel is still unresolved. The risk of transporting spent fuel to the proposed Yucca Mountain disposal site may pose greater risk than keeping it on location.

2.1.3 Offset of Foreign Oil

Additional offsets of foreign oil can be achieved in the automobile industry of the transportation market for generation of hydrogen and with plug-in hybrid vehicles that are recharged through the power grid. Furthermore, locally produced geothermal energy offers the advantage of reducing dependence on foreign oil from politically unstable areas. In the last 35 years, U.S. crude oil and petroleum products net imports have doubled, causing an increase in the portion of U.S. oil consumption coming from foreign imports, as shown in Figure 2.5. Today, about 60 percent of oil comes from foreign imports.

Developing the tools necessary to make geothermal energy feasible and competitive in the electrical energy market will help diversify the portfolio of energy resources available to the United States and reduce dependence on foreign imports.

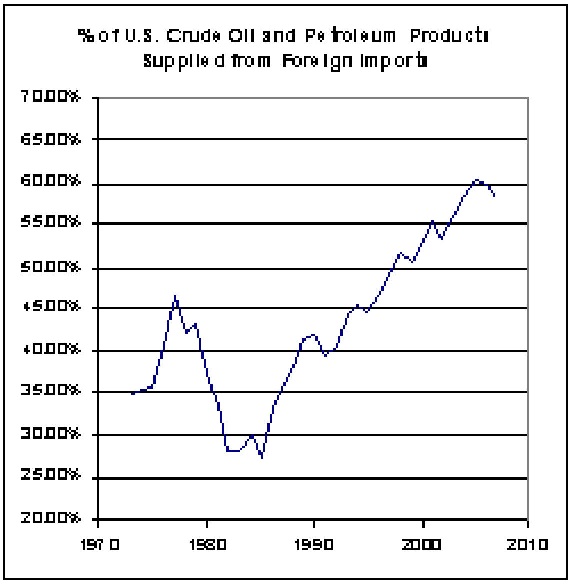


Figure 2.5. Data from EIA website[11]

2.1.4 Contribution to Renewable Energy Portfolios

Twenty states and the District of Columbia currently have a RPS. EGS development can also help states meet Renewable Portfolio Standards (RPS) by complementing other renewable resources.

11 http://tonto.eia.doe.gov/dnav/pet/hist/mttupus2a.htm; http://tonto.eia.doe.gov/dnav/pet/hist/mttntus2A.htm

The major contributions from solar, wind and biomass resources come from the central and southwestern United States. Geothermal energy potential can fill renewable energy gaps in these resource rich locations and can act as a backup at times when solar and wind energy power generation is inconsistent. In these ways, the country has the opportunity to optimize its renewable energy portfolio through increased utilization of geothermal energy. Implementation of renewable energy resources into the energy portfolio reduces these environmental impacts associated with energy production.

2.2 Environmental Benefits

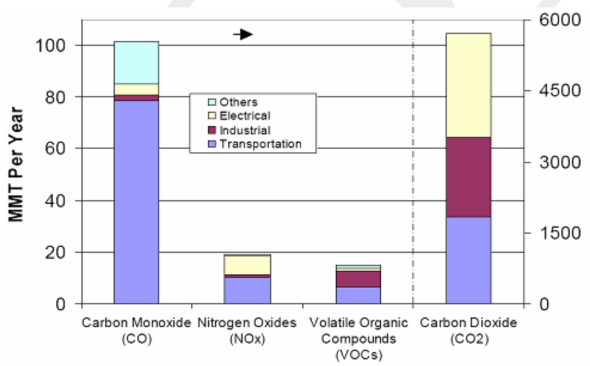
Geothermal energy has the potential to reduce emissions, land use, water pollution, and air quality issues associated with coal production and avoid the security issues associated with massive amounts of nuclear energy production.

2.2.1 Climate Change

Emissions of greenhouse gases (GHGs), like CO2 and methane, have been cited as a major global concern. Build up of these gases in the atmosphere is thought to have detrimental effects on the global climate. Although there is not yet agreement on what the exact impact will be, when it will be realized, or how best to address the problem; there is agreement that emissions of these gases must be reduced.

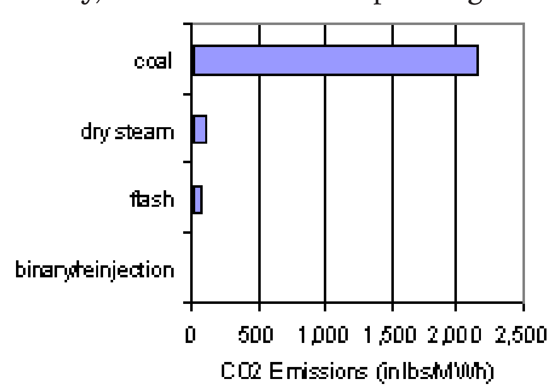
A geothermal power plant emits 35 times less carbon dioxide (CO2) than the average U.S. coal power plant per kilowatt of electricity produced. According to the EIA, dry steam plants such as the Geysers in California emit about 90 pounds of carbon per megawatt-hour (MWh), while flash plants produce only about 60 pounds per MWh. Emission of CO2 can be completely eliminated in closed-loop binary systems, or in systems where waste steam is re-injected into the subsurface reservoir. A coal-fired power plant, on the other hand, produces over 2,000 pounds of CO2 per megawatt-hour of electricity produced.

Geothermal produced electricity can serve as baseload electricity, with some limited operating



Source: Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 25, 2006

Figure 2.6. Emissions from Fossil Fuel Combustion



http://www.eia.doe.gov/emeu/international/gastrade.html, http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html

Figure 2.7. Data from EIA website, and EMPS, Scoping Report, December 2007

variation for peaking production. The benefits of domestic geothermal power plants compare favorably to traditional fossil fuel baseload power plants. Geothermal power plants typically require only minimal short-term outages for equipment repair and overhauls every few years, allowing for high capacity factors. Power output adjustments are possible as demand for electricity fluctuates throughout the day, making geothermal a load following possibility, if needed. The carbon displacement calculations, shown below in Figure 2.8, were conservatively based on geothermal electricity displacing electricity produced by a 50:50 mix of coal-fired and natural gas-fired plants.[12]

Year	Hydro-thermal Capacity	EGS Capacity	Total Capacity	Total Generation	Cumulative Generation	Carbon Avoided	Cumulative Carbon Avoided
	kW	*kW*	*kW*	*GWh*	*GWh*	*Megatonnes*	*Megatonnes*
1990	2800	0	2800	23,300	23,300	191	191
1995	2800	0	2800	23,300	46,600	191	381
2000	2800	0	2800	23,300	69,900	191	572
2005	2800	0	2800	23,300	93,200	191	762
2010	5800	0	5800	48,300	141,500	395	1,157
2015	9800	0	9800	81,600	223,100	666	1,823
2020	13800	1000	14800	123,000	346,100	1,006	2,829
2025	13800	3000	16800	140,000	486,100	1,143	3,972
2030	13800	20000	33800	281,000	767,100	2,303	6,275
2035	13800	40000	53800	448,000	1,215,100	3,662	9,937
2040	13800	60000	73800	614,000	1,829,100	5,030	14,967
2045	13800	80000	93800	781,000	2,610,100	6,397	21,364
2050	13800	100000	113800	947,000	3,557,100	7,765	29,129
2055	13800	100000	113800	947,000	4,504,100	7,765	36,894
2060	13800	100000	113800	947,000	5,451,100	7,765	44,660
2070	13800	100000	113800	947,000	6,398,100	7,765	52,425
2080	13800	100000	113800	947,000	7,345,100	7,765	60,190
2090	13800	100000	113800	947,000	8,292,100	7,765	67,955
2100	13800	100000	113800	947,000	9,239,100	7,765	75,720

Figure 2.8. Carbon Displacement Calculations

12 The factor used to convert electricity production to avoided carbon was 680 metric tones of CO_2 avoided per GWh of electricity produced, based on displacing a 50:50 mix of coal-fired: gas-fired generation, as supplied by David Mooney.

2.2.2 Water Use & Water Quality

Preliminary analysis indicates that geothermal energy may offer significant reductions in water use compared to fossil fuels on a MWh basis. According to the Geothermal Energy Association (GEA), flash geothermal plants, recycling approximately 50 percent of generated steam, use 5 gallons of fresh water per MWh, while binary air-cooled geothermal plants use no fresh water.[13] Analysis is required to evaluate EGS water use. Figure 2.9 shows the relative water use of each of these resources.[14]

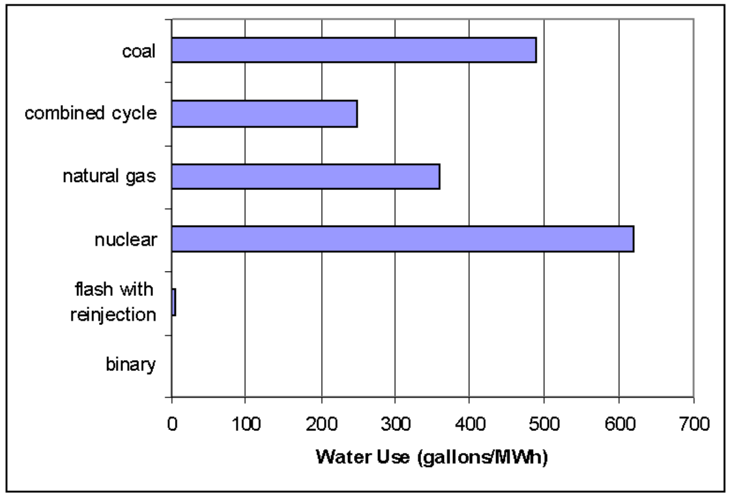


Figure 2.9 Water Use by Energy Technology

Natural geothermal fluids, either occurring at the surface or pumped from depth contain varying concentrations of substances that can be dangerous to humans and the environment. This is one reason geothermal fluids are re-injected into underground reservoirs and are not released into surface waterways. Injection of spent geothermal fluids is regulated by the EPA to ensure that both groundwater and surface waters are protected.

In addition to aiding in pollution prevention, re-injection benefits also include enhanced recovery of geothermal fluids and reduced land subsidence. Wastewater from treatment plants can also be injected into the geothermal reservoir to provide the additional benefit of reduced surface water contamination from municipal water use. At The Geysers facility, 11 million gallons of treated wastewater from nearby Santa Rosa are injected daily into the geothermal reservoir.

As with all technologies, the production of geothermal energy is not without drawbacks. Often hot subsurface water sources have dissolved minerals from the host rock. When these hot waters are pumped to the surface for energy production, gases such as hydrogen sulfide are sometimes released into the atmosphere. Occasionally, geothermal effluents, if stored rather than injected back into the system, deliver beneficial environmental effects such as surface wetland creation and recreational geothermal pools.

2.2.3 Surface Land Use

Both geothermal and coal plants use steam to turn a turbine, which powers a generator that converts rotational energy into electricity. Geothermal plants obtain this steam from below ground, while coal plants require surface land for making steam both for fuel handling and fuel burning. Geothermal power plants can be designed to blend into their and can be located on multiple-use lands that incorporate farming, skiing, and hunting. Over 30 years (the period of time commonly

13 Kagel, Alyssa, Dianna Bates and Karl Gawell; A Guide to Geothermal Energy and the Environment; Geothermal Energy Association, April 2007; http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf
14 AWEA (http://www.awea.org/faq/water.html); http://www.geo-energy/publications/reports/Environmental%20Guide.pdf

used to compare the life cycle impacts from different power sources) a geothermal facility uses 404 m2 of land per GWe.[15]

In addition, with geothermal there is no need for mining (as in coal) or ground disturbance. Additionally, there is no need for processing (as in a coal plant) and no need for transportation of fuel since the plant functions on the surface.

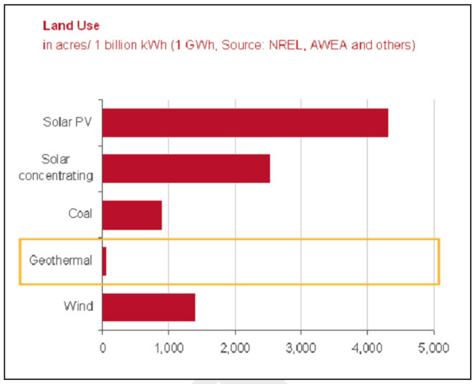


Figure 2.10 Surface Land Use for Renewables

2.2.4 Critical Air Pollutants

Air quality is a major national concern: approximately 60 percent of Americans live in areas where levels of one or more air pollutants are high enough to affect public health and/or the environment. As previously shown in Figure 2.6, personal vehicles and electric power plants are significant contributors to the Nation's air quality problems. Most states are now developing strategies for reaching ambient air quality goals and bringing major metropolitan areas into alignment with the requirements of the Clean Air Act. The State of California has been one of the most aggressive in developing compliance strategies and has launched a number of programs targeted at improving urban air quality.

In 2006, the U.S. production of electric energy emitted an average of 1,271 pounds of CO2 per MWh.[16, 17] This production also emits regulated pollutants, such as NO2 and SO2, and pollutes acres of land and surface water. Emissions of NOx, SO2, and particulate matter (PM) from electricity production are a significant concern. NOx emissions can cause lung irritation, coughing, smog formation and water quality deterioration, while SO2 emissions can cause wheezing, chest tightness, respiratory illness and damage to ecosystems. PM emissions can cause similar effects including asthma, bronchitis, cancer, atmospheric deposition and visibility impairment. Figure 2.11 shows that the burning of coal emits approximately 10,000 times more sulfur dioxide and 4,000 times more nitrous oxides per MWh than a geothermal steam plant.[18]

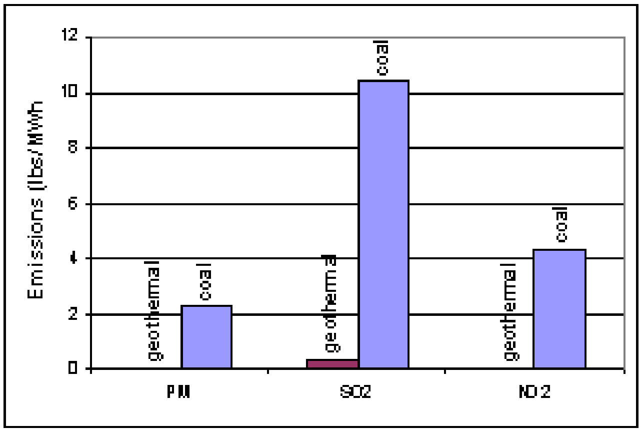


Figure 2.10 Surface Land Use for Renewables

Because geothermal power plants do not burn fuel like fossil fuel plants, they release virtually no air emissions and can offset coal power plants.

15 Kagel, Alyssa, Dianna Bates and Karl Gawell; A Guide to Geothermal Energy and the Environment; Geothermal Energy Association, April 2007; http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf
16 Energy Information Administration, Electric Power Annual, October 22, 2007, http://www.eia.doe.gov/cneaf/electricity/epa/figes1.html
17 Energy Information Administration, Emissions of Greenhouse Gases Report, Table 9, DOE/EIA-0573(2006), November 28, 2007, http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html
18 GEA: http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf (April 2007 report)

2.2.5 Possible Use of CO2

It may be possible to inject CO2 into depleted or dry geothermal systems, providing a win-win situation for both the environment and the energy market. Although the emission levels are less than the ambient levels of these gases, and significantly lower than emissions from coal, it is possible, and often quite useful, to re-inject the steam byproduct back into the underground reservoir, eliminating emissions altogether.

Using CO2 instead of water as a heat exchanging fluid for EGS also offers several other benefits. Re-injecting water into subsurface fractures has the potential to induce landslides, land subsidence and in some cases micro-seismicity, but many experts believe that the overall benefits from this reinjection can far outweigh the risks. At the temperature and pressure conditions expected for EGS, CO2 is a supercritical fluid with characteristics that make it a very effective medium for heat transmission. CO2 is not a strong solvent for rock minerals, nor is it corrosive to metals. Thus some of the problems of water-based systems can be avoided. CO2-based EGS would also avoid the heat losses associated with a binary system. In addition, water is a scarce and valuable commodity in many areas. Finally, CO2-based EGS might provide an alternative means of geologic carbon sequestration.

2.3 Economic Benefits

2.3.1 Job Creation

As the WGA states, "geothermal resources provide economic development opportunities for states, bringing jobs to rural areas as well as tax and royalty income. Based upon the findings of a recent industry employment survey (Geothermal Industry Employment: Survey Results & Analysis, Cedric Nathanael Hance, September 2005), achieving 5600 MW of geothermal production would result in 9,580 new full-time jobs from geothermal power facilities, and an additional 36,064 person-years of manufacturing and construction employment. An economic multiplier effect would increase these numbers further.

2.3.2 Capital Savings and State Income Generation

In addition, while the economic potential of geothermal energy production from EGS is unknown, preliminary economic modeling in National Energy Modeling Systems (NEMS) and the MARKAL family of models predict the potential benefits of DOE research funding only, excluding industry research, development, deployment and build out of geothermal power plants. Figure 2.12 shows the industry and consumer savings at both the fiscal year (FY) 2010 target budget and FY 2009 over budget.

New power facilities would also increase state and local tax and royalty income. In 2003, The Geysers Geothermal Field in California, with almost 1,000 MW of geothermal power generation capacity in place, paid $11 million in property taxes to two counties, while royalty revenues added several million dollars more to state and county revenues."

	Consumer Savings, cumulative		Electric Power Industry Savings, cumulative	
	NEMS	MARKAL	NEMS	MARKAL
	Billion $	Billion $	Billion $	Billion $
Fiscal Year 10 Target Budget				
2015	1	N/A	1	N/A
2020	3	N/A	3	N/A
2030	20	N/A	8	N/A
2050	N/A	N/A	N/A	N/A
Fiscal Year 09 Over Budget				
2015	ns	ns	ns	ns
2020	ns	0	ns	ns
2030	2	12	ns	3
2050	N/A	59	N/A	N/A

ns = not significant
N/A – not applicable
Fiscal Year 10 estimates incorporate approximate impacts of EISA 2007; Fiscal Year 09 does not.

Figure 2.10. Cumulative Consumer Savings for the Fiscal Year 2010 Target Budget and Fiscal Year 2009 Over Budget

2.3.3 Generation Stability

Because the "fuel" (e.g., hot rocks, water) is secured at the initiation of the project, geothermal electricity generation is protected against unstable electricity prices. The resource (heat from the underground rocks) is secured through long-term leases with private, state, or Federal landowners, and the costs to create the heat exchanger prior to electricity generation and distribution are capitalized placing the cost risk on the developer and not on the consumer. The acquisition of a long-term power purchase agreement from a utility further stabilizes the long-term electricity price and supports the financing and operational costs of a project.[19]

19 Western Governors' Association, Clean and Diversified Energy Initiative: Geothermal Task Force Report, January 2006.

This page was intentionally left blank.

3.0 Program Challenges

Like other renewable energy technologies, EGS technologies face perceived institutional and economic barriers, challenges, and obstacles to market penetration including:

- Limited access to transmission infrastructure;
- Lack of available and reliable resource information;
- High exploration risks and high upfront costs;
- Absence of national policy; and
- Complicated siting, leasing, and permitting issues.

The following sections summarize the institutional barriers that the Program must address and overcome in order to increase the development and deployment of EGS. Challenges in resource assessment and data needs are discussed, as are education and workforce development needs.

3.1 Institutional Barriers

3.1.1 Access to Transmission Infrastructure

The ability to transmit electricity from the source to the power grid represents one barrier to expanding the development and deployment of EGS. Geothermal resources are generally remote from load centers requiring investment in transmission infrastructure, which can lead to high delivery costs that may not be competitive with conventional technologies. A large amount of capital is required for transmission expansion providing a disincentive for utilities to build infrastructure to reach remote geothermal sources.

As EGS technologies mature, greater flexibility regarding location will provide an opportunity to develop sites near existing infrastructure to quickly move electricity to the grid. However, expansion of electricity transmission capacity may still be required to connect geothermal energy to the electricity grid.

3.1.2 Lack of Available and Reliable Resource Information

Poor availability of accurate and reliable resource data and information is a significant deterrent to potential geothermal investors. Recent attempts at organizing existing data on geothermal resources in the United States, specifically across western states have done little to improve information quality, since most of the existing information regarding geothermal resources comes from private lands while Federal lands which make up a great proportion of the identified resource.

To address this barrier, GTP has issued a solicitation for a web-based National Geothermal Database. This database will serve as a central repository of new DOE EGS demonstrations and component research and development data, and provide vital links to historical geothermal data, maps and key international geothermal information centers. This central database will help mitigate risk associated with geothermal energy development. Data organized by using common metrics could assist geothermal developers in identifying and assessing sites with the best geothermal resource potential. Industry comments received during 2008 indicated that a standard financial risk classification system could help provide prospective geothermal investors with the information needed to make the most informed decisions possible on the potential for success at different locations. A well designed National Geothermal Database should link diverse data sources, document data origins, ensure data security, and serve all of the named needs.

3.1.3 High Exploration Risks and High Up-front Costs

EGS has significant upfront costs that must be incurred prior to determining the viability of the resource. This investment requirement raises the stakes for investors who must commit capital without clearly understanding the return profile. The high probability of loss in the early stages of development makes supporting geothermal development through the creation of a novel risk mitigation product very challenging.

EGS must be cost-competitive in order for industry to accept the technology as commercially viable. Drilling deep wells to access the resource is currently not economically feasible. In order for the technology to succeed, costs of drilling deep wells must be reduced, plant efficiency must increase and technology innovation must show significant improvement throughout the industry.

3.1.4 Absence of National Policy

The largest problem facing the geothermal industry is the lack of a Federal policy to promoting geothermal development. The economic viability of most geothermal electricity production projects continues to be dependent on the financial support created by national and state energy policy. Carbon and greenhouse gas restriction policies already have a significant economic impact on projects in other parts of the world and could factor into carbon emissions and trade costs. Policy-based support will be necessary to produce any level of investment in all but a select group of fringe projects.

Two policy implements have potential to significantly influence geothermal development. The Federal production tax credit (PTC) has been the single most important program supporting renewable generation in the United States. The PTC pays 1.9 cents/kWh for electricity produced and sold in the United States, but without reliable, long-term extensions, investors may miss out on this opportunity. The recently enacted Energy Independence and Security Act of 2007 (P.L. 110-140) (EISA) contains several provisions designed to further encourage renewable energy development and deployment in the United States and highlights geothermal energy expansion authorizing $95 million for both conventional and enhanced geothermal research, however, Congressional appropriations have not allowed the program to maximize the potential opportunities afforded by this Act.

Policy continuity and clarity, with respect to the PTC as well as state-based regulatory mandates, will provide critical support for geothermal development. In the near term as regulatory programs related to renewable energy and carbon emissions continue to develop and evolve, the continuation of the PTC will be critical to supporting significant investment interest in EGS as clean, secure, and reliable baseload energy.

3.1.5 Siting, Leasing, and Permitting Issues

Most of the geothermal energy facilities in the United States are located on federal lands. The Bureau of Land Management (BLM) has the responsibility for issuing geothermal leases on federal lands and reviews permit applications for geothermal development. Although BLM has the primary authority over leasing, the concurrence of the Forest Service (FS) is required for leases on lands it manages.

Lease nominations are handled by the BLM field office in which the lease occurs. The BLM receives nominations from applicants, which may include proposed tract configurations for parcels. The BLM then, if appropriate, forwards the proposal to the FS, which decides whether or not to consent to leasing and if so, what lease stipulations are necessary to minimize impacts to other resources. Once lease parcels are configured, the BLM is responsible for conducting competitive lease sales and issuing leases.

Source: http://www.blm.gov/wo/st/en/info/About_BLM.html

Figure 3.1. Public Lands States Map from BLM

The Energy Policy Act of 2005 established new procedures for federal geothermal leases. The statute addressed the backlog of geothermal lease applications at that time. One means of addressing the backlog was to call for greater cooperation among the federal agencies involved. The BLM and FS signed a memorandum of understanding (MOU) in 2006. One result of the MOU is that the BLM and FS completed a programmatic environmental impact statement (PEIS) for geothermal leasing in the western United States.[20] The PEIS assesses the direct, indirect, and cumulative effects of leasing, exploration, and development of geothermal resources in order to expedite leasing. The PEIS also amends federal resource management plans and land use plans for geothermal leasing. Site-specific analysis of leasing nominations, permit applications, and operations plans can refer back to the PEIS and best management practices included in the resource management plans, reducing the processing time for leasing and permitting.

Permits and site licenses for geothermal development on federal lands are issued by the BLM. Separate permits are required for exploration, drilling, utilization, and commercial use. The National Environmental Policy Act (NEPA) requires the BLM to analyze the environmental impacts of the proposed geothermal project and then issue either an environmental assessment supporting a finding of no significant impact or an environmental impact assessment. The EIS should contain a discussion of the need for the proposed action, alternatives, and impacts. A draft EIS is published for public comment.

20 http://www.blm.gov/wo/st/en/prog/energy/geothermal/geothermal_nationwide/Documents/Final_PEIS.html

Geothermal projects on state or private lands are under the jurisdiction of state and local regulatory agencies. States are not consistent in how they define geothermal resources or in howsiting and permitting are handled. Mineral rights, water use rights, and environmental laws vary by state. Some states grant power plant siting authority to a public utility commission or siting board. A few of these boards coordinate environmental review and permitting; others leave this in the hands of the developer.

3.2 Resource Assessment and Data Needs

The USGS, the geothermal industry, and DOE have supported a number of studies and data acquisition efforts to obtain exploration-quality near-surface temperature information with reduced costs and drilling time. The net result of multiple studies is that properly corrected shallow temperature data may provide an exploration quality outline of a resource area and may substantially reduce the number of deeper temperature gradient holes required to evaluate the resource prior to drilling exploration wells. A large amount of temperature gradient and heat flow data has been made available through two national online databases: the Global Heat Flow Database of the International Heat Flow Commission, provided by the University of North Dakota;[21] and the Southern Methodist University (SMU) Geothermal Lab Heat Flow - A Transfer of Temperature Database.[22] Through state cooperative programs, DOE drilling projects have resulted in public temperature gradient/heat flow databases.[23]

The following geothermal resources maps of the United States illustrate the estimated subterranean temperatures at depths of 3.5, 6.5, and 10 km.

