

**DOE Geothermal Technologies  
Program  
Multi-Year Program Plan  
2006 – 2011**



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## Table of Contents

Introduction: Program Manager’s Outlook .....	1
1. Program Overview.....	2
1.1. External Assessment and Market Overview .....	2
1.2. Internal Assessment and Program History .....	3
1.3. Program Justification and Federal Role .....	6
1.3.1. Legislative Authority .....	7
1.3.2. National Energy Policy (NEP) and DOE Priorities .....	7
1.3.3. DOE Strategic Planning.....	7
1.4. Vision.....	8
1.5. Mission.....	8
1.6. Organization and Approach .....	8
1.7. Performance Goals.....	9
1.8. Strategic Goal.....	10
1.9. Outputs.....	10
1.10. Outcomes .....	11
2. Critical Functions .....	12
2.1. Structure.....	12
2.2. Portfolio Decision-Making Process .....	12
2.3. Analysis .....	13
2.3.1. Analytical Context and Core Functions.....	16
2.4. Performance Measurement .....	16
2.5. Performance Assessment .....	17
2.6. Logic Model.....	17
2.7. Benefits .....	18
2.8. Relationship to Other EERE, DOE, and Federal Programs .....	19
3. Technical Plan .....	21
3.1. Technology Development .....	21
3.1.1. Enhanced Geothermal Systems .....	21
3.1.1.1. Technical Goals and Objectives.....	22
3.1.1.2. Technical Approach.....	24
3.1.1.2.1. Field Projects .....	25
3.1.1.2.2. Collaboration with Other EGS Research Projects .....	25
3.1.1.2.3. Collaboration with the Private Sector.....	26
3.1.1.3. Program Status .....	26



3.1.1.3.1. Past Research.....	26
3.1.1.3.2. Current EGS Activities.....	27
3.1.1.4. Technical Challenges and Barriers .....	28
3.1.1.4.1. Resource Characterization and Exploration .....	29
3.1.1.4.2. Reservoir Design and Development .....	30
3.1.1.4.3. Reservoir Operation and Management .....	31
3.1.1.5. Barriers to EGS Commercialization .....	32
3.1.1.6. Technology Improvement Potentials .....	33
3.1.1.7. Technical Feasibility Task Plan .....	35
3.1.1.7.1. Task Overview.....	36
3.1.1.7.2. Performance Targets.....	37
3.1.1.7.3. Critical-Path Tasks and Milestones .....	39
3.1.2. Exploration Assessment and Technology.....	45
3.1.2.1. External Assessment and Market Overview .....	45
3.1.2.2. Internal Assessment and Program History .....	46
3.1.2.3. Federal Role.....	50
3.1.2.4. Approach.....	50
3.1.2.5. Performance Goals.....	51
3.1.2.6. Strategic Goals .....	51
3.1.2.7. Market Challenges and Barriers.....	51
3.1.2.8. Technical Challenges and Barriers .....	52
3.1.2.8.1. Technical Targets .....	54
3.1.2.9. Strategies for Overcoming Barriers and Challenges.....	55
3.1.2.10. Tasks .....	56
3.1.3. Systems Development .....	63
3.1.3.1. Wellfield Construction.....	63
3.1.3.1.1. External Assessment and Market Overview.....	63
3.1.3.1.2. Internal Assessment and Program History .....	63
3.1.3.1.3. Federal Role.....	65
3.1.3.1.4. Performance Goals .....	66
3.1.3.1.5. Strategic Goals.....	67
3.1.3.1.6. Approach .....	67
3.1.3.1.7. Market Challenges and Barriers .....	71
3.1.3.1.8. Technical Challenges and Barriers .....	72
3.1.3.1.9. Strategies for Overcoming Barriers and Challenges .....	74



3.1.3.1.10. Tasks .....	77
3.1.3.1.11. Milestones and Decision Points .....	81
3.1.3.2. Energy Conversion.....	87
3.1.3.2.1. External Assessment and Market Overview.....	87
3.1.3.2.2. Internal Assessment and Program History .....	88
3.1.3.2.3. Federal Role.....	90
3.1.3.2.4. Approach .....	90
3.1.3.2.5. Performance Goals .....	95
3.1.3.2.6. Strategic Goals.....	96
3.1.3.2.7. Market Challenges and Barriers .....	96
3.1.3.2.8. Technical Challenges and Barriers .....	96
3.1.3.2.9. Technical Targets .....	99
3.1.3.2.10. Strategies for Overcoming Barriers and Challenges.....	101
3.1.3.2.11. Tasks .....	102
3.1.3.2.12. Milestones and Decision Points .....	106
3.2. Technology Application.....	109
3.2.1. Technology Verification.....	109
3.2.1.1. Enhanced Geothermal Systems.....	109
3.2.1.2. Exploration.....	109
3.2.1.3. Wellfield Construction.....	109
3.2.1.4. Energy Conversion.....	110
3.2.1.5. Geothermal Resource Exploration and Definition (GRED) .....	110
3.2.1.5.1. Technical Goals and Objectives .....	110
3.2.1.5.2. Technical Approach.....	111
3.2.1.5.3. Program Status.....	111
3.2.1.5.4. Current Activities and Technology Status.....	111
3.2.1.5.5. Technical Challenges.....	112
3.2.1.5.6. Technical Targets .....	113
3.2.1.5.7. Barriers .....	113
3.2.1.5.8. Technical Task Descriptions .....	113
3.2.1.5.9. Milestones.....	114
3.2.2. Technology Acceptance.....	115
3.2.2.1. External Assessment and Market Overview .....	116
3.2.2.2. Internal Assessment and Program History .....	116
3.2.2.3. Federal Role.....	117



3.2.2.4.	Approach.....	117
3.2.2.5.	Performance Goals.....	118
3.2.2.6.	Strategic Goals.....	120
3.2.2.7.	Market Challenges and Barriers.....	121
3.2.2.8.	Technical Challenges and Barriers .....	121
3.2.2.9.	Strategies for Overcoming Barriers and Challenges.....	121
3.2.2.10.	Tasks .....	121
3.2.2.11.	Milestones and Decision Points .....	123
4.	Program Administration.....	127
4.1.	Organizational Structure.....	127
4.2.	Program Funding Mechanisms .....	128
4.3.	Cost Management and Monitoring .....	129
4.4.	Environmental Safety and Health .....	129
4.5.	Communication and Outreach .....	130
	Appendix 1: MYPP Drivers .....	134
	Appendix 2: Glossary.....	135
	Appendix X: Resource Allocation Plan .....	140



## Introduction: Program Manager's Outlook

The Geothermal Technologies Program has undergone significant changes during its history. The budget has fluctuated from highs of \$100 - \$150 million in the 1980s to lows of \$15 - \$20 million in the 1990s. During this period, several programs were initiated including loan guarantees, Hot Dry Rock investigations, and Geothermal Heat Pump initiatives, as well as electric generation and direct use research and development activities. Today, the geothermal industry faces both old and new challenges, as the high cost and risk of geothermal development remain major issues that hinder renewed interest in geothermal development.

With rising energy costs in today's market, the Program reduces geothermal development costs through research and development. The Program takes pride in collaborating with industry, national laboratories, and universities to address the complex technical issues facing geothermal development. The Program tackles institutional barriers through GeoPowering the West, and collaborates with the Department of the Interior to better define the U.S. geothermal resource base and to resolve leasing issues.

The Multi-Year Program Plan presents a path forward for the next five years to address technical and institutional issues impeding the full development of the vast geothermal resource base beneath the United States. The approximately 2600 MWe and 600MWt of geothermal energy generated and used in the United States represent only a small portion of the potential. The technology for high-temperature shallow geothermal resources is robust, and is being used by industry. The challenge for the DOE Geothermal Technologies Program that this Multi-Year Program Plan responds to is to develop and deploy the technology needed to economically capture the larger, deeper, cooler, and less permeable resource base - the Enhanced Geothermal System (EGS). Enabling use of this energy could provide a renewable baseload energy source for future generations of Americans.

Other nations also view this resource base as a realistic future energy source. Through research and development activities outlined in this Plan, the United States can maintain its leadership in geothermal power production. Technology development for EGS will spin off improvements for hydrothermal and low temperature resource technologies through better exploration, drilling, and energy conversion.

Geothermal is one of the few baseload renewable energy resources the Nation possesses and, with declining domestic oil and gas resources, it is imperative that the resource be developed to its full capacity. The Program's mission is to research, develop, and deploy necessary technologies so industry can effectively and efficiently develop the U. S. geothermal resource base.

## 1. Program Overview

This Multi-Year Program Plan (MYPP) describes ongoing and planned work with schedules, milestones and performance metrics. The MYPP covers research, development, and deployment of new technology over a five-year time horizon (from 2006 through 2011). Funding is assumed to remain at FY06 request levels (approximately \$23.3M) through FY2011.

Other program documents include the Strategic Plan, which describes the program goals, objectives and priorities and the Annual Operating Plan which describes activities in detail for the current fiscal year.

Key drivers of the Program's content and performance requirements include the recommendations of the National Energy Policy, the National Academy of Public Administration (NAPA), and the National Research Council; findings from the program's Peer Reviews; collaboration efforts with industry, other Federal and state agencies, and other offices within DOE; and the President's Management Agenda.

### 1.1. External Assessment and Market Overview

Geothermal electricity generation is a baseload renewable technology and competes with conventional technologies such as coal and nuclear power plants in the bulk power market, and with other renewables in green power markets favored by consumers and regulators. Commercial geothermal electric power production in the United States began in 1960. The U.S. geothermal power industry underwent a boom in the 1970s and 1980s, followed by consolidation in the 1990s. The industry, once dominated by large oil companies and utilities, is now made up of independent power producers. During the 1990s, the geothermal industry focused on international markets, and only minimal new domestic development occurred. Since 2000, the industry has shown renewed interest in domestic development due to reduced production costs, increased domestic power prices, and incentives such as state renewable portfolio standards. New domestic projects totaling about 400 MWe have been announced since 2002.

Domestic geothermal resources suitable for power generation are found predominantly in the western United States.