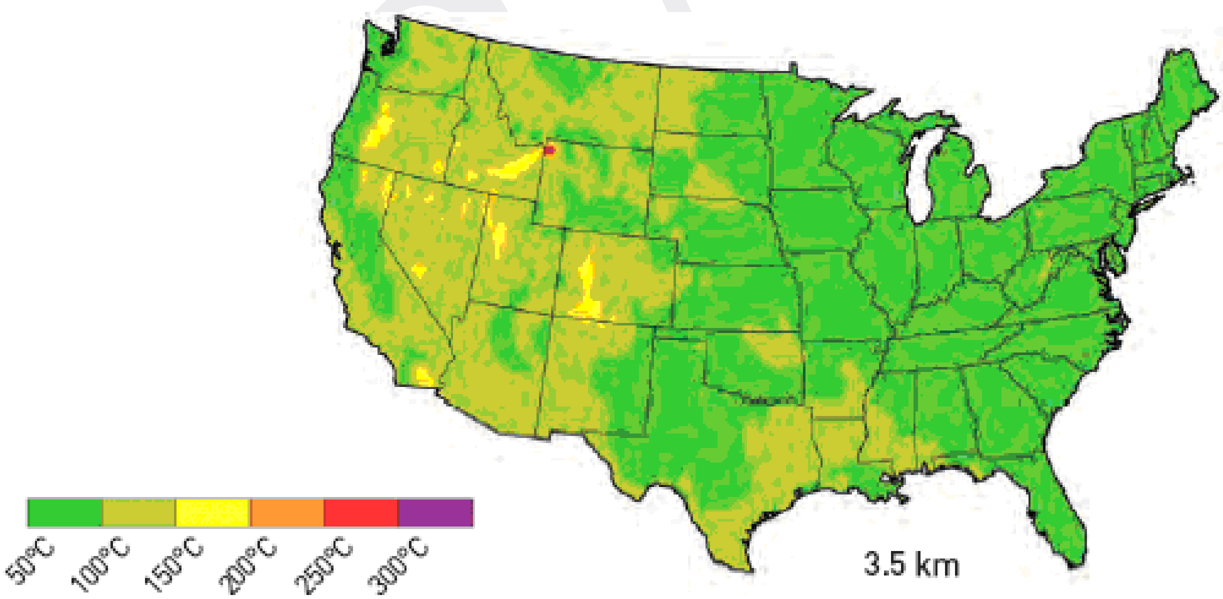


Figure 3.2. U.S. Geothermal Resource Map at 3.5 km[24]

21 Geothermal Heat Flow Database of the International Heat Flow Commission: http://www.heatflow.und.edu/index2.html

22 SMU Geothermal Lab Heat Flow–A Transfer of Temperature Database: http://www.smu.edu/geothermal/heatflow/heatflow.htm

23 A History of Geothermal Exploration Research in the Geothermal Technologies Program, p. 69, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Geothermal Technologies Program

24 "The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Centry,"

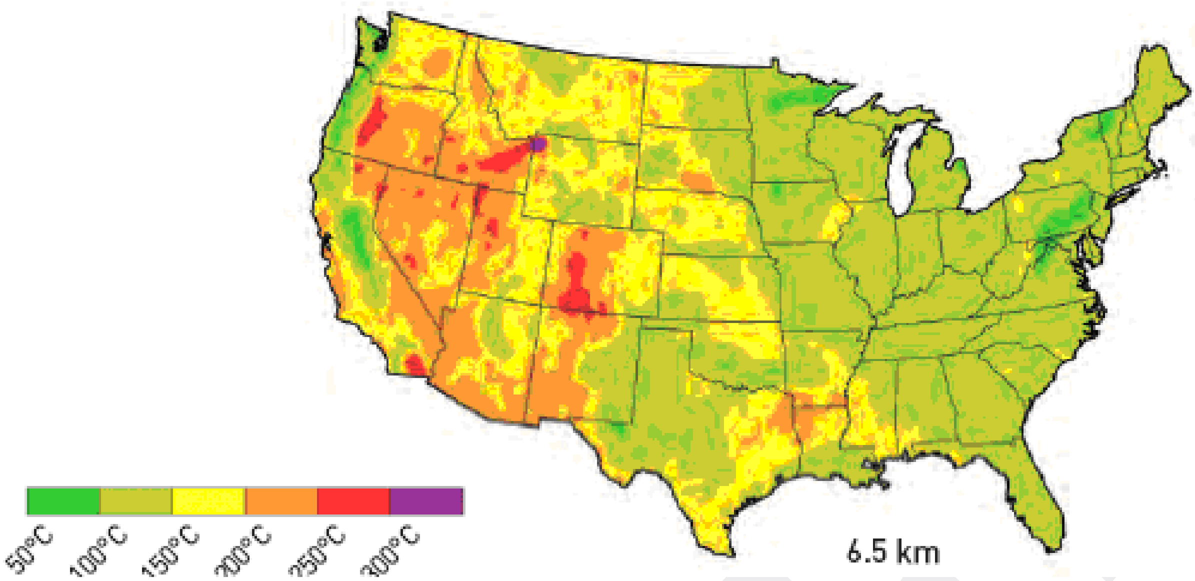


Figure 3.3. U.S. Geothermal Resource Map at 6.5 km[25]

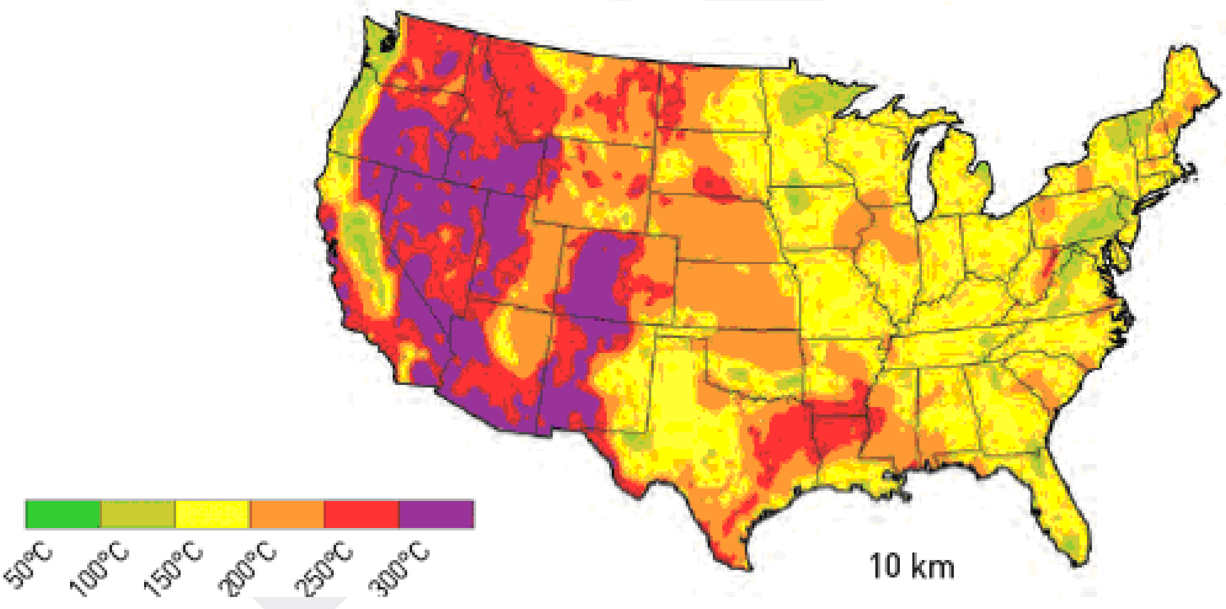


Figure 3.4. U.S. Geothermal Resource Map at 10 km[26]

Massachusetts Institute of Technology, 2007.
25 The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century," Massachusetts Institute of Technology, 2007.
26 Ibid.

Resource Assessment: DOE's National Geothermal Action Plan discusses work underway by the U.S. Geological Survey pertaining to resource assessment.

Data Needs: Analysis shows that there are many geothermal databases available satisfying different purposes and needs. There is not, however, a unified national standard or infrastructure capable of storing or linking comprehensive subsurface data sets. A web-based National Geothermal Database will serve as a central repository to house new DOE EGS demonstrations and component research and development data. The database will also provide vital links to current and historical geothermal data and maps throughout the United States and key international geothermal centers. This central repository for critical national geothermal data will help mitigate risk associated with geothermal energy development.

Data will be organized using a set of common metrics such that criteria useful in assessing and identifying sites with the best geothermal resource potential can be defined. The database will include a standard financial risk classification system in order to provide geothermal prospectors with the information needed to make informed decisions on the potential for success at different locations via an overall favorability index.

3.3 Education Workforce Development

The establishment of a program that includes geothermal curriculum, student exchange, and training/internships is key to ensuring development of the geothermal market. An educated and trained workforce is needed to meet the expected and hoped for industry growth. Incorporation of geothermal curricula into trade schools and higher education programs is necessary. A student exchange/scholarship program would help transfer technology to the United States as would an internship/training program. Curricula must be developed in geology, drilling technology, exploration and characterization technologies, reservoir management/enhancement, power plant operation, power transmission, and other key geothermal technology areas of development where training programs do not exist.

A professional education program could include:

- **Geothermal Educational Curriculum** at the undergraduate or graduate level with a dedicated geothermal curriculum. The curriculum could be in the form of a full degree program, a minor, or a set of classes with a geothermal emphasis.
- **Student Exchange/Scholarship Program** – A domestic and/or international student exchange/scholarship program is needed as either part of the curriculum or as an additional program that is developed.
- **Training/Internship Program** – A domestic and/or international training/internship program is needed, either as part of the curriculum or as an additional program. Students require practical experience working in the geothermal industry through internships and cooperative programs to gain hands-on experience in parallel with their education. Student participation and teaming with U.S. geothermal companies are critical to ensure adequate geothermal workforce development and training.

4.0 Technical Plan

The technical approach addresses the barriers to deployment of Enhanced Geothermal Systems. The technical plan describes two strategic areas of focus which will be implemented concurrently improve geothermal technology and accelerate EGS commercialization:

1. Research and Development; and
2. Enhanced Geothermal Systems Validation.

Section 4.0 Table of Contents

4.1 Enhanced Geothermal Systems Research, Development, and Demonstration

Commercialization of EGS will require technical and economic improvements in a variety of technologies. The principal barriers to EGS commercialization are creating, sustaining, and reducing the cost of reservoirs. Program R&D will focus on these named barriers as well as heat extraction from the reservoir at economically viable and sustained rates.

The Research and Development portion of the technical plan is divided into eight research areas as shown in Figure 4.1. These areas correspond roughly to the phases in the EGS power plant construction scenario as shown below. The R&D in all phases is conducted in parallel; the R&D Outline serves as an aid in identifying opportunities for the incorporation of newly developed technologies into the Systems Deployment and Validation projects, as well as areas for further development.

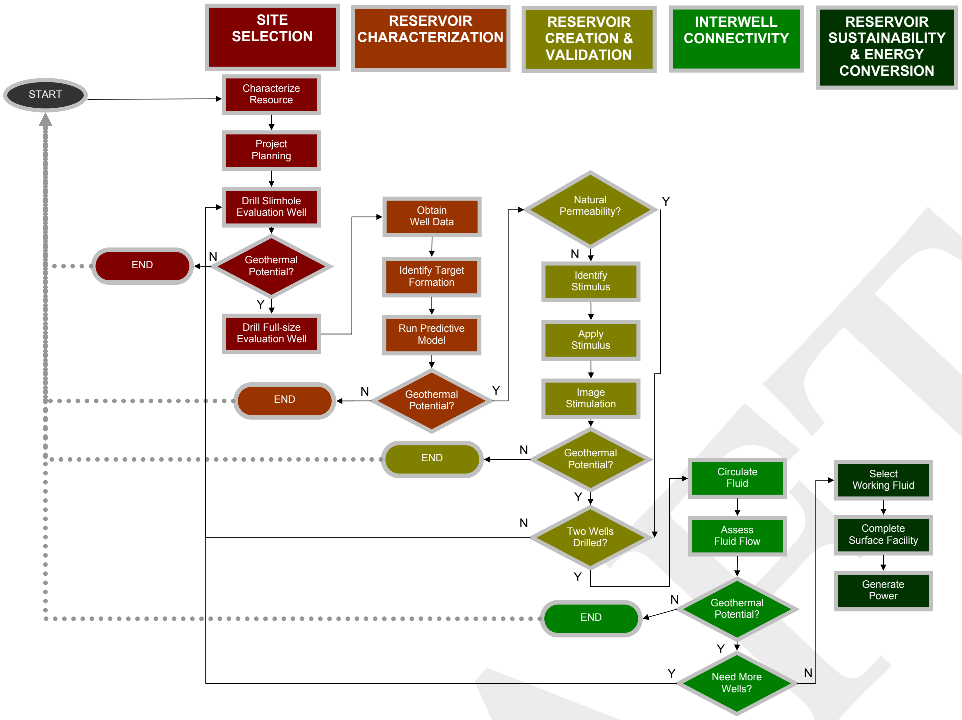


Figure 4.1. Systems Engineering Diagram of GTP Technical Plan Research Areas

Technical Plan Research, Development, and Demonstration Areas:

1. **Site Selection**- addresses tools for the selection of a potential EGS site, both from surface analysis and well bores, logs and well construction.

2. **Reservoir Characterization**- addresses principally downhole instrumentation and the use of this data in modeling the underground environment.

3. **Reservoir Creation- the single** most critical research area establishes permeability and creates and maintains rock fractures. EGS lithology is expected to be primarily igneous, crystalline and generally low porosity, and presents significant technical challenges.

4. **Reservoir Validation**- concerns tools for ensuring that the desired fracturing of the reservoir has been accomplished successfully.

5. **Interwell Connectivity**- deals primarily with tools such as tracers that can be used to ensure that there is a suitable flow path that connects the various injection and production wells in an EGS field.

6. **Reservoir Scale Up**- addresses the development of tools for the determination of the best location of additional injection and production wells as the EGS resource is developed.

7. **Reservoir Sustainability**- seeks to develop tools for the long-term operation and maintenance of an economic EGS installation.

8. **Energy Conversion**- concerns the development of energy conversion (EC) systems that are suitable for EGS applications.

Because of the process-oriented structure of the RD&D program, it is important to note that in every case, relevant technologies are discussed when first initiated in the process of siting, constructing and operating an EGS facility.

Each of these areas is discussed in more detail in the following sections.

4.1.1 Site Selection

The selection of an appropriate site is the initial step in the construction of an economic EGS field. It should be noted that since well drilling is done as part of the exploration process, the discussion of well drilling technology and advancements is included under the "Well Construction" subsections within this section of the plan. Two goals are associated with this research area, and two sets of barriers, objectives, and tasks are discussed with respect to each goal.

4.1.1.1 Site Selection Goals

In the process of selecting a location for an EGS, issues arise in both the large-scale siting of the system and the small-scale location and drilling of the wells within the site. The goals targeting these separate issues are described below.

Site Characterization

Goal 1: Develop low-risk EGS site selection and characterization technology.

The subsurface environment must be characterized in preparation for creation of the EGS reservoir. Many reservoir characterization technologies already exist and are being used by the geothermal industry or the oil and gas industry; now technical capabilities must be extended for EGS application.

Well Construction

Goal 2: Develop low-cost, high-efficiency well construction (drilling and completion) technology.

Although well-drilling capability is highly advanced in the oil and gas industries, , drilling technology must be improved to enable access to hotter rock suitable for EGS. Conditions that are common in geothermal formations increase the risk that wells will be lost during drilling operations or production may be impaired due to twist-offs, lost tools, lost circulation, casing failures, bad cement jobs, loss of wellbore mechanical integrity, formation damage, and other mishaps from which recovery is not possible. Given the sensitivity of EGS to investment costs, these risks must be minimized through technology and field experience.

4.1.1.2 Site Selection Barriers

Site Characterization

Barrier A: **Site Selection & Resource Assessment** – The ability has not been sufficiently demonstrated to assess potential EGS resources, prioritize potential sites for EGS, and achieve acceptable levels of site selection risk ahead of expensive drilling investments.

Barrier B: **Site Characterization** – Inadequate measuring techniques and knowledge preclude low-risk options to effectively select sites and characterize their physical parameters as potential EGS reservoirs before stimulation. Better data is required to enable successful and replicable EGS development.

Well Construction

Barrier C: **EGS Well Construction Capability** – The inability to drill and complete wells meeting EGS requirements (high temperature, high flow rate, low cost) results in a greater risk of impairing production or even losing wells when drilling.

4.1.1.3 Site Selection Background

Site Characterization

Existing wells do not provide the required density of coverage across the entire country. There are large geographic areas where data is missing, and in other areas data sets have not yet been analyzed due to their cost.

Remote (pre-drilling) Assessment Techniques: The best EGS targets have high temperatures (> 200°C) at shallow depth (< 3 km) and a tectonic stress regime that keep fractures open. Current technology cannot identify such sites with a high degree of certainty without drilling. New and improved remote geological, geochemical, and geophysical techniques are needed to find shallow hot rock and favorable crustal stress conditions where there is no surface manifestation.

For further background information on site characterization, please refer to the resource characterization and site selection procedure in Section 5.

Well Construction

Suitable Drill Bits and Alternative Drilling Methods: Existing drilling methods from the petroleum industry can be adapted to EGS well field requirements, but these technologies are not ideal for geothermal subsurface conditions and formations, which are often hard crystalline rocks. Rotary bits designed specifically for these conditions will be required to enable low-cost and low-risk drilling. Drilling techniques from the mining industry are well suited to hard crystalline rocks, but are generally not designed for holes with large diameters. Revolutionary non-mechanical drilling techniques, such as flame jet drilling, hold promise but have not been tested in well field conditions.

High Temperature Logging Tools: Due to insufficient market demand and the limited availability of high temperature components, service companies do not currently provide all the high-temperature logging and drilling tools required to drill EGS wells. Existing logging tools for measuring temperature, pressure, flow, and other formation characteristics, as well as fracture imagining, require heat shielding and can only be used for brief periods. While the drilling industry works within these limitations, tools capable of operating in environments greater than 200°C are needed for EGS. Other reservoir monitoring sensors such as seismometers capable of operating in severe geothermal conditions will be required. Logging tools and sensors will require advances in components, battery technology, materials, and fabrication methods.

Ability to Satisfy the Large Well Diameter Requirement of EGS: Large diameter wells are required for economic EGS production rates. Large initial surface well diameters are costly, and geologic issues, unanticipated borehole stability problems, cold water influx, and other unforeseen events requiring additional casings can reduce the diameter from the original design and reduce the ultimate flow capacity of the well.

Underreamers, which are commonly used in the oil and gas industry to enlarge the wellbore below casing, are not suitable for use in geothermal lithologies and temperatures. In addition, completion and later intervention through production tubing unacceptably small diameter and flow capacity for EGS.

Unsuitability of Existing Casing Designs and Materials for EGS: Casing and cementing costs make up roughly 30 percent of the cost of constructing a geothermal well. Casing designs and casing material properties required for EGS are not available at low cost or are unsuitable in severe geothermal conditions. "Lean" casing designs such as expandable tubulars, casing-while-drilling, and low-clearance casing systems (i.e., with a minimal annulus between casing strings) now emerging in the oil and gas industry offer cost and performance advantages, but have not yet been applied to geothermal wells.

Corrosion and Scaling: High temperatures and fluid chemistry and pH make corrosion and scaling a major challenge. Improved anti-corrosion and anti-scaling materials are difficult to develop at reasonable costs.

4.1.1.4 Site Selection Objectives

The EGS concept is to engineer a geothermal energy system in the absence of preexisting permeability, fluids, or a natural convective system. As a result, the assessment and selection of EGS sites will differ from traditional hydrothermal exploration. EGS site selection does require estimation of many of the same geologic variables as hydrothermal exploration, such as heat flow and geothermal gradient, past and current stress state, rock type, depth of overburden, and fracture patterns, among other parameters. Among these variables, the principal criterion for EGS will be to identify areas of high temperature gradient where a reservoir can be created at economically drillable depths. EGS resource assessment and site selection will be aided by the U.S. Geological Survey's (USGS) ongoing update of the U.S. hydrothermal resource assessment.

Site Characterization

The most pressing R&D needs related to regional-scale exploration concern remote data acquisition, such as developing satellite or other remote-based (e.g., aeromagnetic) technologies to measure heat flow and regional deformation or to "see" through the shallow sub-surface. The primary objectives of research are to improve signal quality and reduce noise.

Table 4.1. Site Characterization Objectives

Number	Description	Barrier
1	By 2012, provide EGS feasibility information to the public based on data available.	A
2	By 2015, analyze the ultimate potential for EGS. The analysis will address necessary resources, transmission, reservoir sustainability, water needs, and interactions between an EGS economic sector and other sectors.	A
3	By 2009, specify needs for characterization of the physical parameters of potential EGS reservoirs before drilling.	B
4	By 2009, set technical objectives for improvement of geophysical methods for the characterization of the physical parameters of potential EGS reservoirs before drilling.	B

Well Construction

The objectives for well construction technology are based on incremental extension of wells into the hostile environment associated with EGS reservoirs. This environment is typified by high temperatures and its concomitant rise in chemical activity as well as the great depth and complex lithology of the setting.

Table 4.2. Well Construction Objectives

Number	Description	Barrier
1	By 2009, define baseline EGS wells (e.g. what kind of diameters will be run, vertical or directional, two small wells vs. one large well, downhole completion schemes, etc.)	C
2	By 2015, demonstrate well construction technologies that reduce the cost of drilling and completion by 10 percent.	C
3	By 2015, demonstrate the use of native drilling electronics and tools capable of operating at 250oC.	C

4.1.1.5 Site Selection Technical Approach

Site Characterization

As a result of the Geothermal Technologies Program research, a range of new geologic, geophysical and geochemical methods has been developed. Although many of these methods were originally borrowed from the mineral and petroleum industries, the uniqueness of geothermal systems requires significant innovation. Improvements in the geophysical methods are the most significant because of their ability to image the subsurface. As the emphasis of the Geothermal Technologies Program shifts toward EGS, and geothermal energy becomes an increasingly important energy source, all three geoscience disciplines will be increasingly tested.

A variety of remote sensing techniques are used in the geothermal, oil and gas, and mining industries. In general, these techniques currently have limited resolution and accuracy, and have not been adapted to the EGS resource assessment and site selection problem. Nevertheless, the following list includes remote exploration techniques with potential applicability:

- **Surface Geological Mapping** – (Section 5.0 Program Analysis discusses in more detail) measuring physical rock properties and interpreting the results in terms of geologic features. Measurements can be taken from the ground surface or via remote sensing (i.e. from aircraft or satellites).
- **Geochemical Surveys** – conducting chemical analysis of rock, soil, stream sediment, plant, or water samples.
- **Electrical Resistivity (or Specific Electrical Resistance) Surveys** – introducing electrical current into the ground via two electrodes and measuring differences in electric potential in the current using two or more other electrodes.
- **Self Potential Surveys** – measuring electrical voltage variations in the Earth's surface.
- **Magnetotelluric Surveys** – utilizing telluric currents (both naturally occurring and controlled source electric currents in the earth) to measure natural electric and magnetic fields.
- **Seismic Surveys** – measuring the variation in the rate of propagation of seismic waves in layered media to delineate subsurface geologic structures.
- **Magnetic Surveys** – mapping variations in the magnetic field of the Earth attributable to changes in structure or magnetic susceptibility in certain near-surface rocks.
- **Gravity Surveys** – mapping variations in the Earth's gravitational field due to irregularities or anomalies in gravity caused by differences in the density of rock formations.
- **Interferometric Synthetic Aperture Radar (InSAR)** – remote sensing technique measuring ground deformation such as subsidence, which may help map the boundaries of producing geothermal systems and explore for new resources.
- **Thermal Gradient Well Drilling** – measuring the temperature gradient in water-filled rotary-drilled wells (typically 30 to 600 meters deep).

Well Construction

The focus of the Well Construction program element is the creation and maintenance of EGS wells. Technologies are required for drilling the wells, determining the native characteristics of the wellbores, engineering the wells to enable stimulation, and ensuring the long-term integrity of the wellbore to enable permanent well completion. Many of the essential subsurface and surface technologies exist and are in use by the geothermal and oil and gas industries, but have technical limitations in regards to EGS application. The current limitations of these technologies, whether rooted in fundamental physics or in economics, represent barriers to development of an EGS energy industry.

The Program will focus R&D activities on the most critical well field construction technology gaps and will coordinate the R&D with the Field Projects program element to insure that newly developed technologies are tested in the appropriate settings as field activities progress. The results of field activities will also inform ongoing R&D planning and priorities.

4.1.1.6 Site Selection Programmatic Status

DOE exploration activities historically focused on the western United States. The following table provides a brief look at site selection program activities.

Table 4.3. Fiscal Year 2008 Site Selection Technology/Program Activities

Task	Approach	Organization
Fracture and water flow detection and imaging	Improve geophysical remote assessment techniques	LBNL; TBD through solicitation 08GO98008 and future solicitations
Enhance EGS well drilling capability	Development of drill bits and drilling systems optimized for EGS drilling conditions	SNL and Others
Provide specialized EGS well completion engineering capability	Development of high temperature components e.g. elastomers to extend range and life of well field operation tools	SNL and Others

Demonstrating the utility of slimhole drilling for exploration purposes significantly decreased the cost of initial exploration for geothermal resources. The Sandia National Laboratories (SNL) slimhole drilling program demonstrated that: 1) flow or injection tests on slimholes could accurately predict production characteristics of production-diameter wells in the same reservoir, and 2) slimhole drilling is cheaper than a comparable large-diameter well in the same location. Field experience showed that costs were 45 to 65 percent of conventional drilling cost, and logging and measurement techniques are adequate to characterize a geothermal reservoir. A Slimhole *Handbook* was distributed to industry and is used as a textbook in Iceland's UN Geothermal Training Program. Slimhole exploration is now widely used by industry.

In the late 1970s, the vast majority of oil and gas wells were drilled with roller-cone bits. In 1977, General Electric introduced a synthetic bit material of diamond grains sintered with cobalt, generically called polycrystalline diamond compact, or PDC, bits. Early field results were disappointing. SNL funded field tests and studies of rock/cutter interaction, diffusion bonding of the compact to the bit, and frictional heating of the cutters. As a result, PDC bits dominate the oil and gas drilling industry at an estimated $1.9 billion in sales in 2007, compared to $1.2 billion for roller-cone bits. The bits reduce drilling costs from $500/foot to $300/foot. Hard rock performance is still insufficient for the geothermal industry, although ongoing research is encouraging.

SNL pursued use of continuous-transmission, high-bandwidth downhole data to reduce the cost of geothermal drilling by providing a real-time report on drilling conditions, bit and tool performance, and imminent problems (known as Diagnostics While Drilling, or DWD). The driller can use this information to change surface parameters (e.g., weight-on-bit, rotary speed, mud flow rate) with immediate feedback. This adds value to virtually every part of the drilling process.

Commercially available electronic components rated at about 85°C (185°F) are not suitable for use in geothermal environments. Drilling technology developments are a significant Program contribution to geothermal technology. SNL designed an electronic mud-turbine control system based on SOI-SiC (Silicon-On-Insulator and Silicon Carbide) technology that can operate at an ambient temperature of 230ºC for hundreds to thousands of hours paving the way for high-temperature electronics.

4.1.1.7 Site Selection Technology Status

Site Selection

New technologies are needed that will reduce site characterization costs and improve confidence in performance predictions. The table indicates target areas of technological improvement.

Table 4.4. Site Selection Technology Status Summary		
Barrier	**Available Technologies**	**Technology Status**
Barrier B: Site Characterization Inability to characterize the physical parameters of potential EGS reservoirs before stimulation, providing sufficient data to enable successful and replicable EGS development.	Characterize subsurface conditions- Stress measurement inferred from natural breaking of rocks in the wall of the wellbore and "mini-frac"	Principal stress direction and magnitude are estimated from limited testing capabilities. Imaging tools for breakouts currently require a heat shield.
	Detect fluid-filled fractures- Remote (before Drilling) Assessment Techniques	Self-potential is commonly used for shallow hydrothermal systems. Significant research is required to develop and demonstrate surface-based technology with adequate resolution at reservoir depth (e.g., streaming potential). Determination of EGS reservoir rock characteristics from the surface appears out of reach in the near term.
	Predict potential for stimulation- Modeling of Favorable EGS Settings	Data and experience from the oil and gas industries are inadequate for modeling of most projected EGS environments due to lack of sufficient measurements under geothermal conditions.
	Active seismic surveys	Resolution of fracture systems is still poor using standard techniques.

Well Construction

Conditions common in geothermal formations increase the risk that wells will be lost during drilling operations or production will be impaired due to twist-offs, lost tools, lost circulation, casing failures, bad cement jobs, loss of wellbore mechanical integrity, formation damage and other mishaps from which recovery is not possible. Given the sensitivity of EGS to investment costs, these risks must be minimized through technology and field experience.

Drilling methods from the petroleum industry can be adapted to EGS well field requirements, but these technologies are not ideal for geothermal formations, which are often hard crystalline rocks, and subsurface conditions. Rotary bits, which are designed for these conditions, will be required to enable low cost and low risk drilling. Drilling techniques from the mining industry are well suited to hard crystalline rocks, but are generally not designed for holes with large diameters. Revolutionary non-mechanical drilling techniques such as flame jet hold promise but have not been tested in well field conditions.

Service companies do not currently provide all the high-temperature logging and drilling tools required to drill EGS wells. Existing logging tools for measuring temperature, pressure, flow, fracture imaging, and other formation characteristics require heat shielding and can only be used for brief periods. While the drilling industry works within these limitations, tools capable of operating in environment greater than 200°C over extended time periods are needed for EGS. Other reservoir monitoring sensors such as seismometers capable of operating in geothermal conditions will be required. Logging tools and sensors capable of operating under the extreme conditions of EGS will require advances in components, battery technology, materials, and fabrication methods.

Large diameter wells are required for economic EGS production rates. Large initial surface well diameters are costly, and geologic issues, unanticipated borehole stability problems, cold water influx, and other unforeseen events requiring additional casings can reduce the diameter from the original design and reduce the ultimate flow capacity of the well.

Casing and cementing costs make up roughly 30 percent of the cost of constructing a geothermal well. Casing designs and casing material properties required for EGS are not available at low cost or are unsuitable in severe geothermal conditions. "Lean" casing designs such as expandable tubulars, casing-while-drilling, and low-clearance casing systems (i.e., with a minimal annulus between casing strings) now emerging in the oil and gas industry offer cost and performance advantages, but have not yet been applied to geothermal wells.

High temperatures and fluid chemistry and pH make corrosion and scaling a major challenge. Improved anti-corrosion and anti-scaling materials are difficult to develop at reasonable costs.

Table 4.5. Well Construction Technology Status Summary		
Barrier	Available Technologies (U.S. and International)	Technology Status
Barrier C: EGS Well Construction Capability Inability to drill and complete wells meeting EGS requirements (high temperature, high flow rate, low cost).	Monitoring tools, sensors (e.g., tools to measure downhole pressure, flow, temperature, seismicity).	Monitoring tools and sensors are available commercially for sustained operation up to about 150°C. Tools capable of operation at >200°C are still experimental.
	Suitable Drill Bits and Alternative Drilling Methods- Drill Bits	Roller bits are used in hard rock. Advanced bits (e.g., PDC-based drag bits) are used in oil and gas, and they drill 60 percent of footage worldwide.
		Alternatives to mechanical methods (flame jet, etc.) are in experimental stages.
	Suitable Drill Bits and Alternative Drilling Methods- Advanced well steering tools	Wireline based systems are used in geothermal. Commercial advanced steering tools allow control over well trajectories. Tools providing limited steering control are in use by one geothermal firm. Commercial tools are limited to ~150°C.
	High Temperature Logging Tools- Logging while drilling/ Diagnostics while drilling	The technology is commonly used in the oil and gas industry. Commercial tools are limited to ~150°C.
	Metal casing in various diameters and production tubing (e.g., slotted liner)	Fully commercial systems to complete wells are available. Advanced technology, such as expandable tubulars and casing-while-drilling and low clearance casing systems, is emerging in oil and gas applications. Underreamers work only in “soft” rock. Elastomers used in these systems fail at high temperatures.
	Design methods for selective cementing	Various high-temperature cement formulations are available from the drilling service industry. Design methods for selective cementing of casing exist for wells with small temperature fluctuations.
	Design anti-corrosion and anti-scaling materials	Improved anti-corrosion and anti-scaling materials are difficult to develop at reasonable costs.
	Characterize subsurface conditions: Core sampling and evaluation	Routinely used in mineral exploration. Interpretive techniques for geothermal applications are still evolving.
	Monitoring tools, sensors (e.g., tools to measure downhole pressure, flow, temperature, seismicity).	Monitoring tools and sensors are available commercially for sustained operation up to about 150°C. Tools capable of operation at >200°C are still experimental.

4.1.1.8 Site Selection Tasks

The tasks for the Site Selection research area support the objectives of both site selection and well construction.

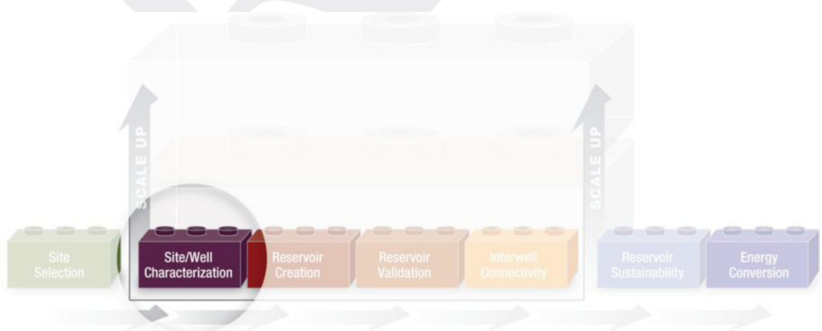
Site Characterization

Table 4.6. Site Characterization Tasks		
Number	Description	Barrier
1	Make available the required data and techniques to analyze the data.	A
2	Prioritize possible locations for commercial EGS based on geologic, topographic, infrastructure and other conditions.	A
3	Develop a working set of criteria for site selection that improves chance of success of EGS.	A
4	Develop effective Remote Sensing Assessment Techniques for pre-drilling site location.	B
5	Improve resolution of geophysical methods for the detection of fractures and water flow. Methods to be investigated include seismic (VSP, 3-D, high frequencies), electromagnetic (CSAMT), and electric (SP).	B
6	Improve accuracy and range to be able to remotely predict subsurface stress regime.	B

Well Construction

Table 4.7. Well Construction Tasks		
Number	**Description**	**Barrier**
1	Perform parametric study for well drilling and construction methodology.	C
2	Develop cost and performance evaluation of innovative drilling and completion well construction technologies for higher rate of penetration, improved reliability, and reduced downtime for maintenance to enable prioritization of future research (e.g., high-temperature MWD Diagnostics While Drilling (DWD) with polycrystalline diamond compact (PDC) drill bits, multilateral completions, underreaming, and spallation drilling).	C
3	Demonstrate advanced drilling system (e.g., DWD, PDC) in a variety of EGS conditions (e.g., rock types, depths, temperatures).	C
4	Develop cost and performance evaluation of advanced casing technologies to enable prioritization of future research (e.g., drilling with casing, expandable tubulars, low-clearance casing, and longer casing intervals).	C
5	Perform cost studies for drilling and identify cost-reduction strategies to meet commercial plant requirements.	C
6	Develop lower-cost depth coring.	C

4.1.2 Site/Well Characterization



4.1.2.1 Site/Well Characterization Goal

In the process of preparing a site for an EGS, it is necessary to create a detailed picture of the underlying hot rock system in order to accurately and optimally locate injection and production wells within the site. Better instrumentation and modeling software are needed for this application.

Goal 3: Develop improved tools for the characterization and modeling of the subsurface at EGS project sites.

Many reservoir characterization technologies already exist and are being used by the geothermal industry or by the oil and gas industry, but technical capabilities must be extended for EGS application.

4.1.2.2 Site/Well Characterization Barriers

Barrier D: **Characterization** – Subsurface environments in EGS regimes are inhospitable to existing downhole, in-situ characterization methods.

Barrier E: **Data Interpretation** – Inability to fully exploit data from current oil and gas logging routines for interpretation for EGS needs.

Barrier F: **Modeling** – Insufficient modeling and validation capabilities to effectively couple fluid flow, geochemistry, and thermal-mechanical phenomenon for 1) stimulation prediction, and 2) reservoir simulation.

4.1.2.3 Site/Well Characterization Background

Although many of the field measurements required to characterize the native formation conditions can be obtained commercially through oil and gas industry services firms, the field equipment, procedures, and data interpretation must be adapted to geothermal environments that differ significantly from typical oil and gas-producing reservoirs.

High temperature instrumentation for borehole imaging and other purposes is a key technology deficiency, as described in the Well Field Construction section. Some logging tools and sensors required for reservoir characterization tools are either unavailable or are not suitable for operation at temperatures greater than 150°C to 200°C. Some existing tools can perform for short periods, but for EGS use tools must be capable of collecting data for protracted periods (i.e., days to years) for both well stimulation and reservoir operation.

Structural Data: Knowledge of the structural geology of the EGS site and target formations is critical for modeling and designing a successful reservoir stimulation operation. Fracture mapping using geophysical well logs has relatively poor resolution. Equipment improvements and to measure rock surface area, rock volume in contact with circulating fluids, and other parameters required for accurate predictive models of reservoir performance and lifetime.

Subsurface EGS models will require joint interpretation of geological, geochemical, and geophysical data sets, which avoids the limitations of any individual data collection and interpretation method. Many earth science industries are investigating joint data set interpretations including the petroleum and mineral industries and the nuclear and chemical waste disposal industries. Increased computational power is allowing increasingly sophisticated manipulation and display of critical data in these applications and others.

Stress State: The in-situ stress state in the target EGS volume is critical in designing stimulation programs and predicting results. Tests used to determine stress states during and after drilling (e.g., detailed borehole geometry [breakout analysis] and mini-frac breakdown) are slow and costly, and must therefore be improved. As discussed in the well field construction section, reliable zonal isolation for high-temperature applications at high differential pressures is needed to conduct mini-fracs and other stress state diagnostics.

Active Seismic: Active seismic surveys are commonly used in the oil and gas industry to locate resources and to reveal subsurface structures favorable to the concentration of hydrocarbons. These methods are highly effective for detection of hydrocarbons, but have limitations in some common geothermal environments where the geologic structures are typically massive rather than stratified in nature. Geothermal structures are more complex than most oil and gas environments and have larger velocity and reversing velocity contrasts; both of these characteristics make seismic interpretation more difficult. Additionally, seismic studies in geothermal areas are generally hampered by low signal-to-noise ratios. Equipment positioning and signal interpretation must be improved to attain resolutions similar in quality to those attained in oil and gas surveys. Advanced seismic methods hold promise for fracture mapping, and the geothermal industry may benefit from increasing petroleum industry emphasis on the use of these methods in fractured environments.

Modeling: An EGS' reservoir size and productivity depend on: rock type; local stress field; pre-existing fractures; stimulation technique; reservoir depth; temperature; pressure; system flow impedance; water leakage; reservoir growth; geochemical reactions; and other variables. Modelers must know the rock properties of a site to design a successful stimulation operation.

Standard petroleum and hydrothermal reservoir engineering and modeling techniques must be modified to account for differences between EGS, petroleum and hydrothermal reservoirs. Capable, robust and reliable numerical models must be developed and verified to couple rock- and fluid-mechanics theory with the measured properties and structure of the rocks, enabling reliable prediction of stimulation results and identification of the best options for creating the EGS.

Stimulation Design: Stimulation design involves selecting target zones for stimulation as well as the rate, pressures, volumes of injectate, type(s) of stimulation fluids, and use of proppants. Field experience and data will provide vital to information for developing and revising the design tools required for commercial EGS development

The petroleum industry has demonstrated the ability to model and create hydraulic fractures in sedimentary environments. Likewise, the hazardous waste management industry has used models for the behavior of rock when fluids are injected. Adaptation of tools from the petroleum and hazardous waste management industries will accelerate for development of models for stimulation in EGS environments.

4.1.2.4 Site/Well Characterization Objectives

The objectives of the Reservoir Characterization research area address the issues of instrumentation environment and accuracy, and the use of this improved instrumentation to create better models of the underground environment. The emphasis is on providing hardened instrumentation capable of withstanding the extremely harsh thermal and chemical environments associated with EGS, with improved accuracy, especially in the case of in-situ stress regime measurement, which is crucial to the prediction of fracture propagation.

Table 4.8. Site/Well Characterization Objectives		
Number	Description	Barrier
1	By 2012, demonstrate downhole logging & monitoring instruments and sensor capabilities that can be employed at a depth of 350 Bar and operation temperatures of 250°C.	D
2	By 2015, demonstrate downhole logging & monitoring instruments and sensor capabilities that can be employed at a depth of 600 Bar and operation temperatures of 275°C.	D
3	By 2020, demonstrate downhole logging & monitoring instruments and sensor capabilities that can be employed at a depth of 1200 Bar and operation temperatures of 300°C.	D
4	By 2010, identify candidate oil and gas logging technologies to be used in EGS.	E
5	By 2015, test and adapt chosen candidate logging technologies to EGS applications.	E
6	By 2010, assess the current available models.	F
7	By 2012, perform comparison (inputs vs. outputs) of currently available models.	F
8	By 2013, develop technical criteria for adaptation of these models to EGS requirements.	F
9	By 2015, develop and apply newly developed models in EGS projects.	F

4.1.2.5 Site/Well Characterization Technical Approach

New and improved techniques will be used to characterize the target rock mass and design the stimulation plan. Near-term field projects will utilize existing wells at or near developed hydrothermal systems. Mid- to long-term field projects will begin outside or remote from existing, developed hydrothermal systems.

4.1.2.6 Site/Well Characterization Programmatic Status

Early seismic surveys in highly-faulted volcanic and igneous environments suffered from high noise levels, poor to incoherent reflections, and complex reflection environments. State-of-the-art surface (seismic reflection) and borehole seismic methods including vertical seismic profiling (VSP) have been evaluated and used to locate and quantify geothermal reservoir characteristics. The premise of this work was to determine if new developments in theory and modeling, as well as in data acquisition and processing, could result in a more detailed subsurface image.

Table 4.9. Site/Well Characterization Technology/Program Activities		
Task	Approach	Organization
Reservoir creation and management using stimulation prediction models	Develop and adapt coupled numerical models and software to accurately predict fracture growth and permeability development under stimulation	TBD
Stress determination, geothermometry, logging tools, log interpretation methods, numerical models of stimulation	Improve resource assessment techniques	TBD through future solicitations

4.1.2.7 Site/Well Characterization Technology Status

Logging and borehole imaging tools enable detailed characterization of lithology, fractures, stress field, and the status of well construction, a major source of risk in deeper wells. Borehole logging technology has largely been developed by the petroleum and water well industries, with some minor contribution from the minerals industries. As oil and gas wells are drilled into deeper and hotter rock, improved equipment is being developed to operate in these high-temperature, corrosive environments. While some logging tools are usable in geothermal conditions, wells often must be cooled prior to logging to avoid exceeding the instruments' temperature limitations. Logging techniques include: electrical and electromagnetic (EM) methods, seismic methods, radioactive methods,temperature, pressure, and fluid-flow velocity (spinner), as well as advanced logs such as the borehole televiewer, Formation Microscanner, and others.

SNL chose a precision pressure-temperature tool as one of its first projects in designing high-temperature logging devices. The tool has been commercialized by a geothermal service company, and has been a cornerstone of SNL's program for geothermal logging.

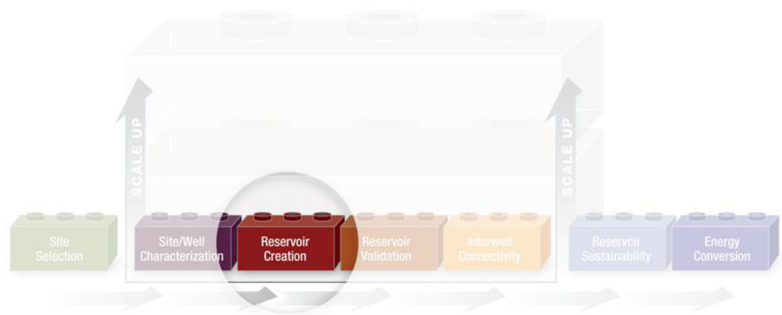
Table 4.10. Site/Well Characterization Technology Status Summary		
Barrier	Available Technologies (U.S and International)	Organization
Barrier D: Site/Well Characterization Subsurface environment in EGS regimes are inhospitable to current downhole sensors	High Temperature Logging Tools- Logging Tools (e.g., tools to measure downhole pressure, flow, temperature, image fractures)	Logging tools and sensors are available for operation up to about 150°C. Higher temperature versions of some tools are available but have limited lifetimes or require heat shielding.
		Unshielded prototypes for pressure and temperature are experimental.
Barrier E: Site Characterization Insufficient tool accuracy and range to obtain in-situ subsurface stress regimes	Perform stress measurements: Micro-fracs and borehole breakouts, core-based measurements	Suitable technology available for lower-temperature applications. Technology lacks zonal isolation capability. Routinely used in mineral exploration. Interpretive techniques for geothermal applications are still evolving.
	Characterize subsurface conditions: Core sampling and evaluation	
Barrier F: Modeling Insufficient understanding of the rock and fluid mechanics and geochemistry to validate model algorithms	Plan and design stimulation (e.g., zones, pressures, volumes, fluids, proppants)	Stimulation models for oil and gas exist, but stimulation modeling techniques for geothermal systems are not a mature technology (i.e., basic numerical models). Current models have not been effective in a geothermal environment.

4.1.2.8 Site/Well Characterization Tasks

The following tasks support the objectives of the Characterization research area.

Table 4.11. Reservoir Characterization Tasks		
Number	Description	Barrier
a	Develop high-temperature, high-pressure downhole instruments and sensors to monitor wellbore conditions such as fracture detection, temperature, pressure, flow rates, and seismic events.	D
b	Develop robust tools for making in-situ stress measurements at high temperatures and pressures for reservoir creation model input.	E
c	Write a report documenting candidate technologies.	E
d	Create database to document logging data and interpretations for future applications.	E
e	Gather and catalog data from field projects for continuous model validation.	F
f	On an ongoing basis, continually update and validate code with data as it is gathered from field projects.	F

4.1.3 Reservoir Creation



4.1.3.1 Reservoir Creation Goal

The greatest technical challenge and uncertainty in the EGS approach is the ability to create the required volume of fractured reservoir rock/heat exchange surface required for decades-long production at sufficiently high rates for commercial production. Because of the inherent thermal insulation capacity of rock (low thermal conductivity) the rate of replenishment of heat extracted by fluid production is exceedingly slow. Large surface areas for fluid/rock heat exchange and large volumes of fluid flow are required in the EGS reservoir to maintain temperature over time.

Goal 4: Develop the ability to create EGS reservoirs with the technical characteristics required for economic viability.

4.1.3.2 Reservoir Creation Barriers

Barrier G: **Reservoir Fracturing** – Stimulation technology and methodology used in the oil and gas industry has not sufficiently been demonstrated for EGS reservoir creation.

Barrier H: **EGS Well Zonal Isolatio**n – The capability has not been sufficiently demonstrated to isolate sections of the wellbore to: 1) enable stimulation; and 2) seal off unwanted flow regions in unknown EGS completion schemes and high-temperature (>200°C) environments.

4.1.3.3 Reservoir Creation Background

A key technical challenge in reservoir creation is to achieve sufficient productivity for commercial EGS energy generation (identified by the MIT report as 80 kg/sec of fluid production) while maintaining appropriate temperatures for at least six years. Important next steps will be to (1) create new, pervasive permeability rather than enlarging a few existing fractures, (2) avoid short circuits and repair them if they develop, (3) measure the fractured rock volume and water-accessible fracture area, and (4) maintain open fractures in a variety of stress regimes.

Research and field projects have demonstrated that reservoirs can be created, but the control required to create large volumes of fractured rock, free of short circuits, has not been thoroughly demonstrated. Key requirements include improved fracturing technology, rheologically controllable fracturing fluids, and high-temperature borehole packers for isolating fracture zones. Alternate technologies such as high-pressure gas fracturing (possibly using controlled-burn explosives) should be tested, and hydraulic fracturing techniques improved to provide fracturing methods for varying geological environments. Although large fractured volumes (several km3) have been created in experiments, circulating fluid through these full volumes has proven difficult.

Fracturing technology for sedimentary formations is highly advanced. The petroleum industry's state-of-the-art equipment creates fracture half-lengths of 200 to 400 feet or more. While a viable EGS heat exchanger will likely be created for use in sedimentary rocks using methods developed for stimulating petroleum wells, it will need to be demonstrated in the field with industry cooperation. Hydraulic fracturing has had mixed results in hydrothermal settings, in part due to inadequate characterization of the host rock (including the stress state and the location, direction, and permeability of pre-existing fractures). This shortfall results in inadequate data and modeling for effective fracture treatment design.

While it is possible to create or stimulate enough fractures to support high flow rates, targeting specific fractures is not yet possible. Once fractures have been created, hydraulic stimulation can be used to increase the length and complexity of the fracture system. Because developers who enhance well productivity work with service companies that view their efforts as proprietary, little data is available relating treatment design and geologic environment to well productivity improvement.

Tests used to determine stress states during and after drilling, such as detailed borehole geometry (breakout analysis), leak-off tests and mini-frac breakdown pressures are standard in the petroleum industry. The stress field can also be estimated from borehole elongation and regional stress field considerations. The usefulness of these techniques has not been validated in geothermal environments.

Proppants used by the oil and gas industry to keep fractures open have not yet been successful in geothermal settings. The temperature, stresses, corrosive brine chemistry and high-volume circulation in many potential EGS reservoirs would destroy the majority of the most widely used proppants. Research is needed to develop high-strength propping agents (such as advanced ceramics and coatings), and/or to develop compositions that will reduce the risk of rapid proppant dissolution. Temperature-hardened proppants may be required for EGS applications.

Zonal isolation is essential for many EGS reservoir development activities. Packers and other zonal isolation tools are required to eliminate fluid loss, to help identify and mitigate short circuiting of flow from injectors to producers, and to target individual fractures or fracture networks for testing and validating reservoir models. General-purpose open-hole packers do not exist for geothermal environments, with the primary barrier being the poor stability of elastomeric seals at high temperatures. Existing borehole packers are incapable of handling temperatures above 175 °C. Experimental packer systems have been developed for geothermal environments but they currently only operate at low pressure, they are not retrievable and they are not commercially available. Cased-hole isolation tools suitable for high-temperature environments are emerging, and these tools have the advantage of metal-to-metal seals.

4.1.3.4 Reservoir Creation Objectives

The following objectives represent important benchmarks in overcoming the technical obstacles to EGS commercialization imposed by the barriers described above.

Table 4.12. Reservoir Characterization Objectives		
Number	Description	Barrier
1	By 2011, set technical objectives for improvement of EGS reservoir stimulation.	G
2	By 2015, develop tools and techniques for the determination of fracture surface area, fracture spacing and rock volume in stimulated reservoirs.	G
3	By 2015, demonstrate the ability to consistently and predictably fracture a range of hard-rock lithologies and geological environment.	G
4	By 2015, develop improved-resolution stimulation monitoring tools, the images of which can be used to adjust stimulation real-time.	G
5	By 2012, demonstrate affordable, reliable, reusable borehole packers that can be employed at a differential pressure of 350 bar and operation temperatures of 250oC. (TBR)	H
6	By 2015, develop chemical or other treatment methods for well treatment to seal unwanted fractures.	H
7	By 2015, develop tools for mechanical sealing of wellbore skin (e.g. expandable liners) for sealing of unwanted fractures.	H
8	By 2015, demonstrate affordable, reliable, reusable borehole packers that can be employed at a differential pressure of 500 bar and operation temperatures of 275oC. (TBR)	H
9	By 2020, demonstrate affordable, reliable, reusable borehole packers that can be employed at a differential pressure of 750 bar and operation temperatures of 300oC. (TBR)	H

4.1.3.5 Reservoir Creation Technical Approach

New and improved techniques will be used to characterize the target rock mass and design the stimulation plan. Near-term field projects will utilize existing wells at or near developed hydrothermal systems. Mid- to long-term field projects will be outside of or remote from developed hydrothermal systems.

4.1.3.6 Reservoir Creation Programmatic Status

The industry has shouldered some of the early responsibility in this area. Some incipient efforts in Reservoir Creation are shown in the table below.

Table 4.13. Reservoir Creation Technology/Program Activities		
Task	**Approach**	**Organization**
Enhanced reservoir size and heat transfer capability	Establish the effectiveness of high-pressure gas, thermal methods, and chemical methods for stimulation	TBD
Learn in-situ stress, rock properties, and MEQ behaviors	Pre Stimulation and Recompletion activities	Industry

4.1.3.7 Reservoir Creation Technology Status

Projects underway in France and Australia currently define the state of the art in reservoir characterization technologies. The Soultz project collaboration began in 1987, between the European Union and the governments of France, Germany and Italy. The first phases of the project created a reservoir at 3,900 m in 165 °C rocks that produced 25 l/s of water at 140 °C at low injection pressure. In 1998, the production well was extended to 5,000 m, where a predicted rock temperature of 200 °C was verified. Hydraulic fracturing in 2000 produced a 1.1 km3 reservoir that has been stimulated to create a circulation loop. The next phase of development, to be carried out from 2005 to 2008, is designed to achieve 100 l/s production rates and drive a 1.6 MWe power plant. If this is successful, an expansion to 6 MWe is planned.

A second project, at Landau, Germany has leveraged the results of the Soultz project to create a small operating EGS. This project produces at a rate of 100 l/s due to the connection of the created reservoir with a pre-existing fracture system. Geodynamics Geothermal, a private sector developer, is undertaking a large-scale EGS project at Cooper Basin, Australia. Rock temperatures of 250 °C have been confirmed at 4,400 m depth. Horizontal fractures from hydraulic stimulation have created a horizontally-oriented underground heat exchanger more than nine times larger than originally projected. Overpressure in some wells may indicate a natural geothermal field capable of flowing under its own pressure.

Packers and other zonal isolation tools are required to eliminate fluid loss, to help identify year and mitigate short circuiting of flow from injectors to producers, and to target individual fractures or fracture networks for testing and validating reservoir models. General-purpose open-hole packers do not exist for geothermal environments, with the primary barrier being the poor stability of elastomeric seals at high temperatures. Existing borehole packers are incapable of handling temperatures above 175 °C. Experimental packer systems have been developed for geothermal environments but they currently only operate at low pressure, they are not retrievable and are not commercially available. Cased-hole isolation tools suitable for high-temperature environments are emerging, and these tools have the advantage of metal-to-metal seals.

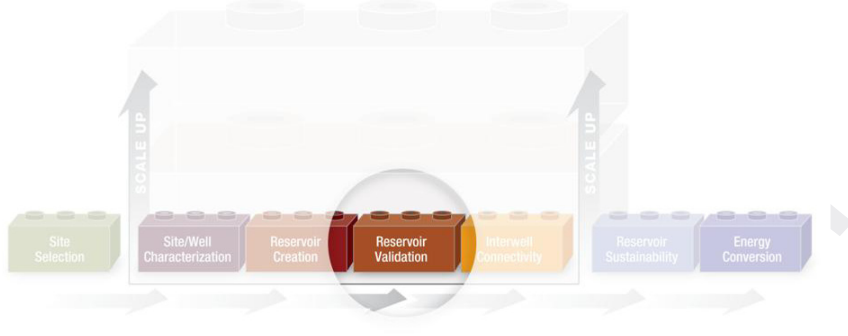
Table 4.14. Reservoir Creation Technology Status Summary		
Barrier	**Available Technologies (U.S and International)**	**Technology Status**
Barrier G: Reservoir Creation Fracture technology used in the oil & gas industry has not sufficiently been demonstrated for EGS reservoir creation.	Scaling, dissolution, and permeability control	Scaling and dissolution control technologies are available but may not be adequate for EGS conditions.
	Effective real-time decision-making capability for stimulation: Oil and gas industry stimulation modeling and control technology	The oil industry has modeling and control capability for petroleum environments, but experience in geothermal systems is lacking.
	Keep flow paths open: Proppants for both near well bore and far field use	Proppants are typically used in oil & gas stimulations. Temperature-hardened proppants have not been evaluated in geothermal environments.
	Create/enhance flow paths: Hydraulic stimulation;	Geothermal stimulations for EGS use water or water weighted with dense chemicals such as barium sulfate salts. Chemical and other stimulation methods have been used in hydrothermal systems.
	Chemical stimulation; and Rate Controlled explosives	
	Mitigate reservoir- Short Circuiting to prevent pressure drop and fluid loss	Cements are routinely used in the hydrothermal industry for lost circulation.
		Coupled modeling tools and simulators are needed.
Barrier H: EGS Well Zonal Isolation The capability has not been sufficiently demonstrated to isolate sections of the wellbore to: 1) enable stimulation; and 2) seal off unwanted flow regions.	Zonal isolation for stimulation: Stimulation packers, slotted liners	Packers that can operate at stimulation pressures and temperatures are not available. Slotted liners and related technologies may not perform adequately for EGS
		Retrievable packers for high pressure operations in high temperature (>150°C for extended operation) wells are not available.
	Open and cased hole packers and expandable tubulars and screens	Elastomer and cement packers are not available for high-temperature applications.
		Experimental versions of low-pressure packers developed for geothermal applications are not generally available.