Geothermal generation is currently limited to California, Nevada, Hawaii, and Utah, but new projects are underway in Idaho, Alaska, and New Mexico. Other states with significant near-term potential for development include Arizona and Oregon. Domestic geothermal energy production, worth \$1 billion annually, accounts for almost 20 percent of all non-hydropower renewable electricity production, and about 0.35

**Figure 1.1 - Five geothermal power plants at The Geysers, Northern California.**



percent of total U.S. electricity production. Installed nameplate geothermal generating capacity has increased from about 500 MWe in the early 1970s to over 2,700 MWe. Total U.S. generation

peaked at about 17,000 GWh in 1993, and has since dropped to approximately 13,149 GWh, due to both steam depletion and plant retirements at The Geysers geothermal power complex in northern California. California currently produces about approximately 5% of its electricity from geothermal energy, largely from The Geysers. Exclusive of The Geysers, power generation increased from approximately 5,500 GWh to a peak of approximately 9,800 GWh in 1996, and has remained nearly constant since.

Direct use systems are operating throughout the western United States and in a few locations in the East. Direct use projects tend to be developed on an ad hoc basis, as a domestic industry dedicated to direct heat applications has not evolved. The direct use installed capacity in the United States is about 600 MWt.

Geothermal heat pump applications exist throughout the Nation.

The Energy Information Administration projects that the capacity of geothermal installations will total 6,800 MWe by 2025, assuming relatively stable natural gas prices. This projection does not include Enhanced Geothermal Systems (EGS).



**Figure 1.2 - A geothermal heat pump system is being installed in a newly renovated building on the Georgia Tech Campus before the 1996 Summer Olympic Games in Atlanta.**

Barriers to the Program's goal achievement include demand for electricity, availability of conventional energy supplies, regulatory requirements, market incentives, cost of competing technologies, federal tax incentives and implementation of other policies at the national level, and proximity of transmission grid. Barriers to new projects include cost, resource development risk, and permitting issues. Progress on these limiting factors has been slow because of a relatively small and conservative industry with little capital for research. The lack of information on the part of utilities and regulators has led to failure to consider geothermal development seriously in planning for new capacity; bureaucratic inertia in permitting processes; and public resistance to power plant development in general.

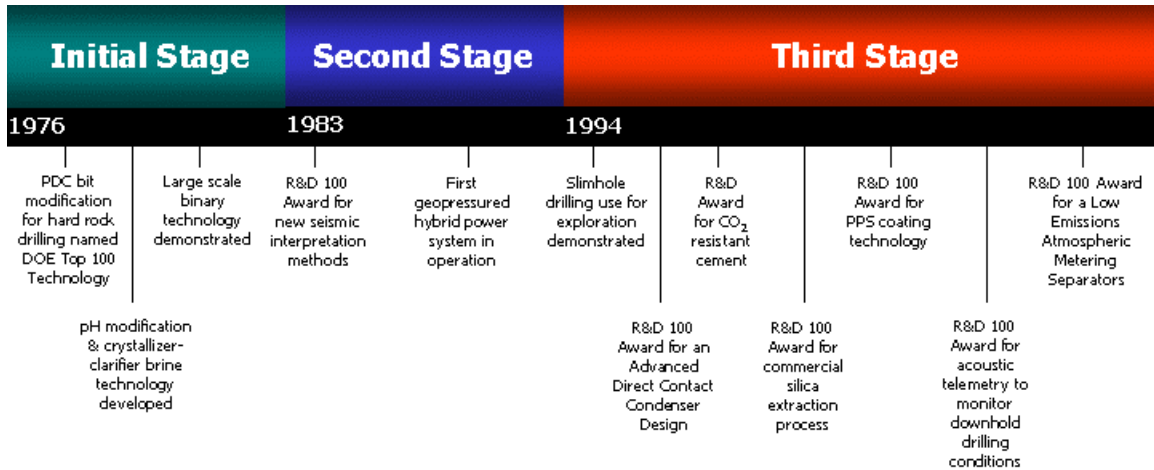
## 1.2. Internal Assessment and Program History

Congress gave the Interior Department responsibility for geothermal resource assessment and leasing of Federal lands in 1970 through the Geothermal Steam Act. Federal funding of geothermal energy research and development began in 1971 with the Atomic Energy Commission and the National Science Foundation. A national commitment to geothermal R&D was made with passage of the Geothermal Energy Research, Development, and Demonstration Act of 1974 (PL 93-438). The Energy Research and Development Administration assumed responsibility for the federal R&D program at its founding in January 1975, and this responsibility passed to the Department of Energy (DOE) when DOE was established in 1977. The total funding of the program for the period FY 1978-FY 2004 was \$1.2 billion in nominal dollars.

The Geothermal Technologies Program, like DOE itself, was created to respond to the need for energy independence. It was designed to develop the technology for geothermal exploration, drilling, and energy conversion and to facilitate development by addressing public awareness and institutional barriers.

The Program's history can be divided into three stages, as shown in Figure 1.3.

**Figure 1.3 - Program History and Accomplishments**



**A. Initial Stage**

Between 1976 and 1983, the Program’s annual budget ranged from \$43 million to \$157 million with an average of \$96 million. These funds were used for research on high-risk concepts with the potential for a large long-term payoff such as geopressured-geothermal energy, binary cycle technology, and Hot Dry Rock (HDR) resources. The Program’s strategy was based on research and development conducted by DOE national laboratories with industry functioning in an advisory capacity. The Department of Interior’s U.S. Geological Survey (USGS) and the DOE Office of Science researched improved resource assessment and exploration techniques. The Program took advantage of resource assessments performed by the USGS.

The Program’s major accomplishments were:



**Figure 1.4 - PDC drill bits account for more than one-third of the total footage drilled worldwide.**

- Modification of Polycrystalline Diamond Compact (PDC) bits for hard-rock drilling led to their eventual adoption by the oil and gas (O&G) industry. PDC bits are now used for over one-third of oil and gas drilling, and constitute a market of over \$200 million annually. The bits reduce drilling costs from \$500/foot to \$300/foot. PDC bits were selected as one of DOE’s Top 100 technologies.
- pH modification and crystallizer-clarifier brine technology developed by the program enabled the development of hundreds of megawatts of otherwise uneconomic resources with high concentrations of dissolved minerals.
- The Program demonstrated the technical feasibility of large-scale binary technology. Because geothermal resources suitable for flash plants are relatively rare, binary power plants are expected to be the dominant method of geothermal development.
- Elastomeric materials designed to withstand high temperatures in geothermal drill bit applications were adopted for applications in nuclear power plants.
- Technical assistance and cost-shared exploration drilling programs in concert with industry resulted in development of eight domestic geothermal fields.
- A proof-of-concept system for HDR was developed at Fenton Hill, New Mexico.

## **B. Second Stage**

From 1984 through 1993, the Program's budget ranged from \$18 million to \$33 million (average \$23 million.) The program focused on completing research from the initial phase, improvement of drilling economics, and technology for smaller power plants. Research on geopressured resources was stopped when it was demonstrated that the technology was not economically feasible under existing market conditions, but not before it achieved its stated objectives of characterizing the resource and demonstrating power conversion technology. Research on generating power from magma, transferred from the Office of Basic Energy Science to the Geothermal Technologies Program in 1986, was shown to be technically impractical and was terminated.

The Program's major accomplishments during this period were:

- Development of new seismic interpretation methods, resulting in an R&D 100 Award in 1984.
- Operation of the first geopressured hybrid power system in 1989, using both heat and natural gas dissolved in the geothermal brine.
- Development of a reinjection strategy for The Geysers that has maintained generating capacity that would otherwise have been lost due to falling steam pressure. ReInjection is now standard industry practice.
- Long-term flow testing of an HDR reservoir in collaboration with Germany and Japan at Fenton Hill, NM.

## **C. Third Stage**

Beginning about 1994, the program strategy changed from resource-oriented, long-term, high-risk R&D, with industry functioning in an advisory role, to cost-shared competitively-selected R&D to meet immediate industry needs in geosciences, drilling, resource engineering, and energy conversion technologies. A subprogram on geothermal heat pumps that was initiated in 1994 at the direction of Congress was terminated in 1998 after effective commercialization of the technology. Program budgets during this period have ranged from \$23 million to \$37 million (average \$27 million). The increased budgets in the late 1990s were due to heat pump funding.

This strategy has led to numerous technological successes, but the focus on industry needs has come at the expense of data collection and analysis needed for strategic planning and implementation. Data on technology capabilities and limitations that could be used in setting program priorities have not been completely analyzed. Although a new resource assessment by the USGS is needed to support development of meaningful supply curves for different geothermal resource types, funding for the assessment has not been made available by Congress.

In 1995, the Program dropped its effort to develop technology for extracting energy from HDR (geothermal resources that lack fluids for extracting heat) at the Fenton Hill site. The HDR effort has been replaced by the broader EGS program. EGS is an incremental approach to development of a broad range of new geothermal resources, whereas HDR targeted the most problematic resources.

Since 2000, GeoPowering the West, an outreach initiative, has cooperated with state and local entities to remove institutional barriers to geothermal development and to identify opportunities for development activities.

Major program successes have included:

- The program demonstrated the utility of slimhole drilling for exploration purposes, significantly decreasing the cost of exploration. Slimhole drilling is now a standard industry practice.

- A Polyphenylene Sulfide (PPS) coating technology developed in cooperation with industry for inexpensively reducing fouling in geothermal plants won an R&D 100 Award in 2002. PPS resists corrosion at high temperatures, transfers heat well, and can repair itself when damaged. This technology has been commercialized.
- A CO<sub>2</sub>-resistant cement won an R&D 100 Award in 2000. This cement may extend well life from less than one year to as much as 20 years in acidic environments. This technology has been commercialized by an oil field service provider.
- Acoustic Telemetry technology for monitoring downhole drilling conditions, developed in cooperation with industry, won an R&D 100 Award in 2003.
- A Low Emissions Atmospheric Metering Separator, developed in cooperation with industry, won an R&D 100 Award in 2003. This technology provides a single system for cleaning steam of polluting solids, liquids, and gases during well testing.
- An Advanced Direct Contact Condenser Design won an R&D 100 Award in 1999. This technology can also reduce emissions from coal and natural gas power plants, and improve the efficiency of any industrial process in which steam is condensed.
- A commercial silica extraction process for improving the economics of geothermal brine processing won an R&D 100 Award in 2001.
- The program successfully commercialized Geothermal Heat Pump technology.

### **1.3. Program Justification and Federal Role**

Geothermal energy benefits the public on a national scale. The distributed nature of geothermal energy promotes national security. Geothermal energy increases the diversity of the Nation's energy supply. Increased use of geothermal energy will result in a cleaner environment and reduced emissions of greenhouse gases. Geothermal energy creates jobs in manufacturing, operating, and servicing the technology. Its ability to generate baseload power and its cleanness make it a compelling renewable energy choice.