4.1.3.8 Reservoir Creation Tasks

The following tasks will be undertaken in support of the Reservoir Creation research area.

Table 4.15. Reservoir Characterization Tasks		
Number	Description	Barrier
1	Develop stable (temperature-hardened and chemical-hardened) proppants for enhancing permeability and water flow, if necessary.	G
2	Establish the effectiveness of high-pressure gas generation, thermal methods, and chemical methods as compared to the baseline of hydrofracturing using field test data.	G
3	Test candidate methods for creating an EGS reservoir.	G
4	Test candidate techniques for fracturing in the subsurface.	G
5	Develop and test additives for controlling the attributes of fracturing fluids.	G
6	Develop and test methods of controlling short-circuiting and fluid loss.	G
7	Conduct field demonstrations to determine best stimulation techniques for various geological environments.	G
8	Demonstrate affordable, reliable, reusable borehole packers, especially open-hole packers applicable to EGS environments.	H

4.1.4 Reservoir Validation



4.1.4.1 Reservoir Validation Goal

Goal 5: Demonstrate ability to accurately describe the physical characteristics of created EGS reservoirs.

After the fracturing of a potential EGS resource has been performed, it is essential to establish that the desired result has been achieved and is replicable.

4.1.4.2 Reservoir Validation Barrier

Barrier I: **Images of Fractures After Stimulation** – Inability to characterize the physical parameters of potential EGS reservoirs after stimulation.

4.1.4.3 Reservoir Validation Background

Because of the small number of successfully stimulated resources, the reliability of the stimulation process has not been firmly established. After a potential EGS reservoir has been stimulated, the subsurface environment has necessarily been altered, in many cases significantly. The accurate prediction of the stimulation results can validate the process used to create the reservoir. These predictions can be verified with improved fracture imaging.

Reservoir validation will require many of the same methods and tools described in RD&D Sections 1, 2 and 3.

4.1.4.4 Reservoir Validation Objectives

The following objectives support the goal of Reservoir Validation.

Table 4.16. Reservoir Validation Objectives		
Number	Description	Barrier
1	By 2010, characterize needs for quantification of fracture detection and water flow.	I
2	By 2010, set technical objectives for improvement of geophysical methods for the downhole detection of fractures and water flow.	I

4.1.4.5 Reservoir Validation Technical Approach

New and improved techniques will be used to characterize the target rock mass and design the stimulation plan. Near-term field projects will utilize existing wells at or near developed hydrothermal systems. Mid- to long-term field projects will begin outside or remote from existing, developed hydrothermal systems.

4.1.4.6 Reservoir Validation Programmatic Status

Some early work in Reservoir Validation has begun, as shown in the table below.

Table 4.17. Reservoir Validation Technology/Program Activities		
Task	Approach	Organization
Identification of flow paths during and post-stimulation	Improve resolution of geophysical methods by (TBD) percent for detection of fractures and fluid flow	LBNL and others TBD
Improve temperature and chemical sensitivity of down-hole sensors	TBD	TBD

4.1.4.7 Reservoir Validation Technology Status

Streaming Potential (SP) is a method for identifying flow paths through rock based on the detection of charge imbalances at the interface of fluid and rock that are generated by flow of electrolytic fluid. SP monitoring has the potential to be a valuable tool for geothermal water flow characterization. SP uses electrodes connected to a data logger to make low-cost remote measurements of water flow. Laboratory testing suggests that SP combined with interpretation and modeling may be able to effectively map fluid flow in three dimensions throughout a geothermal reservoir.

Passive Microseismic: Passive seismic techniques enable the monitoring of reservoir stimulation through the analysis of induced microseismic events. Although the petroleum industry is advancing the state-of-the-art active seismic technologies, passive seismic technologies are not receiving the same level of research despite the potential value as an essential tool for tracking and evaluation of results from reservoir stimulation. Microseismic monitoring is a promising technique, but the relationship between the MEQ cloud and the created fractures is not fully understood. New and improved real-time methods are needed to monitor fracturing progress and to indicate when and how to modify the stimulation program. Increased resolution and accuracy of passive seismic mapping techniques will require downhole tools that can withstand the temperatures associated with EGS. While remote sensing of fracture growth via microseismic analysis indicates possible fluid flow paths, the ability to directly map the flow through the created reservoir does not currently exist.

The resolution of remote sensing techniques such as SP can be improved by joint interpretation (joint inversion) with other data sets including geological data (e.g., rock type, structures such as faults or contacts, hydrothermal alteration), geochemical data (e.g., fluid chemistry, soil geochemistry) and geophysical data (e.g., electrical and electromagnetic survey data, seismic data, magnetic data, gravity data, well logging data).

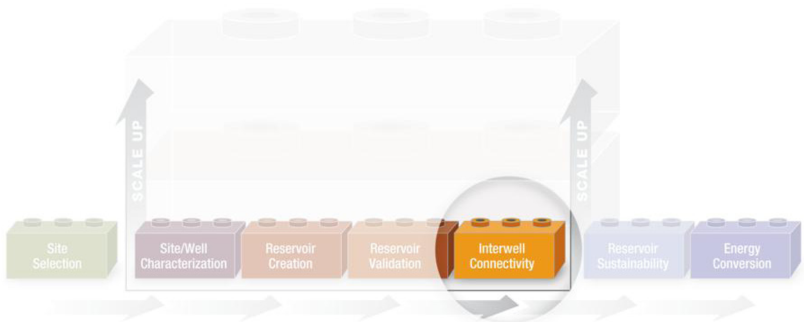
Table 4.18. Reservoir Validation Technology Status Summary		
Barrier	Available Technologies (U.S. and International)	Technology Status
Barrier I: Imaging of Fractures After Stimulation Inability to characterize the physical parameters of potential EGS reservoirs after stimulation, providing sufficient data to enable successful and replicable EGS development	Passive Microseismic techniques	Currently the best method for monitoring the reservoir creation. Used at hot dry rock and hot fractured rock field sites in the past.
	Identification of flow paths during and post-stimulation-Remote Sensing techniques (e.g., Microseismicity, gravimetry, SP, tiltmeter arrays)	The utility of existing techniques for tracking fluid flow has not been demonstrated. Microseismic techniques are not hardened for downhole use. Suitable downhole instrumentation for standard flow tests is available up to 200ºC.
	Imaging and mapping of fractures: Microseismicity, gravimetry, self potential (SP), tiltmeter arrays	Surface microseismic and gravity tools are adequate for most purposes, but the resolution may be insufficient for EGS. Self-potential is not proven for this purpose. Tiltmeter results are difficult to interpret in zones of multiple fractures.
	Conduct flow tests: Pressure, temperature, and fluid-flow measurement tools	Suitable downhole instrumentation for standard flow tests available up to 200ºC. Some existing tools can perform for short periods, but for EGS use they must be capable of collecting data for protracted periods.
	Logging and borehole imaging tools to enable detailed characterization of wells-Logging Tools	Logging techniques include electrical and electromagnetic, seismic methods, radioactive methods, temperature, pressure, and fluid-flow velocity, as well as advanced logs such as the borehole televiewer, Formation Microscanner, and others. As oil and gas wells are drilled into deeper and hotter rock, improved equipment is being developed to operate in these high-temperature, corrosive environments.

4.1.4.8 Reservoir Validation Tasks

The following tasks support the Reservoir Validation research area.

Table 4.19. Reservoir Validation Tasks		
Number	Description	Barrier
1	Perform technical assessment and needs quantification of fracture detection and water flow.	I
2	Improve resolution of geophysical methods for the downhole detection of fractures and water flow.	I

4.1.5 Interwell Connectivity



4.1.5.1 Interwell Connectivity Goal

Goal 6: Demonstrate ability to accurately detect reservoir characteristics including fluid pathways, dynamics, residence time, etc.

The tracing of the fluid pathway is essential in the determination of important heat transfer surface area, permeability, pressure drop, and fluid residence time in geothermal reservoirs, all of which enable the construction of accurate predictive models of reservoir behavior.

4.1.5.2 Interwell Connectivity Barriers

Barrier J: **Tracers** – Inadequate tracers and/or tracer methodology to accurately define the subsurface system of fractures and mapping of fluid flow.

Barrier K: **Downhole Pumps** – Inadequate pump technology available for EGS downhole conditions of temperature, depth, pressure, and pump diameter-vs.-casing-diameter.

4.1.5.3 Interwell Connectivity Background

Tracers do not exist that can reliably measure and/or monitor the surface area responsible for rock-fluid heat and mass exchange, thereby allowing for the quantification and prediction of EGS heat extraction efficiencies. Pumps capable of sustaining the necessary flow rate through the reservoir, given the temperature of the working fluid and the small diameters of the production wells, have not yet been developed.

4.1.5.4 Interwell Connectivity Objectives

The following objectives represent important benchmarks in overcoming the technical obstacles to EGS commercialization imposed by the barriers described above.

Table 4.20. Interwell Connectivity Objectives

Number	Description	Barrier
1	By 2012, demonstrate tracer technologies at operation temperatures of 250°C.	J
2	By 2015, demonstrate tracer technologies at operation temperatures of 275°C.	J
3	By 2020, demonstrate tracer technologies at operation temperatures of 300°C.	J
4	By 2010, validate the capabilities and limitations of current pump technologies.	K
5	By 2012, improve the performance of downhole pumps, especially ESPs, to operate at temperatures of 250°C, mass flow rates of up to 80 kg/s, setting depth as great as 1 km, for wellbore diameters of 6 5/8” to 10 5/8”, and operating at pressures up to 200 bar.	K
6	By 2015, improve the performance of downhole pumps, especially ESPs, to operate at temperatures of 275°C, mass flow rates of up to 80 kg/s, setting depth as great as 2 km, for wellbore diameters of 6 5/8” to 10 5/8”, and operating at pressures up to 200 bar.	K
7	By 2020, improve the performance of downhole pumps, especially ESPs, to operate at temperatures of 300°C, mass flow rates of up to 80 kg/s, setting depth as great as 3 km, for wellbore diameters of 6 5/8” to 10 5/8”, and operating at pressures up to 200 bar.	K

4.1.5.5 Interwell Connectivity Technical Approach

New and improved tracers will be developed to better determine the fluid flow pathways. Improved downhole pumps will be developed to withstand EGS environments while providing EGS- quality flow.

4.1.5.6 Interwell Connectivity Programmatic Status

Some early work in Interwell Connectivity has begun, as shown in the table below.

Table 4.21. Interwell Connectivity Technology/Program Activities		
Task	Approach	Organization
Tracers and tracer interpretation	Develop improved tracers and interpretation methods to define reservoir surface area and validate reservoir models	LBNL and others TBD

4.1.5.7 Interwell Connectivity Technology Status

Tracer compounds can be divided into two groups: chemically inert and physio-chemically reactive. Inert tracers are useful in providing model-independent information, such as the degree of well-to-well connectivity, dispersive characteristics and fracture volume, and tracking of the thermal front when used in conjunction with reservoir simulation. Temperature-sensitive chemically-reacting/adsorbing tracers can provide insight into fracture surface area and heat extraction efficiency along a flow path and track the thermal front, leading to construction of detailed reservoir models with predictive capabilities.

Tracers are invaluable tools for detailed reservoir studies. Theoretical work has shown that tracer tests can be analyzed to quantify numerous reservoir variables that are of value for modeling including sweep efficiency, total pore volume, flow geometry, and others; however, only limited field work has been done to demonstrate the effectiveness of quantitative tracer analysis. Although DOE-sponsored research has significantly advanced the sophistication and use of tracers for characterizing hydrothermal systems, development of new "smart" tracers is warranted.

EGS reservoir are expected to be hot and high in pressure; downhole pumps capable of withstanding EGS conditions while sustaining sufficient EGS flow rates do not yet exist.

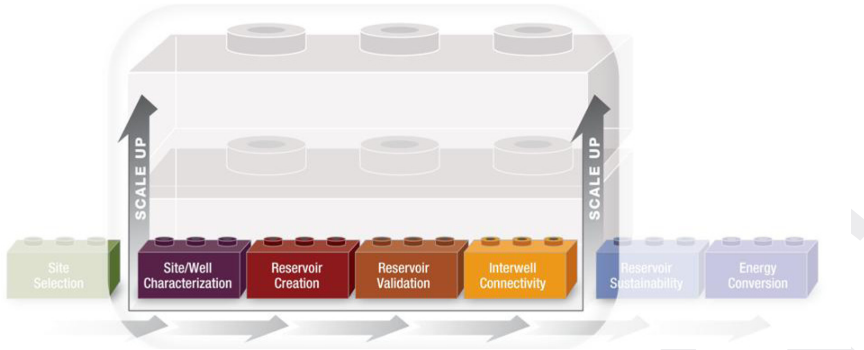
Table 4.22. Interwell Connectivity Technology Status Summary		
Barrier	**Available Technologies (U.S. and International)**	**Technology Status**
Barrier J: Tracers Inadequate tracers and/or tracer methodology to accurately define subsurface system of fractures and mapping of fluid flow	Development of new “Smart” Tracers	Tracer tests are an established method of validating reservoir models, but “Smart” tracers needed for EGS have not been developed.
Barrier K: Downhole Pumps Inadequate pump technology available for downhole chemistry, depth, pressure, and volume-vs-casing-diameter needed	TBP	TBP

4.1.5.8 Interwell Connectivity Tasks

The following tasks support the Reservoir Validation research area.

Table 4.23. Interwell Connectivity Tasks		
Number	**Description**	**Barrier**
a	Perform technical assessment and needs quantification of tracer and tracer interpretation technology.	J
b	Develop improved tracers and tracer interpretation methods to define heat exchanger surface area (for thermal drawdown) and validate the reservoir model.	J
c	Improve the performance of downhole electric submersible pumps to operate at higher temperatures and deeper setting depths.	K
d	Initiate a program to develop improved downhole pumping technologies for deep, high-temperature meter wells, and the conversion of large pumps to DC operation.	K
e	Improve pump and motor seals to withstand harsh downhole chemical environments.	K

4.1.6 Reservoir Scale Up



4.1.6.1 Reservoir Scale Up Goal

Goal 7: Develop technologies and methods for achieving low-cost scalability of EGS.

Since no commercial-scale EGS have been deployed in the US, it is unknown how best to expand an EGS wellfield to optimally utilize the potential resource.

4.1.6.2 Reservoir Scale Up Barrier

Barrier L: **Well Field Design** – Inability to assess and select the most efficient well-field design.

While some schemes for drilling new wells in a hydrothermal field have been developed, it is not known to what degree these can be applied to EGS because of temperature profiles, variable lithology and depth including optimization of parameters such as well diameter, spacing, multiple small wells vs. fewer large wells, etc.

4.1.6.3 Reservoir Scale Up Objectives

The following objectives are associated with Barrier L.

Table 4.24. Reservoir Scale-up Objectives		
Number	Description	Barrier
1	By 2010, understand current standard (lessons learned from Soultz and Cooper Basin) for well layout and use of sidetracks for efficient EGS reservoir systems.	L
2	By 2012, develop methods to integrate well development schemes with overarching needs of reservoir development.	L

4.1.6.4 Reservoir Scale Up Technical Approach

New and improved procedures will be developed to better determine the best layout of an EGS wellfield for the generalized EGS case.

4.1.6.5 Reservoir Scale Up Programmatic Status

TBD.

Table 4.25. Reservoir Scale-Up Technology/Program Activities		
Task	Approach	Organization
Assess the most effective use of wells and sidetracks	TBP	TBP

4.1.6.6 Reservoir Scale Up Technology Status

TBD

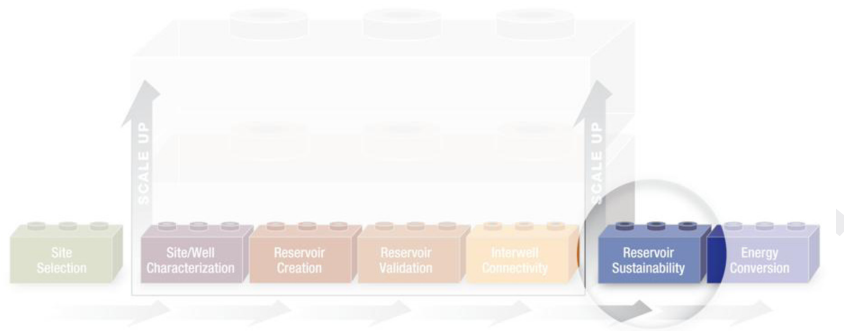
Table 4.26. Reservoir Scale Up Technology Status Summary		
Barrier	Available Technologies (U.S. and International)	Technology Status
Barrier L: Inability to assess the most effective use of wells and sidetracks	Design field expansion-monitoring & modeling of reservoir evolution	Existing reservoir simulation models are not fully coupled to enable planning of field expansion. Sufficient data to validate models is not available.
	Validate reservoir model using field data- monitoring & modeling of reservoir evolution	Few monitoring tools and sensors (e.g., tools to measure pressure, flow, temperature, and seismicity) can operate at high temperature for long periods. A temperature sensor is available, but it must be hardened for geothermal conditions.

4.1.6.7 Reservoir Scale Up Tasks

The following tasks supports the Reservoir Scale-up research area.

Table 4.27. Reservoir Scale-up Task		
Number	Description	Barrier
1	Conduct parametric studies for better understanding of interaction between various well-field designs and the stimulated reservoir.	L
2	Optimize methodology to economically exploit EGS resources using the most efficient well-field design.	L
3	Investigate cost trade-off between increased power plant efficiency vs. increased well productivity.	L
4	Understand well productivity index.	L

4.1.7 Reservoir Sustainability



4.1.7.1 Reservoir Sustainability Goal

Goal 8: Develop the ability to manage EGS reservoirs for maintenance of reservoir lifetime and productivity

The ability to manage an EGS resource over time is crucial to creating an economically feasible energy source from EGS.

4.1.7.2 Reservoir Sustainability Barrier

Barrier M: **Long-Term Sustainability** – Unknown ability to manage long-term rock temperature, transmission, fluid quantity and fluid chemistry.

4.1.7.3 Reservoir Sustainability Background

The most critical aspects of EGS sustainability depend on achieving the same general operating parameters as commercial hydrothermal systems. A good hydrothermal well yields about 35 MWt, which can be used to generate about 5 MWe at an energy conversion efficiency of 14 percent. An average hydrothermal well must produce for seven years or more to permit recovery of the capital investment. The operating time of a well in an EGS must be at least as long given the added cost of drilling and fracturing the reservoir.

Corrosion and Scaling: High temperatures and fluid chemistry and pH make corrosion and scaling a major challenge. Improved anti-corrosion and anti-scaling fluid management are difficult to develop at reasonable costs.

4.1.7.4 Reservoir Sustainability Objectives

Long-term economic operation will require systematic management of the EGS reservoir. Technologies are required to mitigate problems that are expected to arise in the course of reservoir operation. The following objectives support the stated goal for reservoir sustainability:

Table 4.28. Reservoir Sustainability Objectives		
Number	**Description**	**Barrier**
1	By 2012, re-evaluate hydrothermal technical objectives for adaptation to EGS reservoir sustainability.	M
2	By 2012, complete feasibility studies of utilizing various working fluids.	M
3	By 2015, understand current standard (lessons learned from Soultz and Cooper Basin) for reservoir sustainability.	M

4.1.7.5 Reservoir Sustainability Technical Approach

The focus of the Reservoir Operations and Maintenance program element is to maintain the technical and economic performance of the EGS reservoir through design life. Applicable essential technologies for reservoir maintenance exist and are being used by the geothermal industry or by the oil and gas industry, but have not been tested under EGS conditions.

4.1.7.6 Reservoir Sustainability Programmatic Status

Work to date in the Reservoir Sustainability research area has been performed at LBNL and has focused on improving understanding of rock-fluid geochemistry for scale and dissolution prediction and maintaining fluid flow and reservoir lifetime.

Table 4.29 Reservoir Sustainability Technology/Program Activities		
Task	**Approach**	**Organization**
Stimulation and management of created reservoir	Improve understanding of rock-fluid geochemistry for scale and dissolution prediction	LBNL and others TBD
	Improve stress measurement technology for reservoir creation at a depth of 3 km.	
	Develop temperature-hardened proppants and emplacement technology	
Maintaining fluid flow and reservoir lifetime	Improve understanding of rock-fluid geochemistry for scale and dissolution prediction	LBNL

4.1.7.7 Reservoir Sustainability Technology Status

Reservoir operation and management requires detailed knowledge of the rock and geometric properties of the circulation system. Wells must access the entire reservoir volume and create an efficient heat-mining system. Geophysical techniques must be able to map the reservoir in three dimensions and monitor changes with time. Numerical models of reservoir performance are needed that account for hydraulic, thermal and chemical properties and changes, and that model the fracture-dominated EGS reservoir environment. The combined use of chemical tracers, natural-fluid tracers, microseismic monitoring, active seismic surveys, and advanced forms of electrical geophysical methods have shown potential for determining heat exchange area and the useful volume of fractured rock, monitoring changes with time, detecting thermal drawdown before it effects production wells, and for targeting new production and injection wells.

On a short-term basis, downhole tools can measure temperature, pressure, flow and natural-gamma emissions; however, these instruments cannot be used for long-term monitoring because of temperature limitations, as noted previously. MEQ monitoring tools are limited to 120°C. Downhole tools must be developed to withstand temperatures above 200°C for extended periods. Temperature-hardened tools for real-time down-hole monitoring of temperature, pressure and flow along with in-stream surface monitoring of fluid chemistry would significantly enhance the ability to track the hydrologic and thermal evolution of the reservoir, monitor rock-fluid interactions and provide the appropriate field data for validating and updating reservoir models and simulators. Tools for logging and recording pressures and temperatures during testing are needed for long-term, high-temperature deployment. Surface and down-hole geophysical, seismic, electrical, geochemical, and other techniques must be adapted for reservoir monitoring.

Understanding and forecasting reservoir evolution is crucial for reservoir operation and management. After stimulation, the reservoir expands as the rock cools and shrinks, transferring mechanical load to adjacent rock and propagating fractures. Fracture growth is affected by the local and regional stress regimes, so growth can be managed by controlling injection and production well pressures. As the local stress is relieved due to thermal and pressure gradients, the reservoir grows and the system permeability increases. Once the desired size is achieved, the pressure can be adjusted to prevent further growth and reduce fluid losses.

Reservoir management and operation relies heavily on models and simulators that can accurately predict reservoir behavior. For optimum EGS operation, fully coupled Hydrologic-Thermal-Mechanical-Chemical (H-T-M-C) models and simulators will be necessary to predict fluid flow, heat extraction, temperature drawdown, rock-mechanical processes, and chemical processes that will have either beneficial or deleterious impacts on reservoir performance and longevity.

Increased permeability is a primary requirement for improving economics, but the creation of high-flow channels in the rock (short circuits) that lead to cooling of the reservoir must be avoided. Reservoir flow short-circuiting is not well understood, and techniques for sealing short-circuit pathways are not available for use in geothermal systems. There are no methods to measure short-circuiting directly, although tracer testing can help determine its magnitude.

Additionally, new technologies for control of fluid flow between injection and production wells are required to mitigate short circuiting. Rheologically controllable fluids hold potential for repairing short circuits, directing fluids to specified parts of the reservoir, and preventing excessive water loss. The temperature limit for fluid additives that control rheology is around 175°C, well below the target of 200°C. Industry has revived research on extending the temperature range for fluid additives as production of higher-temperature oil and gas fields has become economic due to increased oil prices.

Operation of an EGS reservoir will require injection of fluids that are not at equilibrium with the reservoir rock mass. As fluid flows through a geothermal reservoir, the chemistry of the reservoir is affected by fluid flow, reinjection of fluid with different chemistry than the original reservoir fluid, and temperature changes. These changes in chemistry lead to variations in the dissolution and precipitation of minerals in the system. Such mineralogic changes may affect the permeability of the system.

Rock/water interactions are likely to have a significant impact on the evolution of the reservoir. Although understanding of the chemistry of rock/water systems is improving, long-term predictive models are still under development. Better technology is needed for control of scale formation and rock dissolution. As a result, scaling and/or dissolution will likely occur in the wellbore or the reservoir. Treatments available today may not be adequate for long-term operation.

The chemical and transport processes that influence the creation and maintenance of permeability in typical geothermal rock types have not yet been determined. Accumulation of deposits in geothermal wells, caused by the dissolution and redeposition of soluble chemicals, gradually reduces production by narrowing and eventually blocking flow paths, including the wellbore. Better methods are required for controlling scaling and dissolution of rock. Silica behavior at high temperature and pressure is not well understood.

Creating and operating a reservoir will result in some induced seismicity and perhaps some degree of subsidence. Experience at The Geysers and Soultz, as well as numerous other sites, has shown a correlation between injection and induced seismicity. Geothermal energy production is occasionally associated with seismic events large enough to be felt by people nearby. Repeated seismicity may cause structural damage to buildings and public annoyance. Induced seismicity has the potential to halt if not end a project, as demonstrated in Soultz, France, and Basel, Switzerland.

Studies of induced seismicity, including one released under the auspices of the International Energy Agency, conclude that damaging earthquakes as a result of EGS reservoir operation are unlikely. The initial impact in the United States is believed to be low, since many candidate sites for early development are in unpopulated areas. Unfortunately the current state of knowledge does not point to technological solutions. Protocols for operation of EGS facilities to manage induced seismicity have been proposed, but have not yet been adopted or even proven effective.

Controlling the pressure regime can control reservoir fluid movement. Artificial lift (pumping) in production wells increases the pressure drop across the system without increasing injection pressures. High injection pressures may open undesirable fractures and allow short circuits. High-pressure pumping also adds to energy consumption. Pumping of production wells to decrease pressures may prevent microseismicity.

An ideal EGS system will have little or no water loss. Water losses must be minimized because of the negative implications of excessive parasitic pumping power, and because makeup water is cooler than re-circulated water, hastening cooling. Methods are needed to control water loss in EGS by proper injection- and production-well siting and pressure-regime control, as water cost and availability particularly in the western United States, can be a roadblock to development.

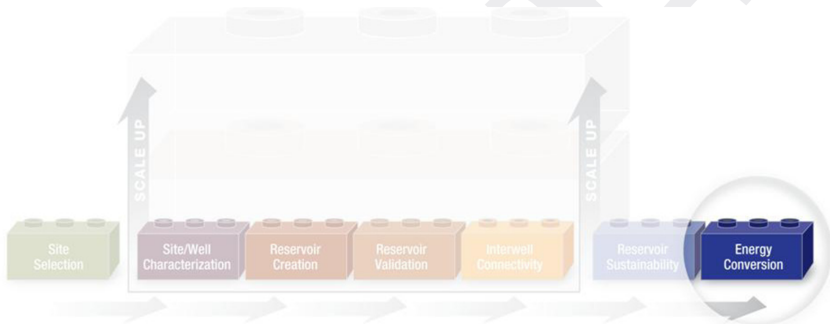
Table 4.30. Reservoir Sustainability Technology Status Summary		
Barrier	**Available Technologies (U.S. and International)**	**Technology Status**
Barrier M: Long-Term Sustainability Unknown ability to manage long-term rock temperature, fluid quantity and fluid chemistry	Maintain reservoir and track reservoir evolution-long-term monitoring	Monitoring tools and sensors (e.g., tools to measure pressure, flow, temperature, and seismicity) are available for sustained operation up to about 150°C. Downhole monitoring tools capable of sustained operation at >200°C do not exist.
	Monitor rock/fluid interactions- monitoring & modeling of reservoir evolution	Geochemical analytical techniques are understood for a large subset of relevant chemicals, but real-time detection technology has limited scope and poor accuracy.
		Geochemical models lack confirmatory field data.
	Manage induced seismicity	Operation protocols that limit injection/production pressures are considered a useful management tool. Rock mechanics models are available, but cannot predict seismicity.
	Managing system geochemical effects	Chemical management (e.g., additives for pH control) and scale control technologies are used in the hydrothermal industry to mitigate well bore and known geothermal resource scaling. Technologies for hydrothermal systems may not be as effective for EGS which will operate in chemical disequilibrium.
	Keep flow paths open- power and flow management	Proppants (for both near well bore and far field use, scaling, dissolution, and permeability control) are typically used in oil & gas stimulations. Temperature-hardened proppants have not been evaluated in geothermal environments.
		Scaling and dissolution control technologies are available, but may not be adequate for EGS conditions.
	Water loss minimization- due to parasitic pumping power, reservoir water cooling and water scarcity in western United States	Methods are needed to control water loss in EGS by proper injection- and production-well siting and pressure-regime control.