In spite of its obvious public benefits, there are barriers to geothermal development that are best addressed by the Federal government. These include:

- A small market and underdeveloped infrastructure increase costs and limit the pool of technical expertise. A public-private partnership between government and industry will be needed to realize the potential for geothermal energy.
- Conventional energy costs do not reflect environmental and health costs, and geothermal power producers cannot capture the environmental, health, and national security benefits of their product, leading to private sector underinvestment in research and development.
- Appropriate regulations, standards and codes are lacking.
- Regulatory barriers hamper development. Licensing of geothermal resources on federal lands has been slow and cumbersome, discouraging investors. Regulatory procedures must be streamlined to accelerate geothermal leasing.

The Geothermal Technologies Program responds to these issues by performing fundamental scientific, engineering, and technical research, engaging industry in research and commercialization of new technologies, and providing essential information to regulators and other stakeholders.

### 1.3.1. Legislative Authority

The Geothermal Technologies Program operates under the statutory authorizations:

- PL 93-410, “Geothermal Energy Research, Development, and Demonstration Act of 1976”
- PL 95-91, “Department of Energy Organization Act (1977)”
- PL 95-618, “Energy Tax Act of 1978”
- PL 96-294, “Energy Security Act (1980)”
- PL 101-218, “Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989”
- PL 101-575, “Solar, Wind, Waste, and Geothermal Power Production Incentives Act of 1990”
- PL 102-486, “Energy Policy Act of 1992”
- PL 109-190, “Energy Policy Act of 2005”

### 1.3.2. National Energy Policy (NEP) and DOE Priorities

In May 2001, the President's National Energy Policy Development Group released a set of recommendations that have become a cornerstone of U.S. energy policy. Pursuant to the National Energy Policy (NEP) recommendations, Secretary Spencer Abraham described the three priorities of the Department of Energy as:

1. Ensuring energy security by strengthening the energy production and delivery infrastructure,
2. Focusing on programs that increase the supply of domestically produced energy, that revolutionize how the country approaches conservation and energy efficiency, and
3. Directing R&D budgets at ideas and innovations that are relatively immature, and ensuring the greater application of mature technologies.

The National Energy Policy sets goals of increasing energy supplies and researching innovative technologies with a long-term payoff, and recommends improving the process for leasing federal lands for geothermal energy production. Other important recommendations include near-term activities to address the critical shortage of domestic generating capacity, development of next-generation technologies, and increasing renewable energy production on Federal lands.

EERE’s implementation of the Secretary's priorities would include reducing dependence on foreign oil and reducing the burden of energy prices on the disadvantaged, among others. One means of achieving these goals has been to increase the viability and deployment of renewable energy, by developing a diverse portfolio of renewable energy technologies that reduce the average cost of renewable energy production by 20% by 2010 and achieve cost-competitive parity with the average cost of energy by 2020.

### 1.3.3. DOE Strategic Planning

DOE’s and EERE’s Strategic Plans provide the foundation for Program planning. The Department of Energy’s Strategic Plan defines how DOE will meet the President’s energy goals. Three of these goals (energy resources, environmental quality, and science) are supported by the Geothermal Technologies Program’s strategic objectives.

The EERE Strategic Plan (2002) supports the DOE Strategic Plan. EERE’s Plan describes its response to Secretary Abraham’s challenge to “leapfrog the status quo” and to pursue “dramatic environmental benefits” in its approach to efficiency and renewable energy technologies. Three strategic goals specified in EERE’s Strategic Plan are directly relevant to the Geothermal Technologies Program:

- Promote the use of diverse, domestic, and sustainable energy resources,

- Reduce carbon emissions from energy production and consumption, and
- Increase the reliability and efficiency of electricity generation.

The Program works in partnership with industry, academia, national laboratories, and other DOE Programs to achieve EERE's strategic goals.

#### 1.4. Vision

The **vision** of the Geothermal Technologies Program is to make geothermal energy the environmentally preferred baseload energy option.

#### 1.5. Mission

The **mission** of the Program is to work in partnership with U.S. industry to establish geothermal energy as an economically competitive contributor to the U.S. energy supply.

#### 1.6. Organization and Approach

The Program's organization supports all stages of technology development and technology application, from problem formulation, through basic and applied research, to field-testing of prototypes and deployment in the marketplace. Industry plays a key partnership role, bearing an increasing share of costs as products move toward deployment.

The Program is organized into two major thrusts: Technology Development and Technology Application. The Technology Development subprogram includes EGS; Resource Development; and Systems Development, including the key activities of Wellfield Construction and Energy Conversion. The Technology Application subprogram includes the Technology Verification and Technology Deployment subprograms.

**Technology Development:** This subprogram develops technology to improve the competitiveness of geothermal resources.

- A) **EGS.** EGS are reservoirs created to improve the economics of resources without adequate water and/or permeability. EGS range from enhancements to existing commercial hydrothermal reservoirs (e.g., the Geysers) to resources with heat but low water content and permeability, such as HDR. EGS laboratory and field experiments will increase the productivity and lifetime of reservoirs.
- B) **Resource Development.** Resource uncertainty is a major risk in opening up new geothermal fields. To reduce this risk, the program shares exploration costs with industry and funds research to improve exploration technology. DOE provides up to 80% cost share for high risk research; up to 50% cost share for medium risk research; and up to 20% cost share for low risk research, if the work benefits the program. Resource Development activities address the formation and evolution of geothermal systems in order to be able to better locate, characterize, and assess geothermal resources. Seismicity, isotope geochemistry, magnetotellurics, and remote sensing are being researched as exploration tools. Technology from related industries (e.g., petroleum, mining, waste management) is being evaluated for adaptation to geothermal environments.
- C) **Systems Development.** Systems Development includes Wellfield Construction and Energy Conversion. Wellfield Construction research reduces the cost of geothermal wells by improving and integrating key components such as drill bits, Diagnostics-While-Drilling subsystems, high temperature electronics, and innovative drilling systems. Energy Conversion research improves power plant technologies, including advanced conversion cycles, innovative component development, capital cost reduction, and operation and maintenance of geothermal power plants.

**Technology Application:** The Program verifies new technology and transfers technology and knowledge to the user community.

- A) **Technology Verification.** All technologies are field tested to demonstrate improvements in technology performance at a commercial scale. In cooperation with industrial partners, field projects demonstrate near-commercial technical improvements, and provide collaborative assessments of resources for future development. Technology Verification activities move technologies from research and development to acceptance, active use, and application by the geothermal industry and other stakeholders.
- B) **Technology Deployment.** Collaboration with the stakeholder community encourages adoption of new technology and removes barriers to geothermal development. Technology Deployment addresses factors affecting geothermal project development, such as complex regulations that can stymie the transition from a prototype to a commercial product. Analytical work assesses the performance and economics of geothermal systems. On completion of deployment, the technology is expected to be at an early commercialization stage, with costs reduced enough for private sector commercialization without further program funding.

The Program relies on input from stakeholders, as well as from industry and peer reviewers. As the major stakeholder organizations, the Geothermal Resources Council and the Geothermal Energy Association provide independent comments and recommendations on the Program’s current and future direction.

Peer Reviews evaluate whether projects are meeting their objectives and provide a formal mechanism for industry and other stakeholders to provide feedback for use in setting program priorities. Research activities of lesser value are terminated or deferred. The Peer Reviews are managed by chairs with strong technical credentials who are not directly affiliated with the Program or its contractors. Peer Review leaders work with program personnel to select independent experts for the Peer Review panels. Peer Review and stakeholder recommendations are taken into account in setting program priorities and allocating funding.

### 1.7. Performance Goals

The Geothermal Technologies Program seeks to enable economic development of the nation’s vast geothermal resources. The Program has established three performance goals for research:

Goal #	Description	Projected Completion Date
1	Decrease the levelized cost of electricity from hydrothermal systems to less than 5 cents per kWh (in 2004 dollars)	2010
2	Increase the economically viable geothermal resource to 40,000 megawatts	2040
3	Decrease the levelized cost of electricity from EGS to less than 5 cents per kWh (in 2004 dollars)	2040

**Goal 1: Decrease the levelized cost of electricity from hydrothermal systems to less than 5 cents per kWh by 2010 (in 2004 dollars)**

The cost of geothermal power has varied dramatically over time, but there has been a long-term downward trend. The estimated cost is now between 8-9 cents per kWh, as compared to 10-12 cents per kWh in the 1980s. A recent analysis of commercial hydrothermal systems indicates that costs as low as 3.4 cents/kWh are feasible under favorable conditions.

For this goal, the reference system is based on the more challenging geothermal conditions likely to be encountered in many locations: moderate fluid temperatures (circa 150°C) and depths (1525 m). These conditions will require substantially more drilling, a binary cycle conversion system, and air cooling, all of which contribute to a Levelized Cost of Electricity (LCOE) that is estimated to exceed 7 cents per kWh with current (2005) technology. The LCOE is a function of exploration, wellfield construction, stimulation, and energy conversion costs. Although a 30 percent cost reduction will require major improvements in all of these cost areas, this goal is achievable, given historic trends.

**Goal 2: Increase the economically viable geothermal resource to 40,000 megawatts**

The thirty-year-old USGS assessment of geothermal resources appears to be optimistic. While an updated resource assessment is likely to reduce hydrothermal resource estimates, the current hydrothermal estimate does not include resources that can be developed using EGS technology. EGS may dramatically increase commercial development potential.

Identifying 40,000 MWe of economic resources will require improved exploration capabilities and development of technologies that do not currently exist or are unproven. Approximately 30,000 MWe is expected to come from EGS, with the remainder from conventional hydrothermal systems. This amount of resource will assure long-term growth in geothermal development.

**Goal 3: Decrease the levelized cost of electricity from EGS to less than 5 cents per kWh by 2040 (in 2004 dollars)**

Enabling development of a large portion of the resource base requires reducing the cost of EGS energy to competitive levels. Attaining this goal will enable development even under challenging geothermal conditions (low permeability, unsaturated, deep, hard rock) but will require a more than an 80 percent reduction in LCOE from current estimates of EGS costs.



**Figure 1.5 - Developing more geothermal resources in the U.S. translates to more jobs at home and a more robust economy.**

The strategies for achieving the program goals involve increasing the resource base by identifying additional geothermal resources, and reducing the cost of developing those resources through improved technology. By 2010, the program will have completed an assessment of resources susceptible to enhancement, and tested the feasibility of technologies to be used for modifying these resources.

**1.8. Strategic Goal**

The program's strategic goal is to improve technology performance and reduce market entry costs of geothermal energy to competitive levels, thereby making the large geothermal resource available to the Nation.

**1.9. Outputs**

The program's primary outputs are technologies and practices that lead directly to reductions in the levelized cost of electricity. The expected outputs that will result in completion of the program's strategic goal are expressed in terms of cost:

- Hydrothermal (binary and flash) power plants will produce electricity at less than 5 cents/kWh, and
- EGS power plants will produce electricity at less than 5 cents/kWh.

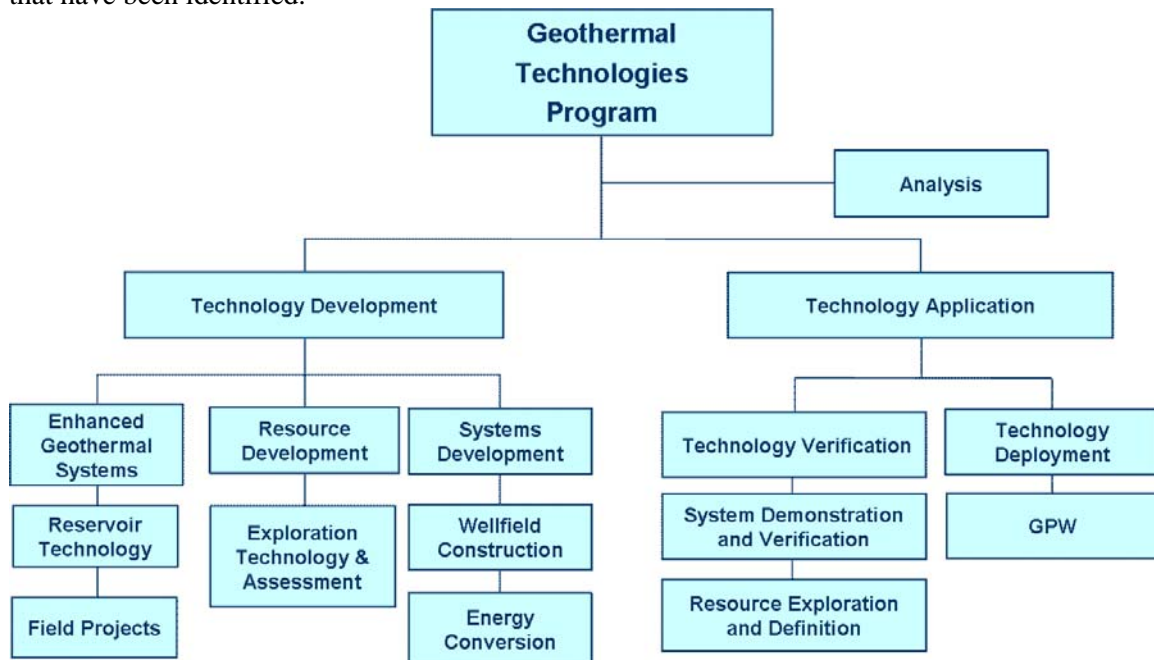
## **1.10. Outcomes**

The outcome for the Geothermal Technologies Program is a 5% market penetration of the domestic baseload energy supply, resulting in enhanced energy-supply diversity, reduced domestic emissions of greenhouse gases, and creation of jobs and economic growth.

## 2. Critical Functions

### 2.1. Structure

The Geothermal Technologies Program has organized its activities into two interrelated subprograms: Technology Development and Technology Application. Figure 2.1 shows how these subprograms are divided. Technology Development improves the economics of industry development, which is facilitated through activities under Technology Application. This structure enables the Program to address all barriers to geothermal economics and development that have been identified.



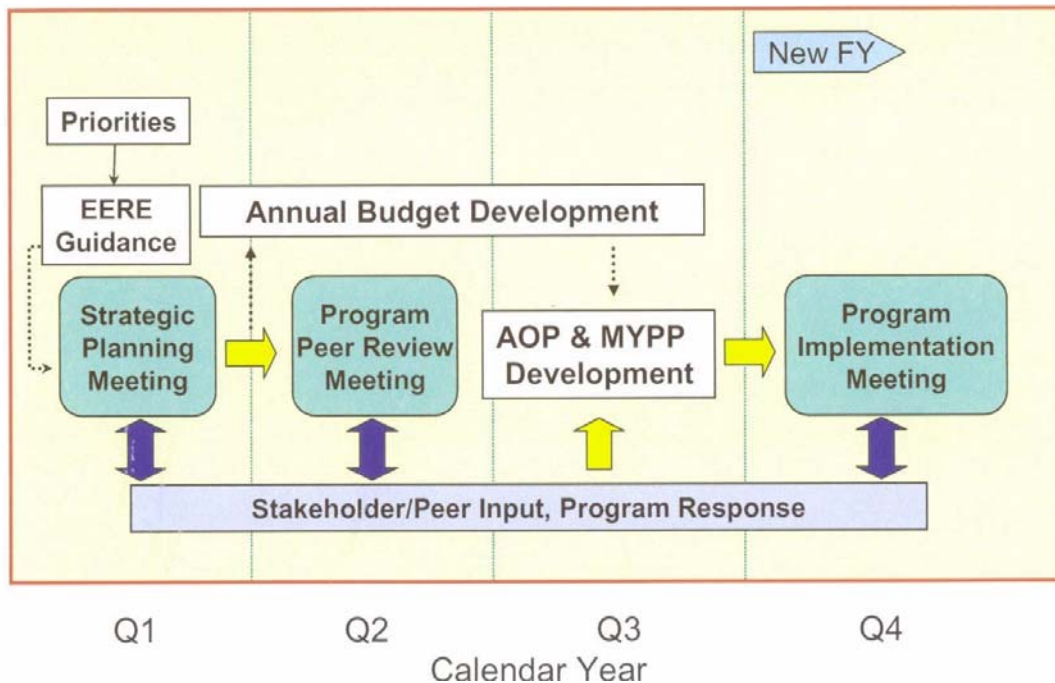
**Figure 2.1: Program Structure**

Each subprogram has objectives and performance targets. The **Technology Development** subprogram works to improve technology for generating electricity from geothermal resources. Research under this subprogram involves finding resources, creating and enhancing techniques for improving reservoirs, and developing advanced wellfield construction and energy conversion technology. The **Technology Application** subprogram promotes the application of advances made under the Technology Development subprogram with field verification, deployment, and commercialization activities, and removes barriers to technology transfer and domestic geothermal development.

### 2.2. Portfolio Decision-Making Process

Figure 2.2 illustrates the Program's decision-making process. The Strategic Plan, the Multi-Year Program Plan, and the Annual Operating Plan establish the Program's strategy, goals, and direction.

Individual projects are typically generated and pursued at the Subprogram level. Review and feedback mechanisms are used to determine the merit of these projects, allowing creation and maintenance of a portfolio that will enable attainment of Program goals. Every two years, independent expert reviewers conduct comprehensive Peer Reviews of projects within a subprogram. In 2005, reviews were held for EGS, Systems Development, and Exploration. These feedback mechanisms are used as guidance by program management. The Program also occasionally confers with outside groups for informal independent viewpoints.



**Figure 2.2 - Annual Cycle**

### 2.3. Analysis

Analysis supports program planning and measurement of progress toward the Program’s performance goals listed in Section 0. All program activities are supported by analysis of benefits, and progress is tracked against quantifiable metrics whenever possible. Analyses are designed to track metrics that are under the program’s control.

#### Analytical Requirements

Program decisions on research priorities require analysis of a supply curve showing the amounts of electricity that can be economically produced from geothermal resources at various market prices. Development of such a supply curve requires both characterization of the resources themselves (collection and analysis on data on heat flow, rock types, permeability, etc.) and analysis of the cost of developing these resources. Research and development is expected to shift the supply curve, resulting from reducing the cost of development as technologies and methods improve.

The Program projects and tracks the achievement of research milestones and reductions in the cost of energy. Projections of the benefits of individual research efforts, or of Technology Improvement Potentials (TIPs), under different budget and reference case scenarios, are used in roadmapping of program activities, and in estimating the level of benefit to be achieved at a given budget level. This permits analysis of the probability of achieving the Program’s long-term goals.

The Program is also required to provide data in support of the Government Performance Results Act (GPRA) and National Energy Modeling System (NEMS), in order to enable tracking of benefits to the nation such as reductions in emissions of criteria pollutants and carbon dioxide; increased power generation; and security benefits.

#### Data Requirements

Obtaining data for development of an accurate resource estimate will be expensive. Some relevant data is in the hands of industry, and may be considered proprietary. Industry information

must be integrated with information from the U.S. Geological Survey and the open literature. A first-order estimate of hydrothermal potential can be developed from a database of known geothermal prospects, but in most cases newer data has not been integrated with the database. Updating and maintaining the database and the USGS resource estimate will be a major element of program analytical activity. The Program's activities are designed to generate data at reasonable cost for a supply curve of sufficient accuracy for setting priorities and tracking performance.

Analysis of the cost of geothermal development requires characterization of the costs and performance of power plants, wellfields, exploration success rates, and exploration costs. While this data is generally considered proprietary by industry, the program does have access to some information through its industry partnerships. The program is actively updating its cost information for use in modeling both current and future cost and performance.

Additional data for analysis of macroeconomic impacts under GPRA includes metrics such as the number of personnel used in running a geothermal facility, emissions of pollutants, and geothermal capacity factors. This data is relatively easy to collect, but it must be revised regularly due to shifting industry practices.

Quantification of TIPs for all subprogram activities is a primary data collection requirement. Program managers and researchers are expected to develop estimates of the minimum, maximum, and most probable benefits to be derived from a given area of research, reflecting the uncertainty and probabilistic nature involved in research. The metrics used to measure TIPs depend on the technologies under investigation. Interpretation of the benefits of TIPs is performed using modeling and statistical analysis.