4.1.7.8 Reservoir Sustainability Tasks

The following tasks support the goal of Reservoir Sustainability.

Table 4.31. Reservoir Sustainability Tasks		
Number	Description	Barrier
1	Define processes and surface equipment to manage fluid chemistry.	M
2	Develop commercial-scale technology to minimize water loss per water circulation cycle over the lifetime of the well.	M

4.1.8 Surface Facility (Energy Conversion)



4.1.8.1 Energy Conversion Goal

Goal 9: Develop low-cost, high-efficiency energy conversion technologies for EGS.

Economically viable energy conversion from EGS will require total project minimization. While performance improvements to the energy conversion system and its components will decrease the contribution of the wellfield and EGS reservoir to the energy conversion cost, it is probable that these improvements will also increase the energy conversion system contribution to generation cost. For generation to be economically feasible, it is imperative that increases in the cost of more efficient energy conversion system be minimized.

Research to utilize the energy produced from EGS resources will focus on the generation of electrical power. Given the likelihood that wells for EGS will be deeper than conventional hydrothermal wells and need deeper production pump setting depths, the non-power plant costs (both in terms of capital dollars and parasitic power) will probably be significantly higher for an EGS resource than for an equivalent hydrothermal resource. If so, in order for power production from EGS to become economically feasible, it will be necessary to develop more efficient energy conversion systems that maximize the power generated from the produced fluids.

4.1.8.2 Energy Conversion Barrier

Barrier N: **Energy Conversion at Low Temperature** – Inability to lower the temperature conditions under which EGS power generation is commercially viable.

Barrier O: **Chemical Conditions** – Insufficient understanding of effects of high temperature fluid chemistry from EGS resources on EGS power systems.

Viable energy conversion from EGS resources will require energy conversion system characteristics not found in commercial technologies used with hydrothermal resources. Requirements include:

- Energy conversion systems are needed that increase the amount of power that can be produced from a given geothermal fluid flow.
- In order to sustain the economic life of the EGS resource, the operation of the energy conversion system must be integrated into the reservoir management. This will require energy conversion systems that have more operational flexibility than existing commercial hydrothermal plants.
- Issues related to water availability may preclude the use of evaporative heat rejection systems in EGS plants as in many operating hydrothermal systems. Improvements to sensible heat rejection technologies will improve plant performance and lower generation costs.
- Specific issues regarding both the scaling and corrosion potential of fluids produced from EGS resources will be addressed subsequent to the initial field testing. Because of their potential adverse impact, new treatment technologies and/or materials of construction may be required.

4.1.8.3 Energy Conversion Objectives

The following objectives support Goal 9.

Table 4.32. Energy Conversion Objectives

Number	Description	Barrier
1	By 2009, complete baseline technical assessment of existing energy conversion technology.	N
2	By 2012, determine energy conversion technology requirements for commercial viability of low temperature (<150°C) EGS resources in various geologic settings.	N
3	By 2015, demonstrate energy conversion technology that can economically be employed at temperatures of 150°C.	N
4	By 2012, perform assessment of severity of P-T and chemistry effects on energy conversion.	O

4.1.8.4 Energy Conversion Technical Approach

Existing energy conversion technologies should be adequate for the demonstration of the technical feasibility of producing power from an EGS resource. As such, research to improve energy conversion system technologies will have a lower priority in the near-term, but will have increasing importance once research has validated the feasibility of creating an EGS reservoir and extracting energy from that resource. A rigorous energy conversion technology gap assessment with estimated development timeline is important for synchronizing R&D efforts with future field demonstration and commercialization efforts.

In Fiscal Year 2009, the Program will evaluate the current state of energy conversion technology and assess R&D requirements in this area to support the Program's EGS development goals. The objectives of this effort are (1) to provide a thorough assessment of the technologies needed for EGS energy conversion surface facilities and the improvement of EGS energy conversion efficiency and economics and (2) to evaluate the ability of current technologies to meet those needs with the primary purpose of identifying gaps in technology that must be addressed for long-term EGS viability. This analysis will draw from the experience of project personnel, past DOE-sponsored assessments, existing literature, and interviews with geothermal and other industry professionals. It will provide baseline specifications of future EGS surface plants, evaluate the ability of current technologies to meet envisioned energy conversion targets of future EGS, delineate gaps in current capabilities, and estimate the timeline of the R&D effort needed to close defined gaps. The intent is to minimize anecdotal assessments of technology suitability and provide a more rigorous assessment of improvements needed for EGS development. In parallel to this initial assessment, a workshop will be held with participants from government, industry, academia, and the national laboratories. A report of the energy conversion assessment and workshop will be prepared, and results will inform the Program's ongoing R&D planning and prioritization.

Research efforts will focus on more efficient energy conversion systems. In the near-term, these efforts will build upon the 30-plus years of energy conversion system R&D, as well as the technology advances that the geothermal industry has made and incorporated into commercial hydrothermal plants. This prior work will provide the basis for the specification of the energy conversion systems used in the initial EGS plants to be built. More innovation will be incorporated into each subsequent plant design and construction. Information provided by the initial technology demonstrations will provide information needed to improve the plant design and performance, including the corrosion and scaling potentials of produced fluids, temperature/flow decline rates, and the non-power plant costs.

Using CO_2 instead of water as a heat exchanging fluid for EGS offers several benefits. At the temperature and pressure conditions expected for EGS, CO_2 is a supercritical fluid with characteristics that make it a very effective medium for heat transmission. Supercritical CO_2 will have exceptional mobility vs. liquids in closely spaced, finely fractured EGS reservoirs. Some of the problems of water-based systems can be avoided because CO_2 is not a strong solvent for rock minerals, nor is it corrosive to metals. Thus some of the problems of water-based systems can be avoided. CO_2 -based EGS would also avoid the heat losses associated with a binary system. In addition, since water is a scarce and valuable commodity in many areas, CO_2 -based EGS might provide an economic alternative as the working fluid.

As information is gleaned from the initial demonstration projects, more specific energy conversion system research needs will be identified. Demonstration sites will serve as test locations for subsequent field research to validate energy conversion technologies.

4.1.8.5 Energy Conversion Programmatic Status

Energy conversion systems baseline assessment is to be performed in Fiscal Year 2009.

Table 4.33. Energy Conversion Technology/Program Activities		
Task	**Approach**	**Organization**
Assessment of current technology and identification of R&D needs for EGS energy conversion systems	Utilizing industry and research experiences, literature searches, prior studies and a workshop to provide a current status of energy conversion technologies and to provide initial specifications of the requirements for EGS energy conversion systems.	UTC Power, Chena Hot Springs

4.1.8.6 Energy Conversion Technology Status

Current hydrothermal facilities typically operate in the 10 to 20 percent efficiency range. A comprehensive survey of hydrothermal energy conversion technologies will be performed.

Table 4.34. Energy Conversion Technology Status Summary		
Barrier	**Available Technologies (U.S. and International)**	**Technology Status**
Barrier N: Energy Conversion Unknown ability to manage long-term rock temperature, fluid quantity and fluid chemistry	A rigorous power conversion technology gap assessment with estimated development timeline	TBP

4.1.8.7 Energy Conversion Tasks

The following tasks support the Energy Conversion research area.

Table 4.35. Energy Conversion Tasks		
Number	Description	Barrier
1	Establish costs/ benefits of recuperated binary cycles for high-temperature EGS to optimize reinjection temperatures.	N
2	Evaluate opportunities for energy conversion technology advancements, such as: air cooling, “flexible power plant,” and supercritical CO_2 working fluid.	N
3	Determine needs for chemical control for a given EGS reservoir.	O
4	Evaluate technologies for mitigating scaling and corrosion.	O

4.2 Enhanced Geothermal Systems Validation

The most salient feature of EGS is the intentional fracturing of hot rock to create or increase permeability and, as necessary, allow for the introduction, either naturally or artificially, of a heat transfer fluid (typically water) into the fracture system. The MIT study recommended that the program conduct multiple EGS demonstrations in different regions of the country to reduce risk and uncertainty. Lessons learned from DOE findings will feed into the R&D portion of field project development and support the system demonstrations and technology validation efforts. The program will perform system demonstrations of reservoir enhancement techniques and technology validation to accelerate EGS commercialization.

The Systems Demonstration part of this plan calls for the installation of 5 MWe of new generating capacity by utilizing existing technology adapted to EGS use by 2015. It is understood that this capacity will be installed at or near existing hydrothermal production sites where there is sufficient heat in the underlying rock formations at a well-characterized depth, but insufficient permeability and/ or water flow. Thus, this heat source will require enhancement by localized fracturing, in order to allow water flow through the formation that can be used for power generation. The location of the EGS near an existing hydrothermal field, where the new flow from the EGS can be piped into the existing power plant, allows the focus of this endeavor to be placed on the localized fracturing of the rock, which is the crux of EGS.

This portion of the plan is conceptualized using existing commercial technologies from the oil and gas and mining industries, but any new technologies developed and validated in the R&D area could be considered. This is depicted in Figure 4.2.

There is a continuum between hydrothermal reservoirs, which have enough natural permeability for economic extraction of heat, and enhanced geothermal systems. Sub-economic hydrothermal systems are candidates for remedial reservoir stimulation, making them potential sites for EGS. Sites on the margins of producing geothermal fields can take advantage of known thermal gradient and existing infrastructure. These marginal hydrothermal sites are expected to provide an early proving ground for a number of technologies while leveraging industry support for relatively near-term development.

As the critical enabling technologies for EGS are successfully demonstrated and refined, EGS development will move to previously unidentified geothermal resource sites away from existing hydrothermal areas. While a variety of rock types and subsurface settings may be conducive to EGS reservoir creation, it is unlikely that all reservoir creation techniques will be equally successful in every subsurface situation. A distinct learning curve can be expected for different geologic and lithologic settings.

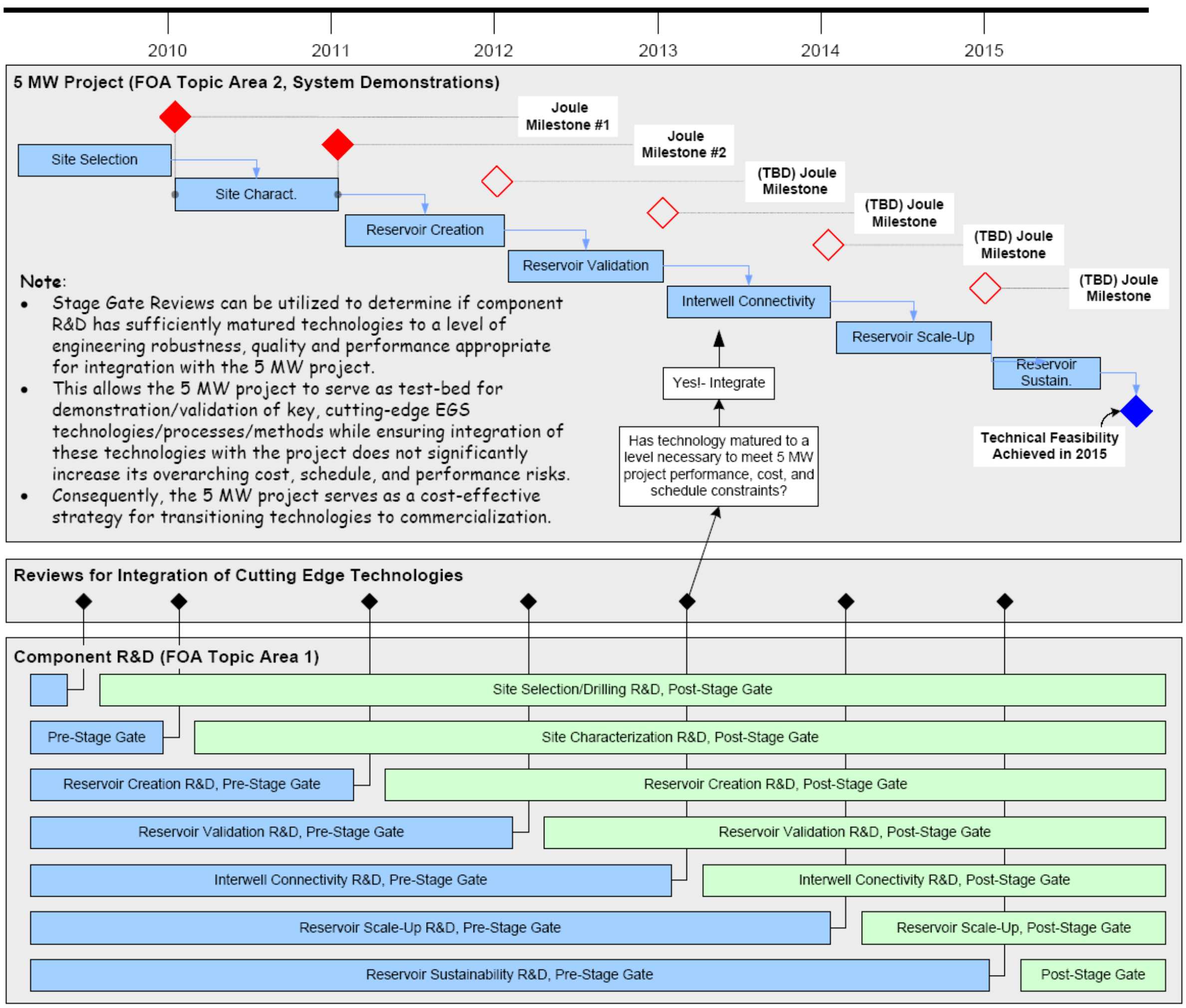


Figure 4.2. Overview of the System Demonstrations and Program R&D Activities

4.2.1 System Demonstrations

System demonstrations are taking place through industry cost-shared projects at and near producing geothermal fields. This approach was chosen to avoid the cost associated with surface development and increase the immediacy of economic benefits. Further site selection criteria (other than proximity to a developed reservoir) will be developed to initiate projects in unknown geothermal resource fields.

Comprehensive data collected from these demonstration projects will feed back into the R&D planning and guide the next steps of research projects. At that point, the projects will be defined as low risk or high risk based on the outcome of industry cost-shared project. Low-risk technology development will be incorporated into new demonstration projects with the focus of study determined by the successes and/or failures of previous project activities. High-risk projects will proceed to independent validation sites. The process for these high-risk projects will be determined at a later date, when the need is more defined. Upon the successful completion of this strategy, the program will have validated the existing technologies, collected the knowledge base necessary for unknown geothermal resources and documented further research and development needs.

Goal 10: Demonstrate the viability of EGS principles.

4.2.1.1 System Demonstrations Barriers to Commercialization

The barriers to creating, sustaining, and optimizing the economics of reservoirs for EGS commercialization are as listed above in the R&D section, and include: limited fracture detection capability, insufficient stimulation prediction models, limited zonal isolation technology, lack of high-temperature monitoring tools and sensors, limited flow path identification capacity, inadequate submersible pumps, and a lack of suitable tracers.

In order to create an EGS reservoir able to operate for six years at 80 kg/s with wellhead temperature of 250+/- 10°C, certain issues must be resolved. Some of these are:

- Enhance rock's permeability and/or porosity (flow rate);
- Increase swept area (reservoir volume);
- Efficient heat mining (temperature); and
- Avoid short circuits/cooling (tools to isolate reservoir).

Barrier P: **Crew Inexperience** – Because of the infancy of domestic EGS technologies, drill rig crews are inexperienced in drilling, construction and completion of geothermal wells for EGS use.

Barrier Q: **Risk of Damage** – Stimulation techniques have the potential risk of damaging existing hydrothermal fields.

Barrier R: **Drilling Rig and Crew Availability** – Because of the increased market price of hydrocarbons, the availability of drilling rigs and crews is diminished.

There may be as-yet-unidentified technology improvements that will be required for optimizing the economics of EGS reservoirs.

4.2.1.2 System Demonstrations Technical Goals, Objectives, and Targets

Table 4.36 lists the two objectives for the Systems Demonstrations.

Table 4.36. System Demonstrations Objectives	
Number	**Description**
1	Characterize the reservoir at a minimum of 75 percent of the selected field sites within two years of initiating field operations while meeting prescribed standards for quality and quantity of data.
2	Successfully stimulate reservoirs at one or more of the field sites within two years of initiating field operations, with at least one EGS of the created reservoirs meeting commercial EGS requirements of flow rate and heat extraction sustainability.

There are two technical targets for the Systems Demonstrations area that were set forth as Joule targets for the Program.

Table 4.37. System Demonstrations Technical Targets		
Number	**Description**	**Year**
1	Determine actual pre-stimulation reservoir flow rate for at least one EGS field site.	2009
2	Select a stimulation design plan predicting an increased reservoir flow rate of 10 percent or at least 10 kg/second.	2010

Three principles will be followed in pursuing the goals of systems demonstrations:

1. Validate the applicability of existing technologies.
2. Create a broad knowledge base covering existing technologies. The systems demonstration effort will apply historical knowledge from the previous geothermal stimulation research and the oil and gas and mining industries to develop a critical knowledge base on stimulation techniques and applicability.
3. Thoroughly document the lessons learned. Lessons learned will inform Program decision making, research and development planning, and ensure that systems demonstrations are of greatest value to industry stakeholders engaged in commercialization of EGS.

4.2.1.3 System Demonstrations Technical Approach

The Program plans to meet the broad goals listed above by establishing financial assistance awards with industry and academia through EGS solicitations. These awards will address particular barriers to EGS development– primarily the ability to create and map permeability, and to maximize heat recovery from the enhanced system.

Reservoir characterization will include collection of all geologic and engineering data needed to plan successful stimulations of the candidate wells. Creation of the stimulation models may include (but is not limited to) the following: petrologic/petrographic analysis, rock mechanics tests, magnetotelluric studies, geochemical analysis, background seismology/ micro-seismic analysis, borehole imaging/logging, fracture analysis, existing flow and/or injection tests, and fracture stimulation modeling. This approach also includes deployment of micro-seismic networks and conduction of a mini-fracs of the targeted interval to assist in designing stimulation plans. Data on in-situ stress and natural fracture distributions shall be developed from borehole testing and logging.

Reservoir creation will include any necessary wellbore modification, redesign of the micro-seismic network if needed to further understand seismicity during stimulations, other monitoring techniques such as tiltmeter, and finally execution of full well stimulations. Work may include mobilization/ demobilization of stimulation equipment, execution of well stimulations, running geophysical or production logs, fluid sampling, monitoring of stimulations through use of microseismicity, tiltmeters or other techniques, flow tests, and tracer tests. Data collected for the first two years of the project will include (at a minimum):

- Microseismic data and interpretation;
- Production and/or injection rates over time and analysis;
- Logs run in the wells (PTS, sonic, natural gamma, tool-head temperature, etc.);
- Borehole imaging logs (e.g., televiewer, FMS, other) for both pre- and post-stimulation;
- Well flow rates and well head temperatures;
- Chemistry of produced fluid and mineral dissolution/precipitation;
- Formation response/evolution data;
- Tracer data, analysis and results of tracer tests if the wells are in communication with other wells in the field or to determine such connection; and
- A populated database documenting the lessons learned and providing feedback to further research and development.

The technical approach for completion of Phase Three includes running a suite of logs necessary to characterize the near wellbore responses of the targeted formation in order to characterize the sustainability of the EGS reservoir. Phase Three work also includes tracer tests, geochemistry, and geochemical analysis for the candidates and associated wells. Data collection and analysis will include:

- Microseismic data and interpretation;
- Productivity or injectivity data and analysis;
- Well flow rates and well head temperatures;
- Chemistry of produced fluid and mineral dissolution/precipitation;
- Tracer data, analysis and results of tracer tests if the wells are in communication with other wells in the field or to determine such connection; and
- A populated database documenting the lessons learned and providing feedback to further research and development.

4.2.1.4 System Demonstrations Programmatic Status

The Program paved the way for EGS technology advancement by supporting the first EGS field demonstration project at Fenton Hill, New Mexico. Although this project met with numerous technical difficulties, it significantly advanced the geothermal community's understanding of the complexity of engineering a fracture network suitable for energy conversion. Numerous important lessons learned from the Fenton Hill project have helped guide EGS projects worldwide. Since Fenton Hill, there have been seven EGS projects in Japan, Europe, (France, Germany, Switzerland), and Guatemala. Two projects have been supported by the GTP: the Coso and Desert Peak geothermal fields. The GTP also participates in an International Energy Agency (IEA) annex for EGS research that fosters cooperation among the various programs worldwide.

Because of its key role in geothermal reservoir development, the practice of reservoir modeling and tool development have been a Program since the 1970s. In the early phase, efforts were directed at clarifying the important physics to be included in models, as well as developing accurate, robust, and efficient methods for solving the governing equations. Models were developed to accurately predict the chemical behavior of geothermal fluids and their associated phases over a wide range of compositions and thermodynamic conditions. New techniques were developed to treat fluid and heat flow in fractured media, and to perform flow simulations with aqueous fluids that include dissolved solids and non-condensable gases. These methodologies permit solution of many geothermal reservoir problems, and have been widely adopted by the national and international geothermal community.

In the near term, the Program has had two projects to demonstrate inter-well connectivity in hydrothermal fields. At one project site, drilling crew errors led to the suspension of work at the first well chosen. The project has completed much of the pre-stimulation phase at a second well. Data has been collected and the geology of the site has been thoroughly characterized. A stimulation plan is being developed. Reservoir stimulation is scheduled for April of 2009. The stimulation plan will include designs for testing and validating the stimulation techniques.
At the second project site, data revealed that deepening the well could result in a permeable reservoir. The well will be deepened and stimulated.

Table 4.38. Fiscal Year 2008 System Demonstrations Technology/Program Activities

Approach	Organizations	Project Focus
Pursue the Funding Opportunity Announcement (FOA 1)	Golden	Select Industry cost-shared projects
Pre-stimulation and recompletion activities	Industry	Learn in-situ stress, rock properties, and MEQ behaviors
FOA 3	Golden	Select wider range of Industry cost-shared projects

4.2.1.5 Systems Demonstrations Technology Status

The following table summarizes the status of Systems Demonstrations Technology.

Table 4.39. System Demonstrations Technology Status Summary		
Barriers	Available Technologies (U.S. and International)	Technology Status
All barriers from Section 4.1: technical challenges to creating and sustaining a reservoir include: limited fracture detection capability, insufficient stimulation prediction models, limited zonal isolation technology, lack of high-temperature monitoring tools and sensors, limited flow path identification capacity, inadequate submersible pumps, and a lack of suitable tracers. Additionally, stimulation may damage existing fields.	Develop fracture detection capability and stimulation prediction modeling	The GTP will provide awards to industry and academia partners to be conducted in three phases: pre-stimulation, enhanced reservoir, and long-term collection and monitoring For the first stage, Pre-stimulation, the GTP has two projects to demonstrate inter-well connectivity in hydrothermal fields. At one project site, mistakes of a drilling crew led to the suspension of work at the first well chosen. A second well has been chosen, and the project has completed much of the pre-stimulation phase at this well. Data has been collected and the geology of the site has been thoroughly characterized. A stimulation plan is being developed. Reservoir stimulation is scheduled for April of 2009. The stimulation plan will include designs for testing and validating the stimulation techniques. At the second project site, data collected revealed that deepening the well could result in a permeable reservoir
Barrier P: Crew Inexperience: Because of the novelty of EGS technologies, drill rig crews are inexperienced in drilling, construction and completion of geothermal wells for EGS use.	TBD	TBD
Barrier Q: Risk of Damage: Stimulation techniques have the potential risk of damaging existing hydrothermal fields.	TBD	TBD
Barrier R: Because of the increased market price of hydrocarbons, the availability of drilling rigs and crews is diminished.	TBD	TBD

4.1.2.6 System Demonstrations Tasks
The following tasks support the Systems Demonstrations area.

Table 4.40. System Demonstration Tasks		
Number	Description	Barrier
1	Collect and analyze data from reservoir creation projects to learn about the factors (geological and engineering) which contributed to success or failure of reservoir stimulation and sustainability.	TBD
2	Test the wells and collect data over a number of years following well stimulations to assess long-term performance of both the stimulated wells and non-stimulated wells.	TBD
3	Create a complete geologic model to enable planning, execution, and learning from well stimulation. Critical reservoir characterization data includes core samples, stress field data, lithology and structural models, permeability.	TBD

4.2.2 Technology Validation

4.2.2.1 Technology Validation Technical Goals and Objectives

The goal of the program is to validate the tools and processes being developed in the research and development community swiftly and successfully.

4.2.2.2 Technology Validation Technical Approach

The approach to validating technologies will have a major experimental component that tests representative configurations of the system. The progression of tests must be chosen to ensure that new findings build upon earlier work.

Past experience will be carefully analyzed and used to predict short-term performance of the EGS. The knowledge thus gained will direct the next step. Technology validation tests will be run under carefully controlled conditions to assure that the results can be compared to predictions.

4.2.2.3 Technology Validation Technical Programmatic Status

Currently, there are no validation sites.

4.2.2.4 Technology Validation Technology Status

Technology Validation status is summarized below.

Table 4.41. Technology Validation Technology Status Summary		
Barriers	Available Technologies (U.S. and International)	Technology Status
Site characterization will be needed for EGS technology in order to find appropriate unknown geothermal resource sites in different geological settings where testing can be performed.	Identify appropriate unknown geothermal resource sites in varying geological settings for EGS reservoir development.	In addition to the Soultz project, a second French project at Landau and a large-scale EGS project at Cooper Basin, Australia (Geodynamics Limited) are currently being developed. There are no technology validation sites in the United States

This page was intentionally left blank.

5.0 Program Analysis

Figure 5.1. Geothermal Technologies Program policy and planning documents

The Geothermal Technologies Program intends to conduct a broad spectrum of analyses–resource and infrastructure assessment, technical and economic feasibility analysis, deployment analysis, environmental analysis, risk assessment, and benefits analysis–to support decision-making, demonstrate progress toward goals, and direct research activities. Programmatic analysis, or strategic analysis, helps frame the overall program goals and priorities and covers issues that impact all aspects of the program. Maintaining these capabilities at the cutting edge is essential to ensuring that the analysis provides the most efficient and complete answers to technology developers and the Program Management. The analytical methodologies and tools planned for use by GTP are outlined below.

5.1 Program Analysis Technical Goal

Goal: The Program Analysis technical goal is to provide program-level analysis products to support geothermal technology development and technology readiness by evaluating technologies and pathways, guiding the selection of RD&D projects, and estimating the potential value of RD&D efforts. Analysis activities provide GTP with information and context for decision-making at all levels. These activities include benefits' analysis, based on modeling projections from the Office of Energy Efficiency and Renewable Energy (EERE) versions of the National Energy Modeling System (NEMS) and the Market Allocation Model (MARKAL), that estimate the program's contribution to the achievement of DOE and EERE economic, environmental, and energy security goals, and technical analysis (techno-economic and engineering systems analysis) that informs R&D activities on a daily basis. Overall, analysis quantifies goals, targets, and potential impacts of program activities, and informs the development of alternative pathways for program R&D.