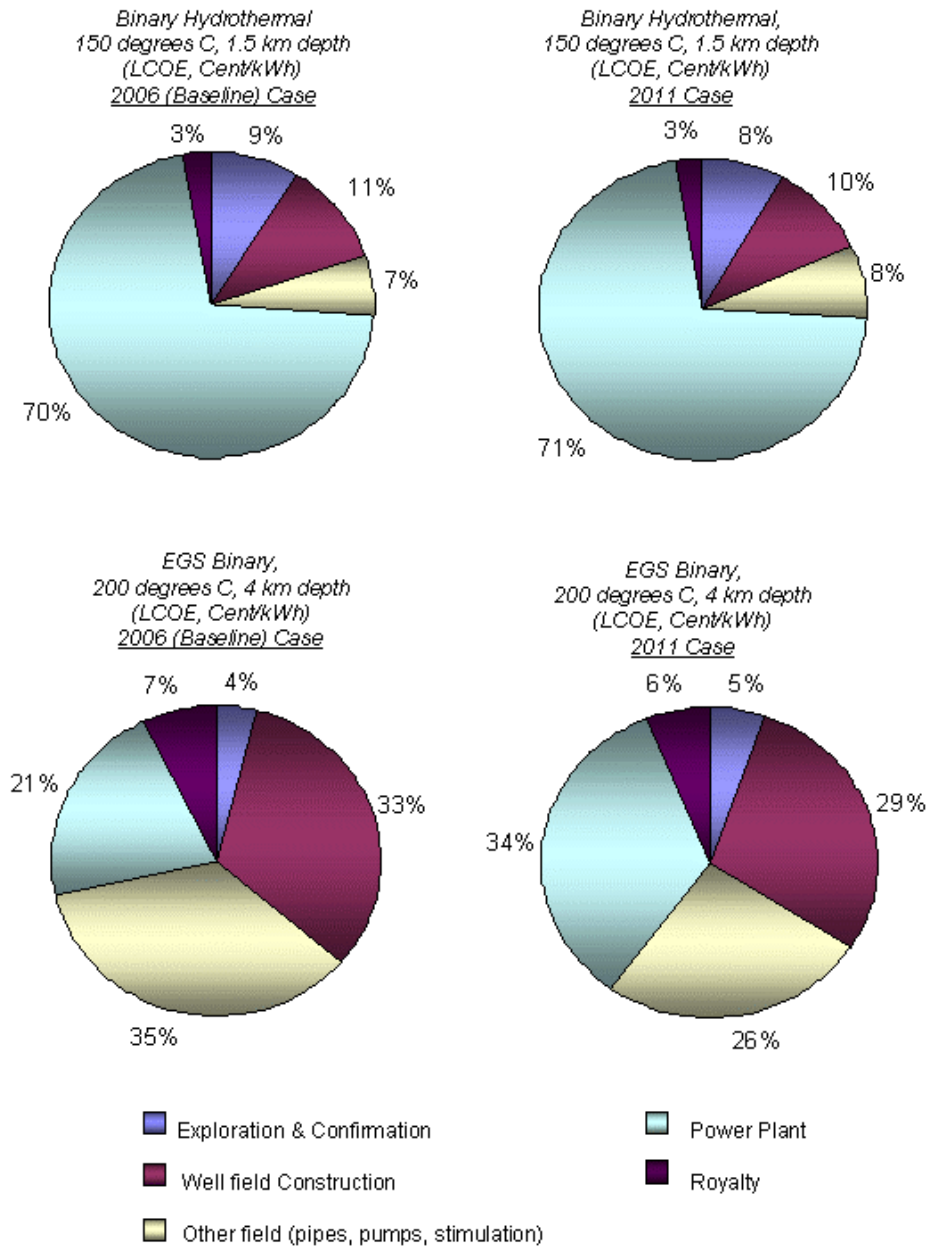
### **Analytical Tools**

Modeling is used to develop reference cases, project performance improvements, and track progress. The Program uses a **Geothermal Electricity Technology Evaluation Model (GETEM)** to aggregate lower-level data on costs and financing and quantify energy cost reductions resulting from the Program's research. GETEM supports analysis by other stakeholders, such as the Energy Information Administration's (EIA's) analyses of the market potential of geothermal energy using the National Energy Modeling System (NEMS). It is a macromodel that is used to interpret economic impacts of technical improvements; it does not yet directly address project-level improvements.

Future development will enable GETEM to better model costs at the project level. Micromodels will enable the Program to estimate the potential impact of TIPs and project-level results on the systems-level variables used by GETEM. Quantified project-level results will be used to track progress against higher-level program goals, and to help management make changes to optimize performance. TIP data will be entered into GETEM to estimate the effects of individual technical improvements on the levelized cost of electricity under various market and finance scenarios and reference cases. This will enable the Program to provide analytical confirmation that goals are valid and attainable. Tracking of metrics on an annual per-project basis will enable cost/benefit analysis of individual projects (cost/benefit analysis is currently performed at the subprogram level).

GETEM is used to calculate performance and economic indicators for geothermal system reference cases. Reference cases (Figure 2.3) have been defined to help prioritize activities and track progress toward the performance goals. These reference cases permit measurement of the contributions of research results to achievement of goals. They provide a basis for modeling program impacts and assessing project-level program outputs by comparing projected LCOE based on improved technology to LCOE based on current technology. The reference cases

integrate information about technology subsystems (e.g., exploration, wellfield construction, and energy conversion) to create a baseline of performance and cost and identify where research and engineering can provide the greatest marginal benefit.



**Figure 2.3 - Current Geothermal Technologies Program Reference Cases**

Analysis of the TIPs defines the technical and economic requirements for achieving program goals. These requirements are used to formulate research activities, plans, schedules, milestones, and deliverables.

The program also has a model for projecting and tracking well drilling costs. This model is used to track the progress of reductions in the cost of drilling, and to generate data for entry into GETEM. This model will eventually be integrated with GETEM.

### 2.3.1. Analytical Context and Core Functions

Management and research teams identify new and improved technologies for finding, acquiring, and producing energy. Research prospects' potential to contribute to the Program's objectives is analyzed. Each project is given performance goals, and the project's contribution to achievement of Program goals is analyzed.

#### **Program Decision Process**

The key driver in geothermal research is the potential impact on the cost of energy. The geothermal energy industry must be competitive, and prices will be determined for the foreseeable future by fossil fuel technologies and by public sector policy that influences energy markets. This determines the target prices reflected in the Program's Performance Goals.

The Program uses quantitative risk assessment and management for analysis and valuation of R&D. Quantitative risk assessment does not ensure the outcome of specific projects, tasks, or subprograms, but it provides insight for informed management choices among research options, maximizing the productivity of funds spent on research. It also permits determination of when a project portfolio is likely to fulfill Program goals.

Program management uses these analytical results to determine research priorities and set funding for research pathways according to their projected contribution to achieving goals. Research may be terminated if a technology has been deployed commercially, if goals are not being achieved, or if another pathway shows greater promise.

### 2.4. Performance Measurement

The Program collects a variety of data for tracking progress toward the three performance goals, listed in Section 1.7. In most instances, data on cost of electricity or the amount of viable resource is not available. In these cases, intermediate metrics are used to track progress, and analysis is used to translate these metrics into progress on performance goals.

A set of lower-level performance goals have been established in support of the top-level performance goals. These include:

- Demonstrate the feasibility of creating EGS circulation systems at commercial production rates by 2010.
- Improve the 20% success rate for finding economic resources at previously undrilled sites to 40%.
- Support a new national assessment of geothermal resources by the USGS.
- Develop and implement improvements to drilling processes for geothermal applications to reduce wellfield costs by 25% (relative to costs in 2000) by 2010.
- Develop and implement advanced technology solutions to reduce the risk of lost or unproductive wells by 25-50% by 2010.
- Lower the cost of converting thermal energy into electricity by 40% through increased conversion efficiencies, reduced capital costs, and reduced operating and maintenance costs.
- Develop and implement advanced technology solutions to reduce the risk of lost or unproductive wells by 25-50% by 2010.

Technical milestones have been established to support these goals. The milestones are tied to cost of power or stage gates (see Section 2.6, Logic Model) and are based on quantifiable metrics whenever possible. Current milestones are:

- **Program Assessment Rating Tool (PART) milestones:** Track success of overall program and program elements in achieving short-term goals
- **2006 Joule Milestone (Diagnostics-While-Drilling):** Stage gate for future technology improvements/cost reductions
- **CPS milestones:** Track projects as outlined in MYPP throughout project life cycle
- **AOP milestones:** Annual milestones developed at the agreement level (consistent with CPS)

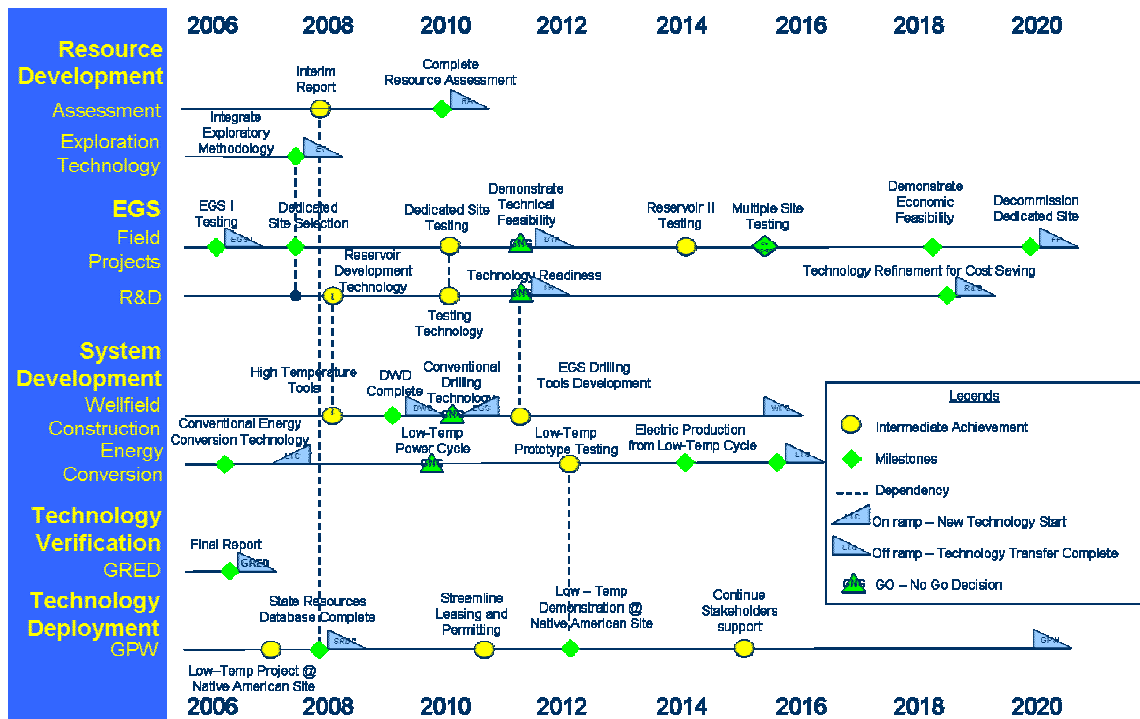
## 2.5. Performance Assessment

The types of reporting and review for performance monitoring and program evaluation include:

- **Results-based performance reporting:** The Geothermal Technologies Program uses the DOE Joule Performance Measurement System and the OMB PART.
- **Peer reviews:** Peer reviews are generally conducted every two years to evaluate new and ongoing projects. Independent experts review the management and status of both individual projects and complete subprograms.
- **General program evaluation studies:** This type of study is needed only infrequently, and covers major subprograms, such as EGS, or the entire Geothermal Technologies Program.
- **Project Merit Reviews:** Merit reviews are conducted prior to commitment of resources to a project. These reviews are typically conducted by the responsible DOE Technology Manager and the senior Principal Investigators at the lead National Laboratories involved in the Program.
- **Stage Gate Reviews:** Stage Gate is a phased project development approach that produces fact-based funding decisions based on a set of defined evaluation criteria. The GTP Stage Gate process builds upon the guidelines for the methodology contained in the *EERE RDD&D Decision Process – Standard Model*. The Program will use following criteria for its Stage Gate process:
  - Provide consistent guidelines for evaluating research
  - Characterize projects in terms of scope, quality, performance, and program integration
  - Evaluate and monitor project progress against technical milestones
  - Assess viability of technology commercialization
  - Guide decisions on project funding (e.g., go/no-go funding decisions)

## 2.6. Logic Model

The Geothermal Technologies Program has developed a Stage Gate approach for its RD&D activities, as shown in Figure 2.4. This timeline-based approach is based on the assumption that implementation and deployment of EGS technology is critical to attainment of the program goals. In the level budget scenario, the increasing requirements of the EGS pathway are offset by decreasing technology support from other subprograms. “Off-ramps” for these subprograms are based on successful completion of these technologies or programmatic changes based on analysis and review. This diagram illustrates milestones, goals, analyses evaluation, and the interrelationships among Program activities.



**Figure 2.4 - Logic Model**

### 2.7. Benefits

Quantitative Program benefits are evaluated annually by EERE’s GPRA Benefits Analysis Team. Recent results are presented in Table 2.1 - FY06 Benefits Estimates for Geothermal Technologies Program (NEMS-GPRA06) and Table 2.2 - FY06 Benefits Estimates for Geothermal Technologies Program (MARKAL-GPRA06). Because these models produce different results due to their differing assumptions and timescales, the estimates intersect, rather than overlap, in the common time frames.

**Table 2.1 - FY06 Benefits Estimates for Geothermal Technologies Program (NEMS-GPRA06)**

Benefits	2011	2015	2020	2025
<u>Energy Displaced:</u>				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.01	0.09	0.16	0.33
Generation (gigawatt-hours/yr)	5	15	20	39
<u>Environmental:</u>				
Carbon Savings (MMTCE/yr)	0	2	4	8
<u>Security:</u>				
Oil Savings (million barrels per day)	ns	0.01	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	0.02	0.04	0.02	ns
Avoided Additions to Central Conventional Power (GW)	ns	1	2	3
Program-Specific Electric Capacity Additions (cumulative GW)	1	2	3	5

**Table 2.2 - FY06 Benefits Estimates for Geothermal Technologies Program (MARKAL-GPRA06)**

<b>Annual Benefits</b>	<b>2020</b>	<b>2030</b>	<b>2040</b>	<b>2050</b>
Energy Displaced: quads/yr	0.23	0.82	1.89	2.36
Econ. Energy-System Cost Savings (billion 2002 dollars/yr)	0.3	1	4	5
Environmental: Carbon Savings (MMTCE/yr)	5	16	38	59
Security: Natural Gas Savings (quadrillion Btu/yr)	0.13	0.43	0.98	0.15
Capacity (gigawatts)	3	11	25	38

Installed capacity is expected to double by 2011 compared to 2006. In the absence of a Geothermal Technologies Program, very modest growth, entirely in conventional hydrothermal systems, is predicted for the years beyond 2011, with about 8700 MWe online in 2050.

Geothermal energy benefits the Nation by helping to solve three national problems – energy reliability and security, economic development, and air quality. Geothermal resources can help address the shortage of new electricity generating capacity in the United States cited in the National Energy Policy. As a baseload generation source, geothermal energy is highly reliable. Geothermal power plants emit little carbon dioxide, very low quantities of sulfur dioxide, and no nitrogen oxides. U.S. geothermal generation annually offsets the emission of 22 million metric tons of carbon dioxide, 200,000 tons of nitrogen oxides, and 110,000 tons of particulate matter from conventional coal-fired plants.

### **2.8. Relationship to Other EERE, DOE, and Federal Programs**

The Geothermal Technologies Program coordinates activities and provides technical consulting services to other agencies and offices. This activity is a formal part of the GeoPowering the West Initiative managed and coordinated by the Program. Many agencies and offices have some stake in the use or management of geothermal resources at the local, state, regional, and federal levels.

**The Department of Interior** – The Bureau of Land Management (BLM) administers leasing of federal lands for geothermal exploration and development. The BLM also has responsibility for collecting royalty payments and disbursing these payments to the federal treasury and to state and local governments. The new Energy Bill of 2005 changes the distribution of these royalty payments, and will require interagency cooperation between DOE and BLM. In another major activity area, the U.S. Geological Survey must develop a new geothermal resource assessment, as required by the new Energy Bill of 2005. The Program has assigned a qualified individual to monitor plans and facilitate cooperation on this crucial resource assessment.

**The Department of Agriculture (DOA)** – DOA has recently initiated the Renewable Energy Systems and Energy Efficiency Improvements Program. The Farm Security and Rural Investment Act of 2002, Section 9006, provides the Secretary of Agriculture with the authority to create a renewable energy and energy efficiency program for rural America. For Fiscal Year 2005, \$22.8 million in grants is available for eligible agricultural producers and rural small businesses to purchase renewable energy systems and make energy improvements. The Program, again through the GeoPowering the West Initiative, is helping interested state energy offices and state farm bureau offices provide guidance and technical assistance to parties applying for these grants.

**The Department of Defense (DoD)** – DoD uses geothermal resources on military bases, for example the Department of the Navy’s Naval Air Weapons Station (NAWS), China Lake, California. About 250 megawatts are generated at the Coso geothermal area adjacent to China Lake for an annual savings to taxpayers of \$4.2 million, or about 33 percent of the total annual

electricity bill. The Program is searching for other opportunities to use geothermal resources at DoD facilities.

**Native American Tribal Activities** – GeoPowering the West provides the locus of responsibility for outreach and technical assistance to tribes in the western United States, where most economic geothermal resources can be found. These activities are coordinated through appropriate state-level agencies for maximal impact. Nevada has provided a model for cooperation and interaction with its tribal constituency. Other states, such as California, Idaho, and New Mexico have also been active with Native Americans and geothermal prospects. The Program coordinates its activities with the DOE Tribal Energy Program.

**Utility Activities** – The Program coordinates its activities with investor owned, rural cooperative, and municipal utilities. The Western Area Power Administration (WAPA) has been a leading contributor, creating the Public Renewables Partnership as a method of outreach to utilities and related service providers. WAPA has aided the Program by creating relationships with key organizations such as the American Public Power Association and the National Rural Electric Cooperative Association.

**The States** – Although most activities are state-related, there are some noteworthy cases of cooperation with state agencies. A 2004 Peer Review of the GeoPowering the West Initiative supported efforts to reach out to and partner with the states, often through their state energy offices. The Program has established seven state working groups, some of which have developed geothermal strategic plans, while others have been active on the policy front, proposing and promoting Renewable Portfolio Standards. In some states, the Program's Geothermal Resource Exploration and Definition (GRED) program is managed in partnership with the appropriate state agency (e.g., the California Energy Commission).

Finally, within DOE, there are opportunities for partnering and cooperation with different offices such as the Offices of Science, Fossil Energy, Nuclear Energy, Science, and Technology, and Civilian Radioactive Waste Management. Cooperative activities have included sharing of subsurface geophysical modeling developments and development of software for nuclear waste management and power plant safety analysis. Within EERE, the Program partners with the Federal Energy Management Program and the Building Technologies Program as a technical consultant for use of geothermal heat pumps.