Analysis plays three main roles in the GTP decision-making process:

- Defines and validates performance targets for geothermal technologies and systems;
- Guides program planning functions, R&D project selection, and assessment of progress;
- Provides engineering knowledge for enhanced geothermal systems development.

5.2 Program Analysis Barriers to Commercialization

The following discussion details the technical and programmatic barriers that must be overcome in order to attain the Program analysis goal and objectives set forth by GTP.

Barrier S: **Stove-Piped/Siloed Analytical Capability** – Lack of coordination and integration of program elements.

Analytical capabilities and resources have been largely segmented functionally by the Program element (drilling, energy conversion, etc.), as well as by performers/analysts (laboratories, specialized teams, industry/academia, etc.). Successful Program analysis requires the coordination and integration of those capabilities and resources across all facets of the analytical domain.

Barrier T: **Market Behavior** – Lack of understanding of how geothermal electricity generation interacts with the behavior and drivers of the electricity markets to determine the long-term applications of EGS.

Understanding the behavior and drivers of the electricity markets is necessary to predict long-term EGS applications. Developing new or refining existing market penetration models will allow analyses of various geothermal deployment scenarios, and enable the GTP to understand emerging issues.

Barrier U: **Policy** – Lack of understanding of applicable current policies and impacts. Geothermal technologies are not on a level playing field with respect to competing technologies at all jurisdictional levels.

A firm understanding of the Federal, state and local policy interaction and impact on geothermal electricity development is necessary to provide input to Program planning. Additionally, results of the analyses will inform policy-makers on the incentives that create greatest value added, leading to development of geothermal electricity and market transformation.

Barrier V: **Infrastructure** – Infrastructure barriers are not clearly understood for EGS development.

Many infrastructure questions arise in addressing commercialization, including water supply, water rights, transmission, permitting, waste water issues/regulations. These and other infrastructure issues must be fully understood for market transformation, policy analyses, and creation of models and tools.

Barrier W: **Benefits** – The environmental, economic, and security benefits of the Enhanced Hydrothermal Systems and EGS are not fully understood or articulated.

Often, the drivers for state and local decision-making are the environmental, economic and energy security benefits of energy technologies. The Benefits section of this plan discusses our understanding of the benefits of geothermal technologies, but as Enhanced Hydrothermal Systems and EGS technologies are developed, created and monitored, these analyses will have to be updated to guide decision-making.

Barrier X: **Data, Assumptions and Guidelines** – Inconsistent and largely uncontrolled datasets are used by individual analysts and organizations, which make their own value decisions in performing analyses.

Analysis results are strongly influenced by the data sets employed, as well as the assumptions and guidelines established to frame the analytical tasks. These elements have been largely uncontrolled in the past, with individual analysts and organizations making independent value decisions. Although this does not necessarily render the results incorrect, it does make it more difficult to place the results and ensuing recommendations in context with other analyses and the overall objectives of the GTP. Establishing a Program-endorsed consistent set of data, assumptions, and guidelines is necessary for program success.

Barrier Y: **Suite of Models and Tools** – Existing models have limitations and cannot sufficiently address all of the GTP analytical needs and requirements.

The limited number of models and tools available to the Program for analysis cannot sufficiently address all of the GTP analytical needs and requirements; current models and tools must be refined and new ones developed.

5.3 Program Analysis Technical Objectives

Achievement of the objectives for Program analyses help to overcome each of the above-listed barriers. These objectives were developed based on an understanding of the gaps in geothermal technology analyses relative to other renewable energy technologies, as well as perceived future analysis needs that will be required as renewable energies applications become more widespread.

Table 5.1. Program Analysis Technical Objectives

Number	Description	Barrier
1	On an ongoing basis, coordinate and integrate geothermal capabilities and resources across the analytical domain.	S
2	On an annual basis, develop new or refine existing market penetration models to allow analyses of various geothermal deployment scenarios, and enable the GTP to understand emerging issues.	T

Table 5.1. Program Analysis Technical Objectives (Continued)		
Number	Description	Barrier
3	By 2009, analyze the current Federal, state and local policies that could affect the commercialization of geothermal throughout the policy development.	U
4	By 2009, design model policies that maximize impact on geothermal benefits (e.g. economic, environmental and energy diversity) and inform policy makers through the models.	U
5	By 2011, develop decision tree tool for geothermal policy implementation.	U
6	By 2015, develop a road map for best practice policy development throughout the market transformation (R&D for technology development, market preparation, and commercialization).	U
7	On an ongoing basis, understand policy impact on geothermal development at multiple jurisdictional levels as policies evolve and develop and the market for geothermal changes.	U
8	By 2010, identify Federal, state and local laws and regulations that have the potential to apply to EGS development.	V
9	By 2011, set objectives for addressing and overcoming the infrastructure hurdles.	V
10	By 2012, complete life-cycle environmental studies that are necessary to better understand and mitigate the environmental consequences and impacts of geothermal technologies..	V
11	On an ongoing basis, estimate GHG-emission impacts of various types of EGS technologies.	W
12	On an ongoing basis, incorporate GHG-emission analysis results into cross-cutting carbon models for benefits analyses (MiniCAM, MERGE, GREET, and MIT's climate model).	W
13	On an ongoing basis, understand how geothermal energy generation will benefit national energy security in the changing energy market.	W
14	On an ongoing basis, understand the economic benefits of geothermal energy generation as the technology progresses, as construction and knowledge resources evolve with the technology, and as demonstration projects move into commercialization.	W
15	By 2010, establish a Program-endorsed consistent set of data, assumptions, and guidelines necessary for program success.	X

Table 5.1. Program Analysis Technical Objectives (Continued)		
Number	Description	Barrier
16	On an ongoing basis, update the data set with program and industry data as it is obtained and/or gathered.	X
17	By 2010, refine current models to meet the analytical needs and requirements of the GTP.	Y
18	On an ongoing basis, update the model assumptions and calculations with program and industry data as it is obtained and/or gathered.	Y
19	By 2010, develop a technology characterization report, outlining the current state of the technology for each of the program elements (drilling, energy conversion, etc.), both implemented and unimplemented.	S,V,W,X
20	By 2015, develop a technology readiness report, outlining the latest technologies, improvements and demonstrations of Enhanced Hydrothermal Systems and EGS technology.	S,V,W,X
21	By 2015, analyze the ultimate potential for EGS. The analysis will address necessary resources, transmission, reservoir sustainability, water needs, and interactions between an EGS economic sector and other sectors.	A,V
22	By 2015, conduct deployment analyses exploring how rapidly EGS might be deployed to make a significant contribution to the country's electrical energy need.	T,U,V,X,Y
23	By 2011, incorporate risk analyses into refined geothermal technology models.	Y,S

5.4 Program Analysis Technical Approach

The overall approach to implementing a robust Program analysis capability is based on the need to support Program decision-making processes and milestones, provide independent analysis when required to validate decisions and/or ensure objective inputs, and to respond to external review recommendations. Program Analysis will generate outputs necessary to support programmatic needs, which include recommendations, reports, input to plans, validated results, and supporting data. As depicted in Figure 5.2, the outputs are supported by analysis of EGS development scenarios, environmental analyses, and technical analyses. The analyses are dependent upon tools that the program is developing and/or modifying. Both the analyses and tools are dependent upon the framework that has been developed and will be continuously updated. To ensure that the analysis effort is focused, objective and effective, internal and external peer reviews will be conducted. The peer review process is further described in Section 8.2.4 Program Evaluation.

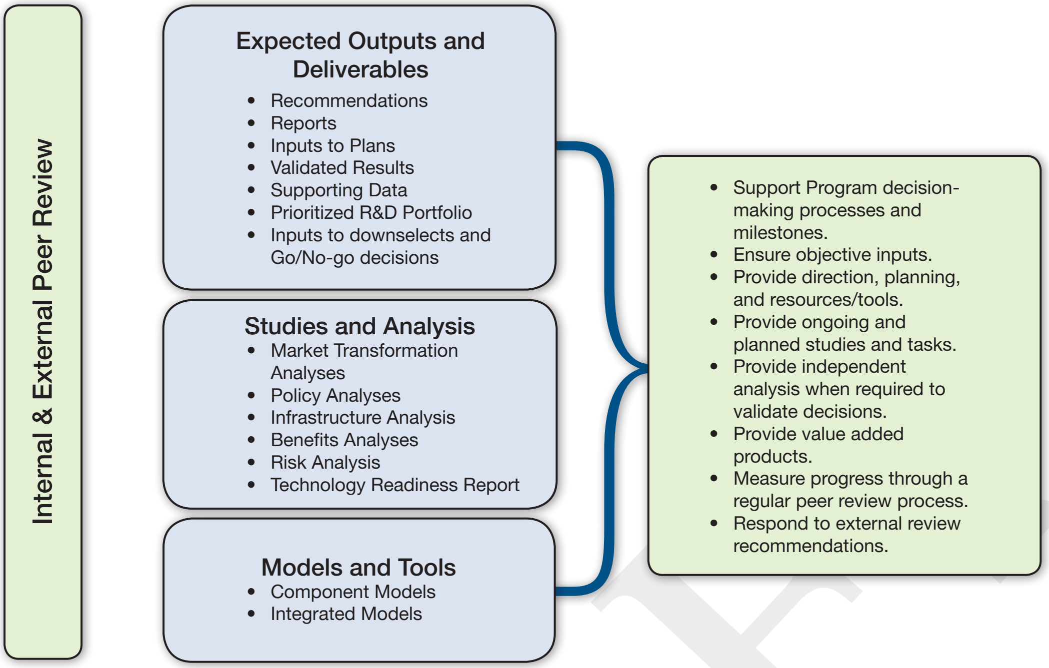


Figure 5.2. Systems analysis approach overview

5.4.1 Studies and Analysis

The analysis work planned for the next five to 10 years builds on past efforts to understand the economic factors and key uncertainties related to geothermal technologies and systems. Continued public-private partnerships with the geothermal scientific community and multi-lab coordination efforts will help ensure that the analysis results from the program are transparent, transferable, and comparable. Studies will include:

Market Analysis: *(Barrier T)* Market Analysis helps the program to understand the behavior and drivers of the electricity markets that determines the commercialization potential for geothermal applications. Analysis of the market drivers as renewable energy technologies and policies become more widespread will be. Developing new and refining existing market penetration models will allow analyses of various geothermal deployment scenarios, and enable the GTP to understand emerging issues.

Policy Analysis: *(Barrier U)* Policies are one way that markets can be altered to promote renewable energy implementation. A firm understanding of the Federal, state and local policy interaction and impact on geothermal electricity development is necessary to provide input to program planning. Results of the analyses will inform policy-makers of the incentives that add the greatest value and lead to development of geothermal electricity and market transformation.

Infrastructure/Environmental Analyses: *(Barrier V)* The Program will use analysis to quantify the many infrastructure questions that arise, including water supply, water rights, transmission, permitting and wastewater. These and other infrastructure issues must be fully understood for market transformation, policy analyses, and creating models and tools. The environmental impacts of geothermal production technologies will also be assessed. Specifically, life-cycle assessment (LCA) will be used to identify and evaluate the emissions, resource consumption, and energy use in all steps of the process of interest. Also known as cradle-to-grave or well-to-wheels analysis, this methodology helps users understand the full impacts of existing and developing technologies, so that efforts can be focused on mitigating negative effects. Analyses related to EISA reporting requirements will also be conducted.

Benefits Analysis: *(Barrier W)* Benefits analysis helps the Program quantify and communicate the overarching outcomes from within the Program, such as greenhouse gas mitigation and displacement of conventional fossil fuel generation, using integrating models such as NEMS and MARKAL. The scenarios that are developed and the costs and benefits that are quantified are used to develop a broad understanding of the most viable routes for achieving geothermal utilization. Results are useful in crosscutting benefits analysis and are one of the key inputs to decision-making across all renewable technologies in the EERE portfolio. Using the program-provided outputs and assumptions, the Office of Planning, Budget, and Analysis (PBA) works with the Program to prepare the technical assumptions needed to run the NEMS and MARKAL models. These models estimate the economic, energy, and environmental outcomes that would occur over the next 20 to 50 years if the Program is successful and the future unfolds according to the business-as-usual scenario. PBA also coordinates the assessment of Government Performance and Results Act (GPRA) benefits, which estimate some of the economic, environmental and security benefits or outcomes from achieving Program goals.

Supplemental analysis tasks that will be conducted to support the above analyses include:

National Geothermal Database: *(Barrier X)* A technical data management system will be developed to provide a consistent database and a list of assumptions, information standards, and tools for analytical activities supporting GTP. This geothermal data center will provide data for standardized input to systems analysis, for the establishment of the base case geothermal system, and for development of the subsequent trade-off analyses. This technical data management system will ensure consistency in analyses conducted by the Program. The database will be updated annually and made available to the community through the Web. For additional information, program data needs are described in Section 4.2.

Models and Tools: *(Barrier Y)* Modeling tools provide the basis for analyzing alternatives at the system, technology or component level in terms of their cost, performance, deployment potential, and impacts. While specific tools are used to analyze system components (e.g., elements of the energy conversion system) and discipline-specific concerns (e.g., drilling, geochemistry), there are two types of models currently in use to provide an integrated framework for analysis:

- A techno-economic systems analysis modeling tool for evaluating and comparing the cost of geothermal project cases, addressing all elements of a project, from exploration to power generation. The Geothermal Electric Technology Evaluation Model (GETEM) is the tool currently used.
- Integrated energy/economic models that project the deployment and associated impacts of electricity generation technologies, including geothermal, based on cost and performance characterizations of specific technologies and economic, market, and policy assumptions (e.g., GDP growth, future fuel prices). There are several models in use, each of which provides a unique perspective, including: NEMS, MARKAL, the Regional Energy Deployment Systems Model (ReEDS), and the Stochastic Energy Deployment System (SEDS).

In addition to the analyses relating to a particular barrier listed above, further cross-cutting analyses will address multiple barriers. Planned cross-cutting studies and analysis are separated into the following categories:

Resource and Infrastructure Assessment: *(Barriers A, V)* Resource assessment determines the quantity and location of geothermal resources at regional, state and county levels. A variety of integrated modeling tools and databases will be used for estimating geothermal resources. Geographic Information Systems (GIS) modeling tools can be used to portray and analyze resource data.

Technical and Economic Feasibility Analysis: *(Barriers S,V,W,X)* Feasibility analysis determines the potential viability of a process or technology and helps to identify the most significant opportunities for cost reduction. Results from the feasibility analysis provide input to decisions regarding portfolio development and technology validation plans. The economic competitiveness of a technology is assessed by evaluating its implementation costs for a given process compared with the costs of either current technology or other future options. These analyses are useful in determining which projects have the highest potential for near-, mid- and long-term success. Parameters studied include production volume benefits, economies of scale, process configuration, materials, and resource requirements. Tools used for technology feasibility analysis include unit operation design flow and information models, process design and modeling, capital costs and operating cost determination, discounted cash flow analysis, and Monte Carlo sensitivity analysis/risk assessment (e.g., Crystal Ball software).

Deployment Analysis: *(Barriers T,U,V,X,Y)* Analyses exploring how rapidly enhanced geothermal systems might be deployed to make a significant contribution to the country's electrical energy must be initiated.

Modeling EGS development will accomplish the following:

- Identify and evaluate paths by which geothermal energy can make a large contribution to meeting future demand for electricity. This will help answer questions such as:
  - Which technologies are most likely to be a part of an enhanced geothermal system?
  - What are the interactions between these technologies and other established technologies?
  - What market penetration pathways are likely?
- Determine what can be done to accelerate geothermal energy use and once deployed, when associated benefits can be realized, by understanding:
  - What external economic factors are most important?
  - What are the most likely bottlenecks or limiting factors?
  - What are the effects of government policy?

Risk Assessment: *(Barriers Y, S)* The identification, quantification, and evaluation of risk and uncertainty are used to focus RD&D activities and resources where they are most critical. Clearly identifying critical-path technologies and addressing and mitigating issues that could derail technological progress are all crucial to ensuring the success of program activities and to encouraging greater private sector investment by increasing confidence in the likelihood of technical and commercial success. Risk analysis will be conducted across the program activities along with benefits analysis. The major objective of risk assessment is to evaluate planned and ongoing technology development activities in the context of industry deployment requirements to maintain focus toward meeting the Program goals. This assessment will include all R&D efforts that DOE has sponsored. Activities making good progress toward the goals will be identified, as well as those that are making little progress or are not contributing. The gaps remaining in technology development will be identified. Finally, commercialization pathways will be identified by estimate of effort (financial and time). The risk analysis will also focus on understanding how program activities could impact specific technology performance measures in terms of the range of potential improvement, and how these impacts compare to ultimate cost and performance targets. The risk assessment tools must be credible for industry, researchers, and managers to realize these opportunities.

The GTP follows the risk analysis principles released by the Office of Management and Budget (OMB), which aids the Program in risk assessment and priority setting. The DOE EERE has issued further guidance through documents such as Risk Analysis for Energy R&D Programs, A Practice Best-Practice Guide for R&D Managers and Staff.[27]

5.4.2 Unplanned Studies and Analysis

Many analysis questions require rapid responses, particularly when they are driven by external requests or needs from DOE senior management, Congress, OMB, etc. A flexible capability to perform additional, quick-response analyses and provide those results is necessary.

5.4.3 Systems Analysis Plan

A detailed Systems Analysis Plan (SAP) may be developed if the extent and complexity of analysis efforts warrant the effort to create the plan. The goal of the SAP would be to lay out the overall approach, tasks and processes for the systems analysis efforts of the Program. It would define how specific analysis activities relate to the objectives of the overall program. The SAP would contain a catalog of resources, systems analysis processes, and analysis results.

27 Risk Analysis for Energy R&D Programs, A Practice Best-Practice Guide for R&D Managers and Staff

5.5 Program Analysis Programmatic Status

Current activities in Program Analysis are listed in Table 5.2.

Table 5.2. Program Analysis Activities

Analysis Type	Description	Organization
National Resource Assessment	Physical Geothermal Resources Evaluation-data collection and evaluation (depth, cost of energy over various regions)	National Renewable Energy Laboratory
Technology + Characterization	Survey of current state of systems and components. Perform technology assessments in each of the major technological areas of drilling, reservoir creation and characterization, and energy conversion. Update of 1997 Renewable Energy Technology Characterizations (EPRI)	National Renewable Energy Laboratory
Technical and Economic Feasibility Analysis	Energy conversion Technology Evaluation GETEM Updates and Revisions	National Renewable Energy Laboratory
Deployment Analysis	Geothermal Modeling in Energy Markets (NEMS, MARKAL, SEDS, ReEDS) Geothermal Market, Policy, and Technology Analysis Integrated Energy Modeling for Budget Support (NEMS and MARKAL)	National Renewable Energy Laboratory
Risk Assessment	Program Risk Analysis (@Risk-GETEM model)	National Renewable Energy Laboratory
Environmental Analysis	Geothermal air emissions (CO2, NOx, SO2) Impact Analysis (NEMS, MARKAL and ReEDS) Water use, Water quality, Land use	National Renewable Energy Laboratory
Benefits Analysis	Greenhouse gas mitigation and displacement of conventional fossil fuel generation, Mitigation of foreign oil dependency, and other activities TBD	National Renewable Energy Laboratory
Provide Support Functions and Conduct Reviews	Maintain and Update the Geothermal Data Center	TBD, per solicitation award

5.6 Program Analysis Tasks

The following program analysis tasks were identified to support the above-named objectives.

Table 5.3 Program Analysis Tasks

Number	Description	Barrier
1	Set first meeting of all analysts to discuss this document and future plans.	S
2	Identify joint projects that leverage different groups' capabilities.	S
3	Incorporate algorithms that distinguish between hydrothermal systems (Hydrothermal Systems), enhanced hydrothermal systems (Enhanced Hydrothermal Systems), and enhanced geothermal systems (EGS) in the market into new and existing models .	T
4	Identify and evaluate early market transformation scenarios consistent with infrastructure needs and EGS resources.	T
5	Identify the range of policy options that could affect the commercialization potential of geothermal technologies.	U
6	Evaluate the targets (e.g., consumer, geothermal industry, utilities, and state governments) of such policies and determine possible impacts on market transformation.	U
7	Understand how different policies (mandates and incentives) drive all parts of the market in various stages of EGS development.	U
8	Identify innovative policies that can lead to the technology and market development of EGS.	U
9	Develop Programmatic Environmental Impact Statement (PEIS) in support of commercial development.	V
10	Quantify exploration, construction, and operation land-use needs and impacts.	V
11	Quantify initial and ongoing water requirements.	V
12	Develop detailed understanding of fluid chemistry impacts on environment - both for flash systems and closed-loop systems.	V
13	Analyze GHG emissions.	W
14	Analyze environmental impacts of inclusion of carbon sequestration into EGS.	W
15	Develop guidelines and standards for data quality and validation.	X

Table 5.3 Program Analysis Tasks		
Number	Description	Barrier
16	Develop consistent and transparent economic assumptions for cost analyses.	X
17	Develop data input guidelines (i.e. units, resolution, completeness, etc.).	X
18	Design a database framework for ease of incorporation and display of all data types.	X
19	Manage and oversee development of database by lab or contractor.	X
20	Establish a robust, consistent, and transparent techno-economic EGS model (expand on GETEM).	Y
21	Identify needed modeling frameworks based on questions that current models are not addressing.	Y
22	Initiate EGS model validation with systems demonstration project data and benchmark to international EGS demonstration projects.	Y
23	Integrate analyses on externalities (e.g., water use, land use, CO2) into EGS modeling and evaluation tools.	Y
24	Continue ongoing EGS model validation with systems demonstration project data.	Y

6.0 Systems Integration

The Program's Systems Integration function provide a disciplined approach to the research, design, development and validation of complex systems to ensure that requirements are identified, verified, and met while minimizing the impact on cost and schedule of unanticipated events and interactions. Systems Integration supports Program evolution and EGS development. The desired end point is achievement and validation of technology targets from which industry can develop a well-integrated EGS that reliably and cost-effectively provides electricity.

The Systems Integrator provides the tools and processes necessary to integrate and measure progress toward Program goals. These tools and processes, tailored to the particular requirements of a robust, long-term R&D program, take advantage of experiences and lessons learned from industry, academia, international sources, and other Federal agencies (e.g., the U.S. Department of Defense [DOD] and the National Aeronautics and Space Administration [NASA]).

6.1 Systems Integration Technical Goal

Goal: To support the Program in the achievement and verification of the capabilities required to effectively reach technology readiness in 2015 at the minimum cost.

6.2 Systems Integration Barriers to Commercialization

The following details the various technical and programmatic barriers that must be overcome to attain the DOE Geothermal Program Systems Integration goal and objectives.

Barrier Z: **Program Complexity** – GTP will include numerous projects addressing a variety of technological disciplines, many of which are on the leading edge of technology. Both vertical and horizontal integration will be necessary to integrate the Program under a unified system and to ensure integrated management and optimization of workflow across organizational boundaries. Completeness is important, because a true assessment of the sufficiency of program efforts against the requirements can only be made if the entire Program is represented.

Barrier AA: **Adapting System Integration Functions to an R&D Program** – Systems integration has most often been applied to the design, development, production, and maintenance of large, complex acquisition or construction projects. Implementing systems integration within an ongoing R&D program without delaying or disrupting current efforts represents a significant challenge, especially when the process has not been institutionalized within the organization.

Barrier AB: **Inherent Uncertainty in R&D** – Most systems integration and engineering efforts have been applied to large hardware and software acquisition projects, not R&D programs. Given the inherent uncertainties with regard to achieving desired outcomes from the research and development of new technologies, tailoring the systems integration procedures and tools to the R&D paradigm will be a challenge. Gaining Program and stakeholder acceptance of these processes adds value and will be important to both Program Element and overall Program success.

Barrier AC: **Accessibility/Availability of Technical Information** – The cost-effective availability and accessibility of the most up-to-date technical results are necessary to support programmatic decision-making. Within the Program, technical information relevant to a particular issue must be collected from the original developers, often dispersed through many organizations, who may not have initially considered how the information would factor into management decision-making .To ensure that results from many sources are technically and practically realistic, these diverse technical results require a vetting process.

Barrier AD: **Need to Control Guiding Documents** – Technical and programmatic goals, objectives, and targets need to be developed in order to provide structure to both R&D and Validation activities. Once these elements are established, it is critical to ensure that changes are not made without proper coordination by program staff and approval by the program manager. All related documentation needs to be maintained in alignment with these programmatic elements.

6.3 Systems Integration Technical Objectives

The objectives of the GTP Systems Integration are as follows:

- Develop Program Performance Baseline.
- Provide value-added analyses, with resultant recommendations which aid the R&D focus and portfolio decision-making processes of the Program.
- Provide periodic independent verification of progress toward key technical targets and project performance, and ensure that the overall course of R&D satisfies Program requirements.
- Improve Program effectiveness and efficiency by the appropriate implementation of systems engineering and management processes, including risk management and configuration management/change control.
- Provide processes and products that review and document the progress of the program on an annual basis.

6.4 Systems Integration Technical Approach

Systems Integration provides technical and programmatic support to the Program by:

- Establishing, validating, and maintaining the Integrated Baseline as EGS technologies and systems are advanced from concept to technology readiness;
- Providing consistent and independent (when required) results of analyses to support programmatic decisions;
- Verifying that technology progress and results meet Program requirements;
- Implementing formal systems engineering processes that provide the Program Manager with ample insight into, and control of, the entire Program; and
- Supporting the implementation of strong program engineering and management processes.

Figure 6.1 is a graphic description of how the baseline, analysis, and verification functions interrelate, along with their supporting process and management disciplines.

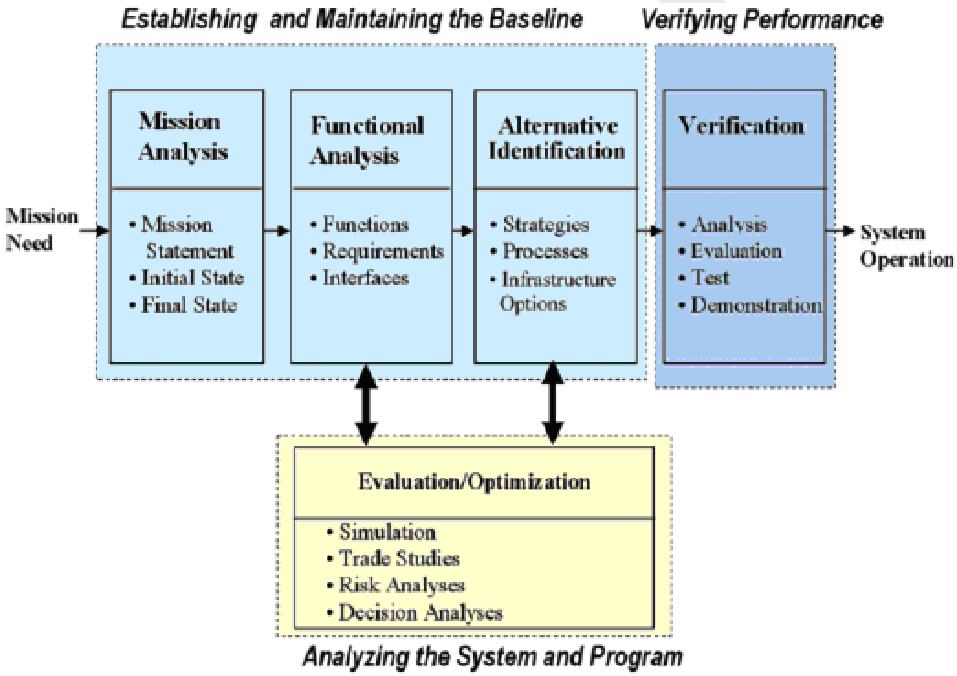


Figure 6.1. Systems Integration Approach Overview

6.4.1 Systems Integration Integrated Technical and Programmatic Baseline

Integrated Baseline: The Integrated Baseline (IB) is a tool and process that helps manage the Program by ensuring that (1) RD&D and analysis projects proper address all of the Program requirements and (2) that the cost, schedule, and performance of the Program and Program projects remain understood and controlled. The first objective ensures that the Program is pursuing work that advances Program mission and the second ensures that Program work is correctly performed.