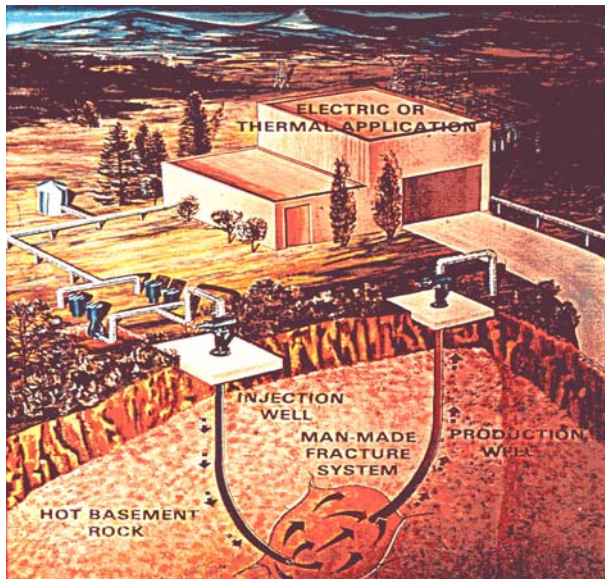
### 3. Technical Plan

#### 3.1. Technology Development

##### 3.1.1. Enhanced Geothermal Systems

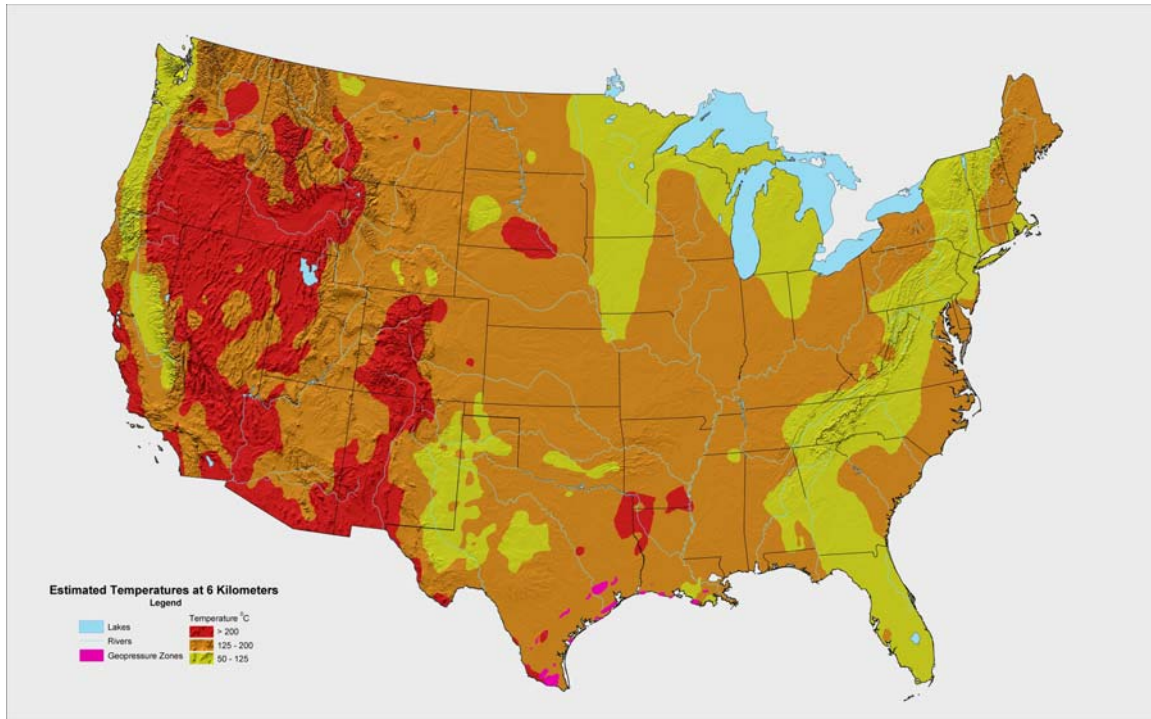
Development of technology for commercial energy production from Enhanced Geothermal Systems (EGS) is a top priority. This technical plan presents a research program that plans to demonstrate by 2011 the feasibility of creating EGS reservoirs capable of producing hot fluids at the high rates needed for commercial development. This feasibility demonstration will eventually lead to tens of thousands of megawatts of EGS electrical generation capacity. A more aggressive research program with an increased budget would significantly shorten development schedules and total costs.

The EGS concept is to extract heat by creating a subsurface fracture system to which water can be added through injection wells. The water is heated by contact with the rock and returns to the surface through production wells (Figure 3.1), as in naturally-occurring hydrothermal systems.



**Figure 3.1 - EGS Conceptual Drawing**

Since temperature increases with depth, hot rock can always be reached by drilling. Figure 3.2 shows estimated temperatures at a subsurface depth of 6 km. At this depth, which is commonly reached by oil and gas wells, temperatures exceed 150 °C under most of the United States, and temperatures above 250 °C occur throughout the West. These temperatures are sufficient for generation of electrical power and direct use. The practical drilling depth limit is currently about 10 km. A preliminary characterization of the EGS resource base to a depth of 10 km indicates that EGS could meet a significant fraction of U.S. electric power demand. If projected technological improvements are ultimately realized, more than 100,000 MWe of economically viable capacity may be available in the continental United States.



**Figure 3.2 - Temperature Profile at 6 km**

Creating an enhanced, or engineered, geothermal system requires improving the natural permeability of rock. Rocks are permeable due to minute fractures and pore spaces between mineral grains. Rock permeability extends over several orders of magnitude, from water wells and hydrothermal systems that readily produce fluid, to tight gas sands and HDR that produce almost nothing. The vast majority of the heat resource is contained in rocks of low natural permeability. The object of the EGS program is recovery of heat from such rocks in commercial quantities at competitive costs.

Field studies are seeking to extend operating hydrothermal fields into adjacent rocks. The plan is to extend this work into progressively less permeable rocks at increasing distances from known hydrothermal systems to increase the economically usable portion of the EGS resource base. Ultimately, this will allow EGS energy to be used across the United States, and in areas which now have no geothermal development.

Although components of EGS technology have been developed and demonstrated in the United States, Europe and Japan, further work is needed to establish commercial viability for electrical power generation.

### 3.1.1.1. Technical Goals and Objectives

Demonstrating the feasibility of commercial EGS energy production will require (1) locating resources that are ideal for near-term research and development, and (2) developing technology for creating and managing enhanced reservoirs. Initially, the program will focus on high-grade resources where temperatures of 200 to 250 °C can be found at depths of 3 to 4 km. Beyond 2011, technology will be needed for both higher-temperature (> 250 °C) and lower-temperature (125 to 200°C) resources, and for progressively deeper (4 to 10 km) resources.

## Goals

Long-term goals include:

- *Decrease the levelized cost of electricity from EGS to less than 5 cents per kWh.*
- *Increase the economically viable geothermal resource to 40,000 megawatts.*

The Program projects that at least 30,000 MWe of EGS generation will be on line by 2040. About 10,000 MWe of economically viable hydrothermal resources are also available. Together, EGS and hydrothermal generation have the potential to reach 40,000 MWe by 2040, with additional resources totaling 100,000 MWe or more. The projected development profile for EGS resources in the United States for the years 2006, 2011, and 2040 is given in Table 3.1.

**Table 3.1 - Projected EGS Development Profile**

<b>Target</b>	<b>Units</b>	<b>2006</b>	<b>2011</b>	<b>2040</b>
Accessible EGS Resource	MWe	1,500	5,000	100,000
EGS Generation	MWe	0	0	30,000
Cost (levelized, in 2004 dollars)	Cents/kW-hr	28	9-13	<5

The EGS program has set a near-term goal to *demonstrate the technical feasibility of creating circulation systems which produce at commercial flow rates.*

Achieving this goal is planned by 2011. Once technical feasibility has been demonstrated, research will focus on increasing the rate of fluid production per well, and on reducing the costs and risks of EGS projects to make more of the resource commercially viable. This plan will be updated and extended beyond the current planning horizon to cover additional activities as critical-path targets are achieved.

## Objectives

The near-term technical objectives are to:

- Increase net thermal power extracted per production well, and
- Increase reservoir lifetime.

Net thermal power extracted is the average heat recovery rate at the surface per production well over the lifetime of the reservoir, after deducting parasitic loads such as pumping power. Reservoir lifetime is the length of time the reservoir can be operated before temperature drawdown exceeds 10°C, which is the limit that today's geothermal power plants can tolerate. Future improvements in power plant design and efficiency will increase the acceptable range for temperature drawdown.

Since net thermal power production and reservoir lifetime determine the desired performance of a commercial EGS, progress in research and field demonstration will be evaluated by these metrics as shown in Table 3.2.

**Table 3.2 - EGS Near-Term Reservoir Performance Targets**

<b>Performance Measure</b>	<b>Current*</b>	<b>2011 Target**</b>
Net Thermal Power Extracted, MWt/well	10	35
Reservoir Lifetime, years	approximately 1	7

\*Based on the state of the art in 2002. \*\*Based on values for commercial hydrothermal systems.

The 2011 performance targets are based on EGS systems achieving the operating parameters of commercial hydrothermal reservoirs. A good hydrothermal well yields about 35 MWt, which can be used to generate about 5 MWe at an energy conversion efficiency of 14%. An individual hydrothermal well must produce for seven years or more to permit recovery of the capital investment. Hydrothermal reservoirs have operated for half a century or more (Larderello in Italy has operated since 1903), and power plants are designed to operate for at least 20 years. The 2011 targets are technically aggressive, but the economics of the operation demand this level of production.

### **Technical Assessment Process**

A formal technical assessment process will be used to ensure that all program activities are on the critical path for achieving the goals and objectives. The process is an ongoing activity involving:

- Identification of TIPs. Potential cost reductions and performance enhancements are discussed in Section 3.1.1.6. The list of TIPs will be updated at least biannually.
- Research Activity Assessment. Individual research activities will be assessed annually to ensure that the latest results are factored into portfolio planning.
- Detailed Portfolio Planning. The project portfolio will be assessed annually, taking account of the latest program results and pertinent results from other research worldwide, including projects being carried out in other countries; geoscientific and engineering research funded by other Federal programs; and research carried out by the petroleum and mining industries, among other sources.
- Performance Assessment and Feedback. Progress will be assessed by peer review, which will provide feedback to DOE management and researchers. Performance analyses will be used to estimate annual benefits under the Government Performance and Results Act (GPRA).

#### **3.1.1.2. Technical Approach**

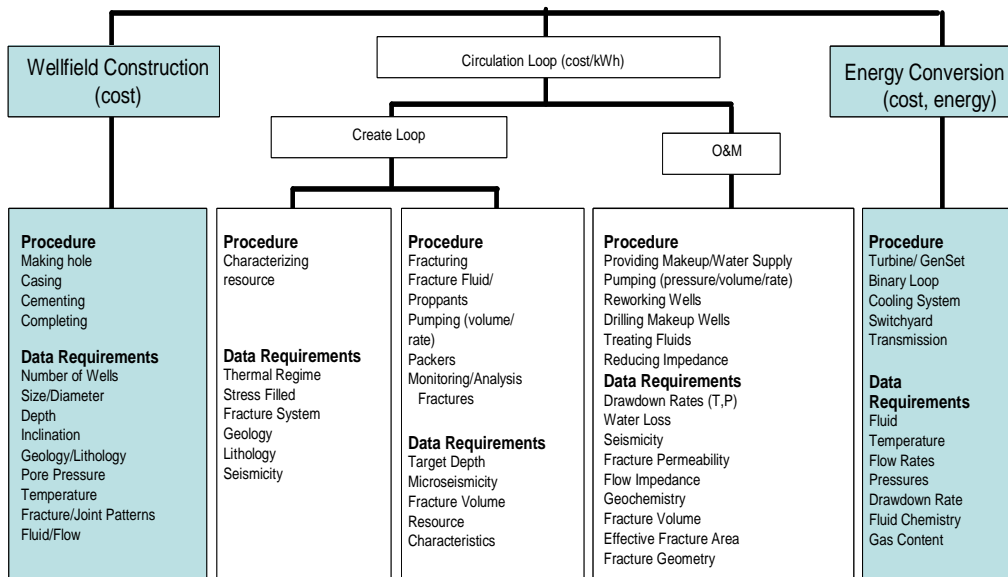
Research and technology demonstration will be carried out through modeling, and through laboratory-scale and field projects. Geothermal expertise at national laboratories, universities, and private companies will be essential to program success. The Program will identify and support supplementary capabilities as needed.