These two components are represented by the Technical Baseline (TB) and Programmatic Baseline (PB), respectively, which are then linked by the technical objectives of the Program to provide the "integrated" aspects of the overall baseline. As shown in Figure 6.2, the IB is derived from the overarching documents that guide DOE research programs.

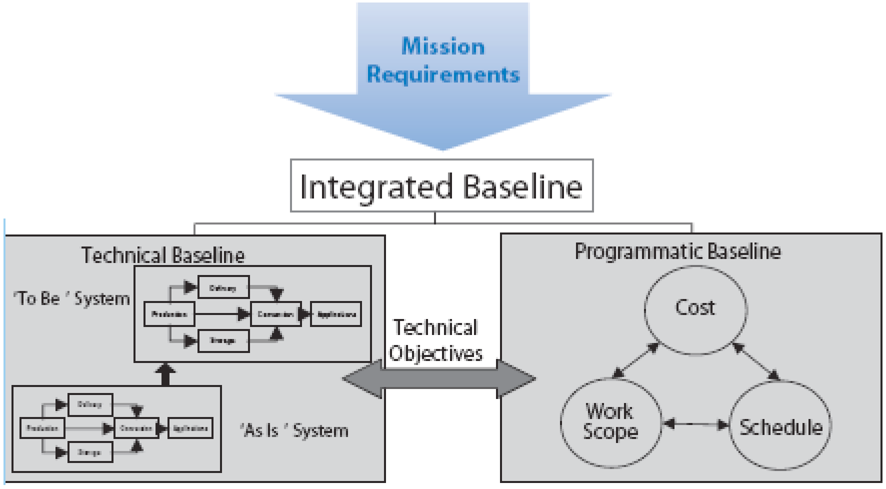


Figure 6.2. The Integrated Baseline

Once approved, the IB becomes the control version against which the Program is assessed by external peer reviewers. The Systems Integrator supports the Program in implementing a formal process to manage and control changes to the baseline per: budget requests and appropriations; identified changes in the market or policy context; newly relevant technical advances; and available information.

Technical Baseline: The TB provides a detailed map starting from the overall requirements, through the objectives and barriers of the individual Program elements, and finally to the task and individual project level. Requirements for the TB are drawn from the National Energy Policy, EPACT 2005, DOE Strategic Plan, and Geothermal Technologies Program Office strategic plans, among others, to ensure that Program work advances Program mission.

The TB includes the prioritization of activities, as well as information on the risk level of individual activities. Questions that can be addressed and answered using the TB include:

- Does the R&D portfolio properly address all the Program requirements?
- Are there gaps or weaknesses in coverage of technical areas?
- Are the high priority items receiving the proper level of programmatic attention?
- Are there sufficient approaches and projects in the higher risk areas to mitigate those risks?
- When funding or focus changes, in what areas should the Program redistribute, add, or decrease resources?

The TB serves as a complete reference set of technical data describing the current ("as-is") state of the Program infrastructure. The CORE® systems engineering tool in which the TB is hosted also has the capability to represent desired ("to-be") end states, in terms of development and deployment scenarios or expected descriptions and at different points in time over the next several decades. Using this feature, the TB can be used to identify and evaluate alternative pathways for meeting the needs/requirements or responding to new programmatic directions. The process of reviewing and validating requirements and aligning the Program with those requirements is recurrent to accommodate advances in R&D, as well as changes that result from the evolution of markets or policies, budget changes, or programmatic focus.

Programmatic Baseline: To ensure that the Program correctly performing activities, the PB provides a tool and process to track the cost, schedule, and performance of the Program at multiple work breakdown structure levels (Figure 6.3). The PB describes these efforts in terms of budget, milestones, and scope. The PB also identifies the dependencies among the activities through an integrated work breakdown structure (WBS) and master schedule. Loaded with the resources necessary to accomplish the work (funding, personnel, tools, facilities, etc.), the PB allows assessment of shortfalls and effects of shifting priorities or funding changes. DOE staff within each Program element uses the PB to address and answer questions, such as:

- Are budgets and schedules on track – for the Program, a Program element, a task, or an individual project?
- If there is a delay in a particular activity's schedule, what is the cost and schedule impact on dependent or related activities?
- If funding is reduced in an area, what is the impact to the schedule, and if resources are reallocated, how are schedules affected?
- How does the Program scope change with respect to different funding-level scenarios?

Once proposed changes to the PB are approved through the Change Control Board, the Systems Integrator updates and maintains the PB.

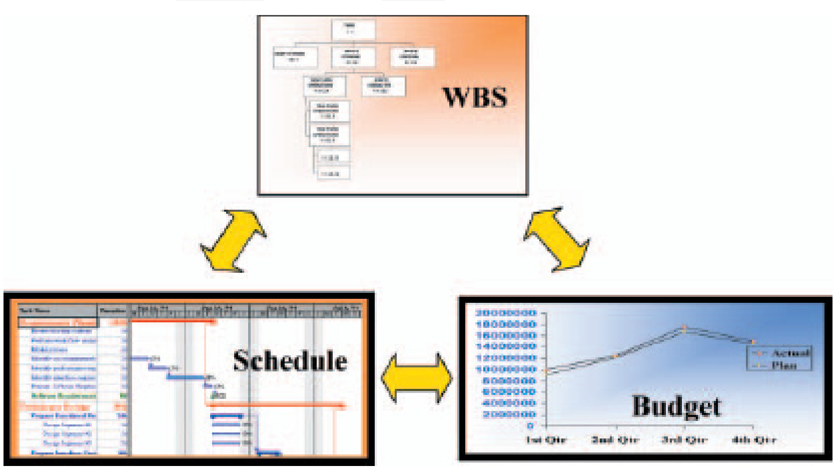


Figure 6.3. Programmatic Baseline Concept

6.4.2 Systems Integration Analysis

Systems Integration supports the review and assessment of alternatives for satisfying the needs of a future EGS system and the Program's progress, a component necessary in setting desired end-states for the TB and to study trade-offs between specific targets. This systems integration provides independent analysis, when required, to help ensure objective and substantiated decisions by the Program.

Additionally, Systems Integration supports the analysis efforts of Program's Planning and Analysis Lead as related to the overall Systems Analysis program element. These efforts include A) Development of (and revisions to) the Systems Analysis Work Breakdown Structure (WBS), which provides the plan and funding estimates for all analysis and modeling activities through 2015; and B) Conducting Systems Analysis Working Groups. These work groups are important activities in terms of dissemination of Systems Analysis products and analysis community input to, and review of, the Systems Analysis program element.

6.4.3 Technical Performance Verification

Technical performance verification will be accomplished through analysis, testing, and/or demonstration. As the Program develops new technologies and produces research results, Systems Integration facilitates technical reviews at key stages to evaluate strategic fit with Program objectives, technical, economic, and market potential, and environmental, health, and safety considerations and additional development plans.

Verification criteria and approaches will vary according to technology maturity; at early stages of development, information available to evaluate concepts is likely to be more general and have higher uncertainty than that available at later stages. Information stemming from these reviews will be used to re-evaluate the baseline. In some cases, Systems Integration convenes technical review panels of peer experts to provide an independent assessment and recommendation to DOE for consideration during the decision-making process. This is particularly true for major Go/No-Go decisions of the Program, as well as when an assessment of progress toward one of the key technical targets of the Program is warranted.

The Systems Integrator works closely with the DOE Technology Development Managers to bring knowledge of system-level requirements that will lead to verification and to review criteria for planning and execution which will guarantee performance verification. In particular, the Systems Integrator supports reviews of the following Program activities:

- Peer review (generally annually) for all projects and activities
- Independent review panels for key Program milestones and Go/No-Go decisions
- Stage Gate reviews at key progress points for significant projects.

6.4.4 Systems Integration and Management

Systems Engineering Management: Systems Integration supports the Program by aiding implementation of several key processes, two of which are described below:

Risk Management: Systems Integration supports implementation of a risk management process to identify potential Program risks and determine actions that will mitigate the impact of those risks. The Risk Management Plan (RMP) describes methods for: identifying, assessing, prioritizing, and analyzing risk drivers; developing risk-handling plans; and planning for adequate resources to handle risk. The RMP assigns specific responsibilities for the management of risk and prescribes the documenting, monitoring, and reporting processes to be followed. A six-step risk process–awareness, identification, quantification, handling, impact determination, reporting and tracking–will be used. Throughout the life of the Program, the Systems Integrator helps identify "potential" risks, focusing on the critical areas that could affect the outcome of the Program such as:

- System Requirements;
- Technology Capability;
- Budget and Funding Management;
- Schedule;
- Modeling and Simulation Accuracy;
- Environment, Safety, and Health; and
- Stakeholder, Legal, and Regulatory Issues.

Configuration Management: Systems Integration manages the evolving configuration of, and continuously monitors and controls the Technical Baseline. Changes to the Technical Baseline and the Programmatic Baseline (the approved work scope, schedule, and cost) must be controlled to ensure that all work being performed is consistent with the approved technical requirements and the current configuration, and that potential impacts throughout the Integrated Baseline are considered before actions are taken. For sufficiently complex programs, a formal change control process ensures that the potential impacts of proposed changes to either the Technical Baseline or the Programmatic Baseline are controlled. Controlled is defined as having been evaluated, coordinated, reviewed, approved, and documented. The decision-making body within the Program that approves proposed changes is known as the Change Control Board. The procedures and processes will be documented in a Configuration Management Plan.

6.4.5 Program Support

Systems Integration provides analyses and recommends DOE-sponsored activities to make sure R&D results are shared throughout the geothermal community, thus ensuring the development of the necessary technological capabilities at the lowest possible cost. Support is provided to the overall Program in the following areas:

- Annual Merit Review – Systems Integration will inform the conduct of the annual review of the Program, during which DOE-funded projects deliver oral or visual presentations. A team of peer reviewers, skilled in the particular disciplines, evaluates selected projects.

- Annual Progress Report – This annual report will summarize the objectives, approach, technical accomplishments, and future plans for each of the projects funded by the Program.

6.5 Systems Integration Programmatic Status

The following table summarizes Systems Integration activities.

Table 6.1. Fiscal Year 08 / Fiscal Year 09 Systems Integration Activities

Activities	Description
Integrated Baseline	**Technical Baseline:** Establish an initial version of the technical baseline, containing requirements, tasks, objectives, barriers, technical targets and projects, in CORE®. **Programmatic Baseline:** Conduct a Budget Estimation exercise for the entire Program, yielding a detailed WBS, schedule and budget estimates for each Program Element and enter into the CORE® baseline. Support the development of an overall Program Master Schedule
Systems Analysis	Support the Planning and Analysis Lead in technical management and monitoring of analysis projects (e.g., develop the Systems Analysis Plan.
Verification of Technical Performance	Organize peer review activities at the Annual Merit Review and issue the review report. Choose and acquire resources to perform independent assessment of progress on key technical targets (as required).
Systems Engineering	Produce the Configuration Management Plan. Facilitate Change Control processes and boards to update the Multi-Year Plan. Produce the Risk Management Plan and initiate pathfinder risk analysis activities to support the budget process.
Program Support	Conduct the Annual Merit Review meeting. Publish the Annual Progress Report.

Table 6.2 summarizes the Systems Integration Program status.

Table 6.2. Systems Integration Program Status Summary		
Barriers	**Program Needs**	**Program Status**
Barrier Z: Program Complexity	Develop an integrated technical and programmatic baseline to provide a detailed roadmap starting from the overall requirements, through the objectives and barriers of the individual Program elements, and finally to the task and individual project level.	The status of the integrated baseline is subordinate to technical decisions that will drive the full EGS program.
Barrier AA: Adapting System Integration Functions to an R&D Program	Development of, and revisions to, the Systems Analysis Work Breakdown Structure (WBS) — the WBS provides the plan and funding estimates for all analysis and modeling activities through 2015.	Conduct Systems Analysis Working Groups — these are important activities in terms of dissemination of Systems Analysis products, as well as analysis community input to, and review of, the Systems Analysis program element.
Barrier AB: Inherent Uncertainty in R&D	Develop a detailed systems-level risk analysis model	The GTP has performed a preliminary risk analysis project and has begun updating its risk model and the Technology Improvement Opportunities tailored to the EGS focus of the program.
Barrier AC: Accessibility/ Availability of Technical Information	Conduct Annual Merit Review and prepare Annual Progress Report	In order to ensure the development of the necessary technological capabilities at the lowest possible cost, when available results of DOE-sponsored activities a will be shared throughout the geothermal community through the Annual Merit Review and the Annual Progress Report.
Barrier AD: Need to Control Guiding Documents	Develop the Configuration Management Plan	The GTP is in process of developing the Configuration Management Plan to ensure that all work being performed is consistent with the approved technical requirements and the current program configuration.

6.6 Systems Integration Tasks

The following table provides descriptions of Systems Integration tasks.

Table 6.3. Systems Integration Task Descriptions		
Task	Description	Barriers
1	• Develop and Maintain the Integrated Baseline (IB). • Update the IB quarterly. • Support development of the Program master budget and schedule.	Z,AA,AB,AD
2	• Support Systems Analysis. • Support Systems Analysis WBS updates. • Develop a Systems Analysis Plan.	AB,AC
3	• Verify year Technical Performance. • Organize Annual Merit Review peer review activities and issue report. • Conduct Go/No-Go Reviews (as required). • Perform Stage Gate Reviews (as required). • Conduct independent Technical Target Assessments (as required).	Z,AA,AB
4	• Implement Systems Engineering. • Produce the Configuration Management Plan. • Implement Change Management/Change Control processes. • Implement Risk Management support to the Program.	Z,AA,AB,AD
5	• Conduct Annual Merit Review meeting. • Prepare the Annual Progress Report.	Z

7.0 Program Coordination

The Geothermal Technologies Program coordinates research, development, and demonstration activities with international agencies and associations, industry and trade associations, academia, Federal agencies, national laboratories and other Program offices within DOE. This section describes how GTP coordinates research, development, and demonstration efforts.

7.1 International Coordination

DOE has found that international externalities in the energy industry are too consequential for an isolationist energy policy. High fuel prices, climate change, and energy security are all issues that affect every nation. The U.S. government has prioritized collaborative work with other governments in order to overcome the aforementioned challenges. The GTP participates in two international memorandums of understanding (MOUs): the International Partnership for Geothermal Technology and the International Partnership for the Energy Development in Island Nations.

International Partnership for Geothermal Technology (IPGT): The United States and the inaugural IPGT partners including Iceland and Australia signed the IPGT MOU on August 28, 2008. The IPGT provides a framework for international cooperation in geothermal energy technology, policy and model development. The IPGT seeks to realize the promise of geothermal energy by facilitating the accelerated deployment of geothermal technologies at a rate consequential to impact energy security and climate challenges.

The IPGT facilitates the development of advanced, cost-effective geothermal energy technologies to accelerate the availability of these technologies internationally, and to identify and address wider issues related to geothermal energy. IPGT activities include promoting the appropriate technical, political, financial, and regulatory environments for EGS development and EGS deployment.

Priority areas discussed at the IPGT inaugural meeting include:

- Zonal Completion-multilateral wells;
- Packers;
- HT Downhole Tools;
- Stimulation Procedures;
- Seismic Risk;
- HTHV Lifting and HPHV Surface Pumping;
- Rock/Fluid Interactions;
- CO2 as Heat Transfer Fluid;
- Air Cooling;
- O&M Benchmarking;

- Existing Federal and State Practices;
- Geothermal Lexicon;
- Hydraulic Hammer;
- Temporary Sealing;
- Revolutionary and Low Cost Drilling;
- Alternative Working Fluids;
- Selection of Cycles;
- Optimum Size of Units/Modularity;
- Methods to Reduce Exploration Well Drilling Costs;
- Education/University Competitions;
- Best Practices; and
- Data Repository.

The United States, New Zealand, and Iceland recently established the International Partnership for Energy Development in Island Nations (EDIN). The EDIN Partnership provides a framework for international cooperation to advance the development and deployment of renewable energy and energy efficiency technologies in island nations or territories within their jurisdiction. Participant Nations or territories will strive to deploy the maximum amount of renewable energy and energy efficiency possible, and endeavor to attain nation-specific measurable clean energy targets (such as providing 70 percent of primary energy from clean energy sources within one generation, which is the State of Hawaii's goal).

Figure 7.1. Puna, Hawaii Geothermal Site[28]

28 Geothermal National Action Plan, U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, Geothermal Technologies Program, 2008

The EDIN Partnership will leverage resources; share knowledge and research findings; bring together intellectual skills and talents to work towards optimal policy and regulatory strategies; and advance technology deployment. It also aims to foster public-private collaboration that addresses the technological, financial, and institutional barriers to a cost-competitive and environmentally benign clean energy economy.

The EDIN Partnership will engage in the deployment of:

- **Renewable Energy Technologies** – Participants will promote the development and adoption of cost-competitive renewable energy technologies and strategies for deployment.
- **Energy Efficiency Technologies** – Participants will advance the utilization of energy efficiency technologies, with an emphasis on the built environment.
- **Grid integration and Storage Technologies** – Participants will advance reliable grid integration and storage technologies and policies that are critical to achieve high penetration levels of renewable energy (especially intermittent wind and solar resources).
- **Sound Policy** – Participants remove barriers to clean energy development and establish policies that provide incentives for growth.
- **Financing Mechanisms** – Participants will attract private capital to islands for development of renewable energy and energy efficiency projects.

7.2 Industry and Trade Associations

The Program works in partnership with industry to establish geothermal energy as an economically competitive contributor to the U.S. energy supply. Additionally, the Program collaborates with potential geothermal investors and developers to reduce institutional barriers associated with project financing. Table 7.1 lists potential investors and developers who participated in the 2008 GEA Finance and Development Workshop in New York City.

Table 7.1. Potential Investors / Developers	
Participants in Geothermal Finance and Development Workshop in NYC, 2008	
• Advanced Technology Ventures	• Alcoa Inc. (Fortune 500)
• Capstar Partners	• AltaRock Energy Inc.
• Dundee Securities	• Bechtel Enterprises
• GE Energy Financial Services	• Calpine Corporation (Fortune 500)
• Glitner Capital Corporation	• ConocoPhillips (Fortune 500)
• Google.org (Fortune 500)	• EGS, Inc.
• International Finance Corporation (World Bank)	• Geothermex, Inc.
• JP Morgan Capital Corporation (Fortune 500)	• Ormat
• Khosla Ventures	• Thayer Gate Energy
• Kleiner Perkins Caufield & Byers	• ThermaSource L.L.C.
• Merrill Lynch (Fortune 500)	• UTC Power
• New Energy Finance	• Vulcan Power Company
• RBC Capital Markets	• Western GeoPower Corporation
• Vulcan Capital	

Other businesses that are potentially relevant to geothermal data development and management include: Black and Veatch, Davis Power Consultants, Jacobs, Schlumberger Consulting and Data Services, KEMA, Inc. and Quanta Technology.

The Program also collaborates with trade associations to promote the development and utilization of geothermal resources. Trade associations present industry views to governmental organizations, compile and maintain statistical data about the geothermal industry, and conduct education and outreach efforts. Trade associations also provide a forum for the industry to discuss important issues and problems regarding geothermal energy while encouraging research and development to improve geothermal technologies. Table 7.2 lists key geothermal trade associations.

Table 7.2. Geothermal Trade Associations	
Agency/ Association	Function/Expertise
Geothermal Resources Council	Develops educational functions on a variety of topics that are critical to geothermal development; convenes special meetings, workshops, and conferences on a broad range of topics pertaining to geothermal exploration, development and utilization; publishes a periodical Bulletin, which features articles on technical topics and geothermal development issues, as well as commentaries and news briefs; maintains the most comprehensive geothermal technical library in the world.
International Geothermal Association	Encourages research, development, and utilization of geothermal resources worldwide through the compilation, publication and dissemination of scientific and technical data and information, both within the geothermal community and the general public.
Geothermal Energy Association	Supports the expanded use of geothermal energy and development of geothermal resources worldwide for electrical power generation; advocates for public policies that promote the development and utilization of geothermal resources; provides a forum for the industry to discuss issues and problems, encourages research and development to improve geothermal technologies, and presents industry views to governmental organizations; compiles statistical data about the geothermal industry, and conducts education and outreach projects.

7.3 Academia

The GTP encourages collaborations with universities in cost-shared RD&D. For example, work with the University of Utah and Southern Methodist University has resulted in new and important information and developments critical to the geothermal industry.
The Energy and Geoscience Institute (EGI) at the University of Utah is a not-for-profit research organization with a 25-year record of conducting multidisciplinary projects worldwide. Through cooperative agreements with universities and research institutes, government agencies and laboratories, and national energy companies worldwide, the Institute undertakes a broad range of projects on all seven continents. EGI is focused on developing new technology for exploration, reservoir delineation, and production of resources in the western United States, Latin America, and Southeast Asia.

Southern Methodist University's Geothermal Lab in SMU's Dedman College of Humanities maps geothermal resources, providing information on the potential for geothermal energy production in regions where geothermal data had previously been unreliable or unavailable. SMU mapping also illustrates the potential for tapping geothermal energy from existing oil and gas wells.

As academic institutions (colleges, universities, and trade schools) across the nation expand new capabilities in geothermal technology, the Program will work with these leaders to implement the Program Plan while drawing on the existing core strengths of long standing geothermal institutions.

7.4 Other Federal Agencies

Interagency collaboration and cooperation are essential to increasing investment in geothermal resources, particularly EGS. Through cooperative efforts, each agency achieves greater operational efficiencies, enhanced resource management and protection, and better serves the stakeholder community. The Program is establishing a Geothermal Inter-agency Working Group to support the development of EGS and to provide a forum to discuss and address geothermal institutional and technology barriers. This interagency working group will support the expansion of geothermal energy resources and provide the guidance and management necessary to support our nation's energy security and emissions reduction goals.
Anticipated co-leaders of the Geothermal Inter-agency Working Group are the Geothermal Technologies Program Office Lead at the Department of Energy and the Bureau of Land Management, Geothermal Technologies Program Officer. Members of the interagency working group include representatives from: the Department of Defense, Environmental Protection Agency, National Science Foundation, Department of Interior (including the U.S. Geologic Survey, Bureau of Indian Affairs, Bureau of Land Management, Minerals Management Service, National Park Service, and Fish and Wildlife Service) and other Federal agencies whose activities may be leveraged to further geothermal development.[29]

According to the 2008 U.S. DOE Energy Efficiency and Renewable Energy National Geothermal Action Plan, four goals of the interagency working group will be to:

- Identify research priorities for the next decade that will release the potential of geothermal energy resources with the least disruption to the environment and the greatest impact to energy security and emissions reductions.
- Oversee the management of the National Geothermal Database for effective resource management and planning.
- Recommend and manage studies that will contribute to the development of this resource and promote its management and stewardship similar to that of other natural resources in the United States.
- Provide leadership for environmentally sound energy development, including transmission and other related infrastructure.

Government agencies are integrated in the identification, exploration, drilling and production phases of a geothermal investment, and play an important role in facilitating geothermal development. The Geothermal Technologies Program continues to focus on important RD&D of EGS technology innovations for long-term geothermal expansion, and directly assists industry which is the crucial driver of the exploration and development process.

7.5 Intra-Agency – DOE Offices

In addition to U.S. government interagency efforts, the Program also fosters U.S. DOE intra-agency cooperative working relationships with the Offices of Electricity Delivery and Energy Reliability, Science, and Fossil Energy and DOE national laboratories. Leveraging these close working

29 National Geothermal Action Plan, Geothermal Technologies Program, 2008

relationships enables the Program to best represent the entire resource base of the DOE while leading actions of the interagency working group.

The GTP plans to partner with other DOE offices, whenever practical to leverage DOE geothermal RD&D investments. GTP may build upon or co-fund efforts of other DOE programs where technology goals are similar but require a different focus and application. These program can be found within the Offices of Science, Civilian Radioactive Waste Management (OCRWM), Environmental Management (EM), and Fossil Energy (FE).

EM and OCRWM support earth sciences modeling, tracers, and microseismic analysis research topics important to EGS development. Other common areas of interest between the GTP and EM and OCRWM are in wastewater management and fluid loss management. All of these research areas are crucial to the success of geothermal subsurface development involving reservoir creation, operation, and maintenance.

The GTP is currently co-funding R&D with the Office of Science in the study of coupled mineral-water-gas reactive transport in unsaturated porous media. A wide range of processes in differing geologic environments are covered, including infiltration/evaporation processes in the soil zone, reactive transport processes in fractured rock under boiling conditions, injection of COivt2 in deep aquifers, and hydrothermal alteration in geothermal systems. Although reactive transport modeling and code development are the predominant activities, the Office of Science is also active in planning the analysis and drilling activities for underground thermal experiments, laboratory experiments, and field studies of geothermal systems and natural analogues for nuclear waste isolation.

Although much of the work is focused on predicting thermally-driven processes accompanying the proposed emplacement of high-level nuclear waste at Yucca Mountain, Nevada, the group has expanded its efforts to studies of geothermal systems, CO2 sequestration, and modeling of stable isotope variations. Potential collaboration with others in EM may address essential pieces of the problem, including hydrological processes in the unsaturated zone, thermodynamics and kinetics of geochemical processes, and isotopic effects.

Additional examples of R&D funded by other DOE programs with potential relevance include:

- Simulation and analysis of an ongoing large-scale underground thermal test, and planning of future drilling and sampling efforts.
- Prediction of coupled thermal-hydrological-chemical processes around potential waste emplacement tunnels to evaluate changes in water and gas chemistry, mineralogy, and flow.
- Analysis of geochemical and isotopic data from Yucca Mountain, including Cl-36 as a bomb-pulse tracer, to constrain models of flow and transport in the unsaturated zone.
- Development of models for reactive transport in unsaturated systems and co-developers of the reactive transport code TOUGHREACT.
- Evaluation and development of improved thermodynamic and kinetic databases for water-rock interaction modeling, including new relations for CO2 solubility to model CO2 sequestration.
- Research on natural analogue sites, including (a) analysis and modeling of continuously cored intervals from the Yellowstone geothermal system to assess effects of mineral

alteration on fracture and matrix permeability; (b) study of flow, transport, and secondary mineralization at Peña Blanca, Mexico; and (c) study of anthropogenic analogues, such as those at the Idaho National Engineering and Environmental Laboratory.

- Modeling of CO2 sequestration in saline aquifers, including the impact of acid gas components, H2S and SO2, and interactions with shale confining beds.
- Modeling hydrothermal alteration in geothermal systems.
- Simulation of the effects of scaling and acidulation on permeability in geothermal injection wells at the Tiwi geothermal field, Philippines.
- Study of chemical interaction between formation waters, injected waste fluids, and host rock during deep well injection.
- Development of a Pitzer-type geochemical reactive transport model and simulation of high-ionic-strength groundwater contamination.

7.6 DOE National Laboratories

In 2008 the DOE GTP funded geothermal research, development, and analysis at Lawrence Berkeley National Laboratory (LBNL), Sandia National Laboratories (SNL), Idaho National Laboratory (INL), and National Renewable Energy Laboratory (NREL). Geothermal areas of excellence within the national laboratories offer interdisciplinary core capabilities that provide the program with intellectual continuity and a bridge for facilitating the transfer of developing technologies between academia, industry and other laboratories. The laboratories provide a level of programmatic continuity and synergy that is difficult, for institutional reasons, to sustain at universities or private organizations. To ensure long-term success, the GTP has identified four areas where the national laboratories can and should be involved to support the program: Planning and Analysis, Technology Support to DOE Funded Research Grants, National Laboratory Direct Research and Development, and Support to EGS field demonstration projects.

The laboratories have a long and successful history of working with industry addressing short-term industry needs and long-term R&D efforts. For example, short-term efforts include the Geothermal Drilling (GDO) and Geothermal Technology Organizations (GTO), formed to facilitate laboratory and industry collaboration on short-term R&D projects such as (1) the first use of well re-drilling technologies to minimize the cost of mitigation and (2) the first deployment and interpretation of MEQ sensors to monitor the impact of reinjection into declining resource reservoirs. Long-term R&D efforts include, but are not limited to: advanced methods to reduce drilling flat time; new geophysical approaches for imaging the movement of fluids in the subsurface; and development of predictive modeling capabilities for geothermal reservoir management. The R&D efforts, particularly the long-term projects, reap the benefits of being heavily leveraged by the broad scientific and engineering capabilities that exist at the laboratories, particularly with respect to science and engineering activities supported by other sponsors (e.g. the DOE Office of Science, NNSA, other governmental agencies such as DARPA, and private concerns) as previously mentioned.

Science and engineering capabilities developed and supported by DOE at the national laboratories also assist the GTP in defining and evaluating broad national scientific and engineering needs pertaining to geothermal energy development. In 2008, the laboratories were vital in peer reviewing GTP's evaluation of the MIT-led panel conclusions regarding the potential for EGS.

Technical Support to GTP Funded Research Grants: In order to attract industry participation through competitive funding opportunities, industry-focused R&D efforts should address shorter-term aspects of the R&D needs; experience suggests that it is unlikely industry will pursue long-term research given uncertain payback. By exploiting the synergies of R&D, the historic knowledge of the laboratories, and the commercial focus of industry, technology can be brought to market faster.

National Laboratory Directed Research and Development: While focusing on industry partners is appropriate, there are aspects of the R&D program where the laboratories can assist GTP at both a programmatic and technical level. Additional information regarding program management and operations follows in **Section 8.2.3 Program Execution**. Where high-risk, fundamental research is required to meet the long-term GTP goals, national laboratories can build programs around core fundamental research efforts to support the long-term R&D program required to make EGS successful.

Success in conquering the challenges of EGS will not only require the incorporation of industry participants, but will also require maintaining a core capability to ensure continuity of the program. The laboratories offer a centralized source of knowledge with institutional missions aligned to meet the programmatic needs of the GTP. The laboratories are capable of providing multidisciplinary teams over long periods of time to ensure the continued progress that is required for program success: Lawrence Berkeley National Laboratories possesses core capabilities in the geosciences in the areas of geophysics, hydrogeology and geochemistry with an emphasis on subsurface geophysical imaging of structures and fluids and hydrologic/reactive transport modeling; and Sandia National Laboratories provides core capabilities in geo-engineering with an emphasis on developing well construction and completion technologies, such as high-temperature/high reliability electronics, drilling technologies, and advanced downhole tools and telemetry systems. There is synergistic overlap between these two labs in areas such as remote sensing, rock mechanics, advanced materials, and nanotechnologies.

Support to EGS Field Demonstration Projects: The objective of planned field demonstration projects is to demonstrate the capability for stimulating a volume of rock to serve as an efficient long-term heat exchanger. To this end, existing and developing technologies will be deployed to evaluate the success of the stimulation and to develop tools for optimizing EGS reservoir creation, management and operation. Operating in collaboration and in parallel with industry, the laboratories provide expertise in many areas relevant to a successful demonstration program. This expertise has been developed through support from the GTP and synergy with various DOE and other governmental programs. Involving the laboratories will ensure that the field demonstration projects provide the best laboratory for developing and testing new R&D concepts and moving fundamental research from the lab to widespread use by industry. The field demonstration projects will lead to the identification of new technologies that will be required to move EGS forward and provide a mechanism for testing new and developing technologies, new tools, and concepts that industry may not be in a position to pursue, even on a cost-shared basis, due to limited resources or institutional interests. The core capabilities of the laboratories provide the DOE with an avenue to ensure that demonstration projects maximize benefits. The laboratories are unique in their ability to couple real-world understanding of industry needs with requirement of researchers and are a necessary partner in the field demonstration projects.

The DOE's Entrepreneur-in-Residence pilot program is furthering real-world understanding by bringing industry to work in the national laboratories. The National Renewable Energy Laboratory, the Sandia National Laboratories, and the Oak Ridge National Laboratory participated in the pilot program in 2008. Venture capitalist firm Kleiner, Perkins, Caufield & Byers is sponsoring an entrepreneur at NREL under its new Entrepreneur-in-Residence Program. The entrepreneur will help identify opportunities for spin-off companies based on NREL-developed technologies. The entrepreneur will then help develop business plans for these promising technologies using a "venture-friendly" license agreement.

Figure 7.2 lists the current geothermal capabilities of the DOE national laboratories.

Figure 7.2 Current Geothermal Capabilities of the DOE National Laboratories

Primary Capability (red)
Significant Capability (yellow)
Capability (green)
Historic Capability, No Current Expertise or Contracts (blue)

	Data and Analysis	Site Selection	Reservoir Characterization	Reservoir Creation	Reservoir Validation	Interwell Connectivity	Reservoir Scale Up	Reservoir Sustainability	Energy Conversion
NREL	Red								
LBNL		Green	Green		Green		Green	Green	
LANL	Green		Green	Green	Green	Green	Green		
SNL	Red			Red					
INEL									
BNL									
ORNL									
LLNL									
PNNL									

10-20 FTE in general area of interest or contract value greater than 10M specifically related to geothermal
= Red shading indicating that the subject area is a primary strength of the lab

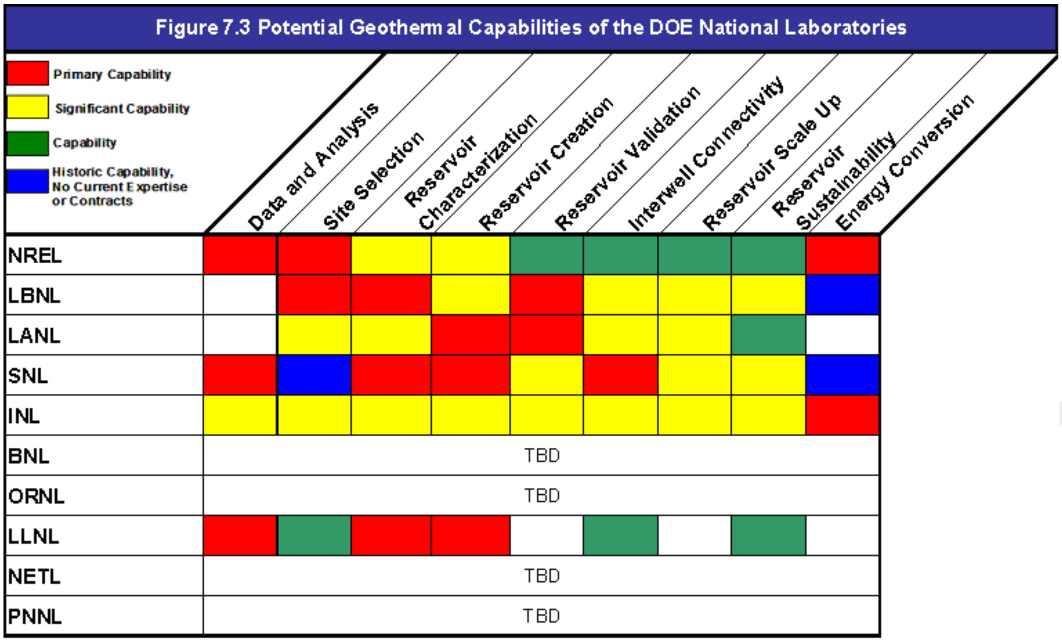
5-10 FTE in general area of interest or contract value greater than 1M specifically related to geothermal   Present
= Yellow shading indicating capability

1-5 FTE in general area of interest or contract value greater than 100K specifically related to geothermal
= Green shading indicating capability

Historic Capability no current expertise or contracts = Blue

Figure 7.2. Geothermal Capabilities of the DOE National Laboratories

Figure 7.3 lists the potential geothermal capabilities of the DOE national laboratories.



10-20 FTE in general area of interest or contract value greater than 10M specifically related to geothermal = Red shading indicating that the subject area is a primary strength of the lab

5-10 FTE in general area of interest or contract value greater than 1M specifically related to geothermal = Yellow shading indicating capability

1-5 FTE in general area of interest or contract value greater than 100K specifically related to geothermal = Green shading indicating capability

Historic Capability no current expertise or contracts = Blue

Figure 7.3. Potential Geothermal Capabilities of the DOE National Laboratories

This page was intentionally left blank.

8.0 Program Management and Operations

8.1 Program Staffing

The following organizational chart provides an outline of the GTP staff structure.

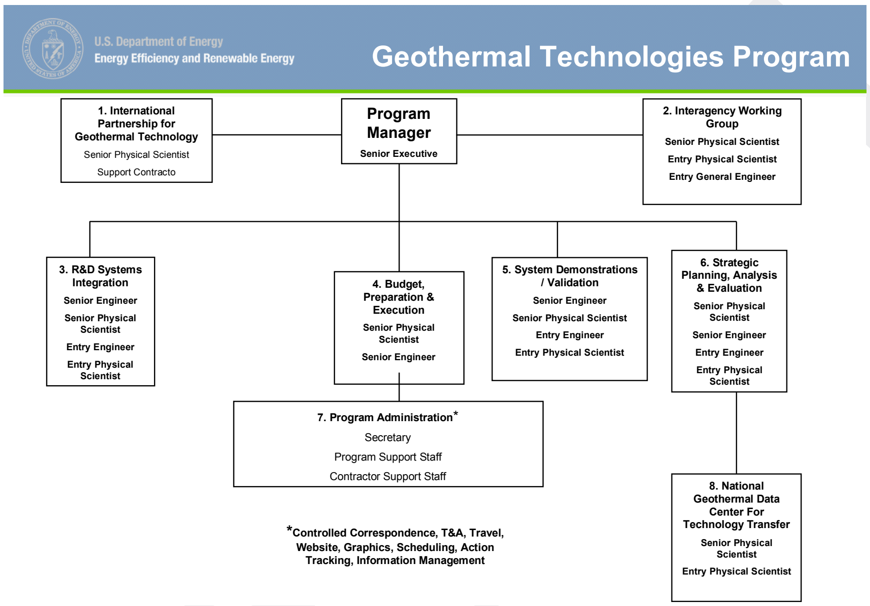


Figure 8.1 U.S. Department of Energy Geothermal Technologies Program Staff Organization

8.2 Program Management

Core GTP RD&D fall under R&D Systems Integration (3) and System Demonstrations and Validation (5). The GTP R&D Integration function is staffed by a GTP senior engineer. The main function of R&D integration is to ensure that R&D is executed and evaluated and that the results inform the EGS System Demonstrations.

The Strategic Planning, Analysis and Evaluation function (6) assimilates key R&D and System Demonstration information to conduct cross-cutting program planning, analysis and evaluation. The National Geothermal Datacenter for Technology Transfer (8) serves as the repository for RD&D results and provides key input to Program performance metrics.

Two critical Program coordination functions include the International Partnership for Geothermal Technologies (1) and the Geothermal Interagency Working Group (2).

Program Administration (7), Budget Preparation and Budget Execution (4) are also functional areas of critical importance.

8.2.1 Program Planning

The Program Analysis activities are led by the DOE Planning and Analysis Lead, and are supported by the National Renewable Energy Laboratory (NREL) planning and analysis team. This team will provide analytical resources, models and tools, and independent analysis capabilities as required. The DOE National Laboratory Annual Operating Plans provide Systems Analysis activities and specific roles and responsibilities.

8.2.2 Program Budget

The Fiscal Year 2009 request of $30 million is an increase from the $10.2 million received in the Fiscal Year 2008 appropriation. The DOE EERE "Budget in Brief" discusses GTP Fiscal Year 2009 activities, specifically EGS technology development at cost-shared field sites. The cost-shared field sites are part of the Systems Demonstrations activities and encompass possible drilling/recompletion of wells, reservoir fracturing, establishment of a fluid circulation loop, and long-term reservoir testing.

In FY 2009, several field sites will be evaluated for selection of a site dedicated to experimentation of innovative EGS technology. Various research institutions will conduct supporting research in priority areas identified by an EGS technology evaluation. These areas include monitoring and logging tools, high-temperature submersible pumps, reservoir predictive models, and zone isolation tools.

8.2.3 Program Execution

After OMB concurrence, on June 18, 2008 the Program was cleared to release its first research call for proposals to demonstrate EGS and fund EGS component research. The Program received six system demonstrations proposals and 20 component technologies R&D proposals. The technical merit review and programmatic review for the proposals concluded the week of September 15, 2008. Awards were issued for four System Demonstrations and 17 component R&D proposals at the end of FY 2008. At least two of the Systems Demonstrations are expected to yield results within a year to ensue since they occur near existing hydrothermal fields where geothermal leases have already been obtained. Although critical EGS data will be gathered, proposed technology targets are challenging given prior considerations.

Results achieved within the next three to five years from these first EGS demonstrations (three to five years), should demonstrate actual flow rates from one of the stimulated geothermal reservoirs. The 2010 Joule target addresses one of the most important phases of EGS development: the reservoir characterization, which will predict the ultimate flow rate and determine the system output and economic viability of power production.

Each GTP staff member has responsibility for executing grants, cooperative agreements, congressionally directed projects and national laboratory tasks.

The DOE's national laboratories are funded directly by DOE where called for in competitively awarded industry applications.

8.2.4 Program Evaluation

Program evaluation provides the means to measure relevant outputs and outcomes that aid the Program in reevaluating its decisions, goals, and approaches and tracks the actual progress being made; it includes performance monitoring and project evaluation. By design, the assessment processes provide the Program with input on progress and efficacy from, stakeholders, independent experts, and other government reviewers. DOE's national laboratory experts provide support to DOE program managers by assisting in the evaluation of RD&D, providing technical expertise to the DOE program managers, and providing DOE with objective, unbiased advice regarding the utility and applicability of industry-based solutions to the needs of GTP.

The various assessments that support the program evaluation process are outlined in Table 8.1

Table 8.1 Program and Project-Level Assessments that Support Decision-Making

Assessment Type		Assessment Synopsis	Documentation
Performance Monitoring	External Monitoring	DOE's Joule performance measurement tracking system	Joule System Reports
		Office of Management and Budget's (OMB) Program Assessment Rating Tool (PART)[29]	PART Report
	Internal Monitoring	EERE's Corporate Planning System (CPS)	CPS Database/ Website
		Project Monitoring with PMC Quarterly Reports	PMC Project Management Database
		Project Monitoring with Integrated Baseline Update	CORE[30] Integrated Baseline Reports
Program Evaluation	Peer Reviews	Conducted by independent experts outside of the program portfolio to assess quality, productivity, and accomplishments; relevance of program success to EERE strategic and programmatic goals; and management.[31]	Public summary documents including Program response
	General Program Evaluation Studies	Conducted by outside experts to examine process, quantify outcomes or impacts, identify market needs and baselines, or quantify cost-benefit measures as appropriate.[32]	Public reports and documentation

30 PART guidance is provided by OMB. Instructions available at http://www.whitehouse.gov/omb/
31 CORE is a systems engineering software package
32 EERE Peer Review Guide, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, August 2004 http://www1.eere.energy.gov/ba/
33 EERE Guide for Managing General Program Evaluation Studies: Getting the Information You Need," DOE/EERE, February 2006.

8.2.4.1 Retrospective Economic Assessment for the Geothermal Technologies Program

In cooperation with EERE's evaluation team, in 2009 the GTP is undertaking an independent evaluation process and a modified National Research Council (NRC) analysis approach to determine the realized energy, economic and other benefits for the Program. The study will not replicate the NRC process of using a committee of experts. Thus, it will avoid the lengthy delays, burdensome data collection requirements, and high cost that characterized the 2001 NRC study.[34]

A nationally recognized expert in R&D evaluation will be selected to serve principal investigator (PI). Additionally, three evaluation and technology subject matter experts will be recruited as peer reviewers. The primary documents for review will be the Study Evaluation Plan and Draft Report. Both the PI and the peer reviewers will be objective, unbiased, and independent experts from outside the program being reviewed.

Objectives

- To estimate realized benefits and costs of the public investment in Geothermal Technologies Program R&D, enabling the program to document realized economic and other benefits.
- To implement the "retrospective benefits estimation" recommendations in the May 2002 EERE Strategic Technical Review.[35]

The key evaluation questions to satisfy these objectives are:

- Are Geothermal Technologies Program expenditures producing actual benefits (energy-savings and renewable market growth), and environmental benefits?
- Are Geothermal Technologies Program expenditures enhancing energy security by providing alternative energy sources and protecting existing sources?
- Do public benefits exceed R&D expenditures, and would today's commercialized technologies have happened without DOE involvement?

Potential technologies for evaluation include:

- Polycrystalline diamond compact drill bit (PDC Drill Bits)
- Calcium phosphate cement
- Geothermal Well Cement
- Advanced Direct Contact Condenser, 1999

34 Energy Research at DOE: Was It Worth It, NRC, 2001, National Academic Press.

35 The EERE Strategic Technical Review prepared by Sam Baldwin in March 2002 called for a consistent retrospective analysis approach in EERE. It recommended using a modified NRC approach for determining the realized economic benefits of EERE R&D programs, and it identified several improvements that could be made to the NRC approach. This study will implement the recommendations.

- Silica Recovery from Geothermal Brine, 2001
- Smart, High-Performance Polypheylene sulfide Coating System, NREL, Brookhaven, 2002
- Acoustic Telemetry Device, 2003
- The Low Emissions Atmospheric Metering System, 2003
- High Temperature Solid-State Battery, SNL, 2006
- Binary Cycle Technology

8.2.4.2 External Performance Monitoring

OMB requires the use of two systems to monitor program performance, the Joule system and Program Assessment Rating Tool. Each program is responsible for establishing and monitoring quarterly milestones and ultimately the annual performance based program and management results as Joule targets. Joule milestones are reported to the OMB quarterly to evaluate progress toward targets as outlined in Congressional Budget Request. The second system, the Program Assessment Rating Tool (PART), also managed by OMB, was developed to assess and improve program performance so that the Federal government can achieve better results. The PART identifies all factors that affect and reflect program performance including program purpose and design; evaluations and strategic planning; program management; and program results. Since the PART includes a consistent series of analytical questions, it allows programs to show improvements over time, and allows comparisons between similar programs. For R&D programs, the PART also incorporates the R&D investment criteria developed under the President's Management Agenda.

The R&D criteria include relevance, quality, performance, and additional specific criteria for programs developing technologies that address industry needs.

GTP Joule targets for 2009 and 2010 are:

- **2009** – Determine actual pre-stimulation reservoir flow rate for a least one EGS field site.
- **2010** – Select a stimulation design plan predicting an increased reservoir flow rate of 10 percent or at least 10 kg/sec.

8.2.4.3 Internal Performance Monitoring

The Program utilizes the Corporate Planning System (CPS) to help formulate, justify, manage and execute Congressional Budget Requests. CPS also serves as a management tool to enable prospective spend planning, project data collection, and portfolio performance assessment. The system stores project-level management data, such as scope, schedule and cost and tracks progress against technical milestones. The performance of the projects ("agreements" in CPS) is monitored and managed by the PMC. Standardized processes used include:

- PMPs are developed to provide details of work planned over the entire project duration and to establish measures for evaluating performance. The plans include multi-year descriptions, milestones, schedules, and cost projections. The PMPs are updated annually.

- Quarterly project progress reports, submitted by funded organizations, outline problem areas, financial and technical status, and identify and highlight achievements. Site reviews are conducted by the PMC annually (at a minimum) for technology validation, and assessment of obstacles and work progress. The PMC assesses project progress against the planned scope and schedule. The PMC assesses financial performance against the cost projection on a quarterly basis. All conclusions are documented in the quarterly management report.

The Program has implemented a systems engineering approach and will establish integrated technical plans across the Program elements to achieve the Program goals. The Program will also develop an integrated baseline which links the technical project activities to the resource-based milestones, illuminates gaps/issues in the current project portfolio approach, and provides the foundation for data-driven decision-making by the Program management. The Program will also use additional systems engineering approaches including interface management, independent performance verification, and robust information management tools to monitor overall progress toward achieving technical goals. The integrated baseline will be updated annually at minimum using project data and information. The updates will identify risks to delivering technical goals, critical technical gaps, cost overruns and schedule slippages.

8.2.4.4 Peer Reviews

In 2009, the GTP will conduct a peer review of EGS RD&D projects awarded in 2008. The emphasis of the peer review will be on the plan and the portfolio as a whole to evaluate organization, structural balance, and performance. Individual projects will also be evaluated by the same criteria.

The OMB issues government-wide policy and procedural guidelines to ensure and maximize the quality of information disseminated by Federal agencies. Per the OMB Peer Review Bulletin[36], DOE must peer-review certain scientific information before public dissemination. More rigorous reviews are required of information that is likely to have the greater impact on public policy or private sector decisions.

Regarding the definition of scientific information:

- "Scientific Assessment" means an evaluation of a body of scientific or technical knowledge; and
- "Highly Influential Scientific Assessments" are information products that the agency or OMB determines to have a potential impact of more than $500 million in any year, or are novel, controversial, or precedent-setting or have significant interagency interest.

Technical experts from industry and academia are selected as reviewers based on experience in various aspects of geothermal technologies under review. Reviewers score and provide qualitative comments based on the presentations given at the peer review and the background information provided. Reviewers are also tasked with identifying specific strengths, weaknesses, technology transfer opportunities, and recommendations for modifying the project scope.

The Program will analyze all the information gathered at the review and develop appropriate responses to the findings for each project. All of the information, including the Program response,

36 http://www.whitehouse.gov/omb/memoranda/Fiscal Year2005/m05-03.pdf

will be documented and published in a review report that will be made available to the public through the Program website.

8.2.4.5 Technical Project Reviews

GTP plans to hold Stage Gate reviews at the project level. The Stage Gate process, as depicted in Figure 8.2, is an approach for making disciplined RD&D decisions leading to focused processes and/or product development efforts.   Specifically, the Program will use Stage Gate reviews to: guide decisions on which projects to include in the Program's portfolio; align R&D project objectives with Program objectives and industry needs; provide guidance on project definition including scope, quality, outputs and integration; and review projects to evaluate progress and alignment with the Program portfolio.

In a Stage Gate review, each section of review, the "stage" is preceded by a decision point or "gate" that must be passed through before work on the next stage may begin. Gate reviews are conducted by a combination of internal management and outside experts or the gatekeepers. The purpose of each gate is twofold: firstly, the project managers must demonstrate met objectives identified in the previous project phase; secondly, project managers must prove criteria satisfied in the current phase. Seven types of criteria are used to judge a project at each stage:

- Strategic Fit;
- Market/Customer;
- Technical Feasibility and Risks;
- Competitive Advantage;
- Legal/Regulatory Compliance;
- Critical Success Factors and Show Stoppers; and
- Plan to Proceed.

Specific criteria are different for each gate and become more rigorous as the project moves along the development pathway.

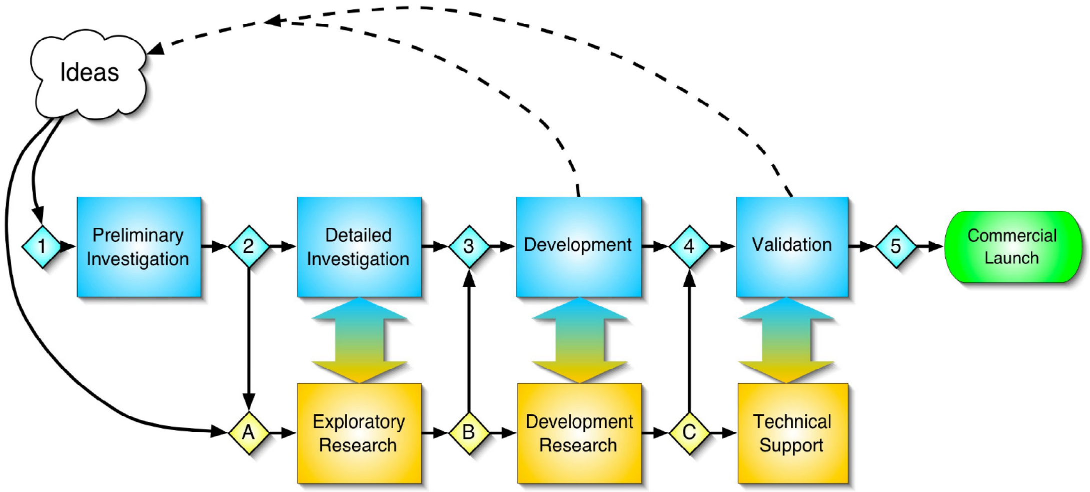


Figure 8.2. Geothermal Technologies Program Stage Gate Process

The possible outcomes of this portion of the review are: pass, recycle, hold, or stop. Passing implies that the goals for the previous stage were met including projected economics and customer satisfaction. Recycling indicates a need to extend work in the current stage as all goals had not been accomplished satisfactorily. A decision to hold suspends a project due to diminished or absent need. For projects placed on hold, the possibility that the project could resume exists if market demands change or future relevance is exhibited. A stop outcome reflects technology development failure, a permanent market shift, or economic disadvantage . In this case, the best ideas from the project are salvaged, but the project is permanently halted.

Only projects that receive a passing outcome move on to the second part of the stage-gate review process. The project leader must propose a project definition and preliminary plan for the next stage, including objectives, major milestones, high-level work breakdown structure, schedule, and resource requirements. The plan must be presented in sufficient detail for the reviewers to comment on the accomplishments necessary for the next stage and goals for completion of the next gate. Once the plan is accepted, the project can move to the next stage. Since the stakes get higher with each passing stage, the decision process becomes more complex and demanding.

The stage gate process is a key portfolio management tool that integrates a number of key decision areas, all of which are challenging: project selection and prioritization, resource allocation across projects, and implementation of business strategy. The gates and gate reviews allow the Program to filter poorly-performing or off-target projects and reallocate resources to the best projects and/or open the way for new projects to begin.

8.3 Technology Management

In FY 2008, the GTP incorporated System R&D Integration principles into technology management. Systems demonstrations and component R&D schedules were adopted in alignment with Program objectives, milestones and key decision points. These schedules, Figures 6.4, 6.5, and 6.6 are located in Section 6.

The GTP administers Program procurements and RD&D project monitoring in close cooperation with DOE's Golden Field Office (GFO). A Project Management Center maintained by the GFO houses GTP contract data and deliverables. The estimated FY 2008 budget for GFO personnel and projects is $293 million which includes services to other renewable and efficiency offices in DOE's Office of Energy Efficiency and Renewable Energy. GFO Federal staff numbers roughly 150 and includes specialists in engineering, scientific research, project management, procurement, finance, information systems, environmental protection, safety, law and human resource management. A support service contract staff of more than 60 provides GFO with additional capabilities in many of these areas.

8.4 Program Requirements

From time to time, the GTP will sponsor activities and processes that support program evaluation studies described in the EERE Guide for Managing General Program Evaluation Studies. The Program will conduct general program evaluations based on this guide, including the following:

- Needs/Market Assessment Evaluations;
- Outcome Evaluations;
- Impact Evaluations; and
- Cost-Benefit Evaluations.

This page was intentionally left blank.

9.0 Appendices

9.1 Fiscal Year 2009 Budget

9.2 Risk Analysis

9.3 Funding Opportunity Announcements

9.4 Barriers, Goals, Objectives, and Tasks

This page was intentionally left blank.