Figure 3.3 shows major cost components and activities in developing an EGS resource. The near-term focus will be on items listed under “Circulation Loop”. Elements listed under Wellfield Construction and Energy Conversion are covered in Sections 3.1.3.1 and 3.1.3.2. Exploration and site acquisition activities are not shown in Figure 3.3 for brevity, but are expected to be important cost elements.

The 2011 goal is to demonstrate the technical feasibility of creating EGS reservoirs that will produce geothermal fluids at commercial flow rates. Measurements needed to verify progress toward achievement of this goal are listed as “Data Requirements” in the table.

## EGS Economic Analysis

Goal < 5 cents/kWh



**Figure 3.3 - Major EGS Technical Components**

Although previous work has been partially analyzed and reported, no in-depth comparative analysis of EGS sites or technology options is available. An analysis will be undertaken to help guide the program.

The Program will leverage results from research in related fields (e.g. drilling, reservoir stimulation, and enhanced oil recovery in the petroleum industry; drilling and rock fracturing in the mining and construction industries), and pursue working ties and collaboration with these industries. The EGS program will also work with and incorporate results from other government-funded programs.

### 3.1.1.2.1. Field Projects

Field testing of technologies and equipment is essential. Individual components of a commercial-scale installation must be tested separately before a system demonstration. Options for field sites include: (1) continuing to work at operating hydrothermal fields, (2) undertaking cost-shared projects with the private sector at sites separate from operating hydrothermal fields, (3) supporting projects in other countries, and (4) establishing a dedicated DOE-operated and funded field site. These options are not mutually exclusive. The first three options would allow the program to gather information in a variety of geothermal environments and leverage its investment. The last option will be used to maintain the control over the field environment and tests required for demonstration of some technologies. (For example, the EGS program cannot test technology for short-circuit mitigation in an operating hydrothermal system because of the risk of disrupting the power plant fluid supply.) Although DOE operation of a dedicated site is currently prohibitively expensive, a site could be developed with additional funding.

### 3.1.1.2.2. Collaboration with Other EGS Research Projects

EGS experiments are underway in France, Switzerland, and Australia. These projects are designed to produce both electrical power and heat. The Geothermal Technologies Program participates in an International Energy Agency (IEA) annex for EGS research that fosters

cooperation among these programs. The Program will support and participate in these activities as appropriate, and incorporate their results into research activities. Program activities will be regularly reviewed to prevent duplication of effort and to leverage the results of other projects.

### **3.1.1.2.3. Collaboration with the Private Sector**

Collaboration with the private sector enhances technology transfer, leverages program funds, and will foster commercial EGS development. The geothermal industry has limited financial and technical capacity for EGS development. In order to assure the level of private sector participation required for achievement of Program goals, the Program must stimulate the interest of large companies that have sufficient capital and expertise to manage the relatively high level of risk. The oil and gas industry is an obvious potential partner. Many aspects of petroleum drilling and production technology are applicable to EGS development, and several major petroleum companies are moving into renewable energy. The Program is working to develop strong working relationships with petroleum sector companies. The mining and construction industries will be contacted to determine their interest in participating in R&D.

### **3.1.1.3. Program Status**

#### **3.1.1.3.1. Past Research**

The EGS research program builds on results from previous geothermal studies, including work on HDR technology performed by Los Alamos National Laboratory between 1970 and 1995, results from past and ongoing DOE-funded EGS and hydrothermal research projects, and other EGS research throughout the world. The results of these programs provide a basis for the EGS program, and many of the original research personnel are still available.

#### **Fenton Hill, New Mexico**

The first attempt to develop a geothermal system in hot, impermeable rocks distant from hydrothermal systems was the HDR program, conducted for DOE by the Los Alamos National Laboratory at the Fenton Hill site in New Mexico. During the 1980s, the Federal Republic of Germany and the Government of Japan supported the U.S. effort at Fenton Hill through collaborative agreements under the auspices of the International Energy Agency (IEA).

Phase I, from about 1974 to 1980, involved field development and research on a 3-km deep reservoir created by hydraulic fracturing of granite at about 200 °C. Phase II created a second reservoir in deeper (4 km) and hotter (325 °C) rocks below the Phase I area. The very low permeability of the rocks required massive hydraulic stimulation, and the geologic stress regime required high injection pressures to keep the fractures open.

The Fenton Hill project proved that fracture systems and fluid circulation could be initiated and maintained in hard rock at depth. While the project made important contributions in developing methods to drill, stimulate, and characterize the structure and performance of HDR reservoirs, and created a valuable database, it failed to demonstrate production at commercial rates. The project was terminated in 1995 when an expert group determined that further work would not provide value commensurate with the cost.

#### **Hijiori and Ogachi, Japan**

After participating in the Fenton Hill project, the Japanese began research at several field sites. At Hijiori, high-temperature rocks with pre-existing fractures were hydraulically stimulated. While fracture growth could be partly controlled by pumping production wells while stimulating the injection well, the formation of preferential flow paths (short circuits) during long-term tests shortened reservoir life. At Ogachi, the Central Research Institute of the Electric Power Industry (CRIEPI) created two vertically separated HDR reservoirs by hydraulic fracturing at 720 m and

1,000 m. The deeper and shallower reservoirs were estimated to have long axes of 1,000 m and 800 m, respectively. Water circulation tests were conducted from 1993 to 1997. Water at 15 °C was injected and recovered as hot water with steam at 165 °C. Despite short circuiting and fluid loss, these experiments were encouraging for future development.

Although the Japanese program was terminated in 1999 due to budgetary constraints, the Japanese government and private companies maintain interest in HDR and EGS technologies, and have sponsored several high-level international symposia on these topics.

### **Rosemanowes, England**

The British developed a site at Rosemanowes in Cornwall that operated through 1993. Since the site had no high-temperature rocks, it was not a potential electricity producer. The low rock temperatures were considered an advantage since research on hydraulic fracturing could be carried out without the expense of special instruments and equipment needed at high-temperature sites. Pre-existing fractures opened during stimulation, creating a large fractured volume, but short circuits formed between injection and production wells. This experiment demonstrated the importance of determining the patterns and characteristics of existing fractures prior to stimulation.

#### **3.1.1.3.2. Current EGS Activities**

DOE is sponsoring EGS studies at several sites within or near operating hydrothermal systems in the United States, and EGS research is occurring in France, Switzerland and Australia.

### **Coso, California**

The Coso project in southern California is a collaborative effort with the University of Utah and Coso Operating Company at the well-known Coso geothermal area. The thermal anomaly covers about 200 square miles, with the hydrothermal system, which generates 236 MWe, situated in the northwest portion of the anomaly. The area of EGS interest, characterized by low permeability and high temperatures (250 °C), is on the margin of the hydrothermal system. Low-permeability wells originally drilled for injection are being tested to determine whether thermal, chemical and hydraulic stimulation can create a viable fracture system. A DOE-funded research team performed thorough geoscientific studies to characterize the area and assess the site's potential for stimulation. In 2005, an injector was selected for deepening, but an unexpected natural fracture system was encountered at the bottom of the well, precluding its use. Another injector will be tested in 2006.

### **Desert Peak, Nevada**

The Desert Peak hydrothermal field operated by Ormat Geothermal in north-central Nevada generates 50 MWe. Ormat has drilled a new well near the existing power plant, but outside the area of hydrothermal production. Geological, geophysical and geochemical characterization of the well and its environs has been carried out to assess its potential for hydraulic stimulation. The well seems ideal for an EGS experiment. Plans call for hydraulic fracturing in 2006, and drilling of another well to attempt to complete a circulation loop.

### **Soultz-sous-Forêts, France**

The Soultz project is a collaboration between the European Union and the governments of France, Germany and Italy. The project began in 1987. The project is in an area of extensional tectonic stress that was well characterized geologically because crude oil had been produced from the field. 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. This flow rate was achieved at low injection pressure – the fractures remained open naturally due to a favorable tectonic stress regime. 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 km<sup>3</sup> reservoir with low impedance. Two additional wells have been drilled and stimulated to create a circulation loop with one injector and two producers. A successful 120-day flow test showed no reduction in temperature of the produced water at the end of the test. The next phase of development, to be carried out from 2005 to 2008, is designed to achieve 100 l/s production rates to drive a 1.6 MWe power plant. If this is successful, an expansion to 6 MWe is planned. The results of this project and the database generated are valuable for Program research.

### **Basel and Geneva, Switzerland**

The Deep Heat Mining (DHM) project in Switzerland is intended to establish 'HDR-type cogeneration plants' at sites in Basel and Geneva within the next ten years. At the Basel site, a 2.7 km exploration well is being equipped with seismic instrumentation to monitor planned hydraulic fracturing. Plans call for development of a reservoir at 5,000 m capable of producing 3 MWe and 20 MWt for a local heating system. At the Geneva site, detailed investigations are being conducted to position the first exploratory well, which will be drilled within the city limits.

### **Cooper Basin, Australia**

Australia is believed to have sufficient EGS resources to generate electricity many times its national demand. The Australian government has funded EGS research at several universities and at its own research institute, the CSIRO. Geodynamics Geothermal, a private sector developer, is undertaking a large-scale EGS project at Cooper Basin, an area believed to contain a significant portion of the Australian EGS resource. Their goal is to become the largest renewable energy producer in Australia by developing EGS resources. The thermal energy at less than 5 km in the area covered by two Geodynamics Geothermal licenses is estimated to be equivalent to 50 billion barrels of oil. Rock temperatures of 250 °C have been confirmed at 4,400 m depth. A thermally insulating blanket of sedimentary rocks overlies granitic rocks containing natural radioactive isotopes, which are decaying and heating the granites. Horizontal fractures from hydraulic stimulation have created a horizontally-oriented underground heat exchanger due to the local tectonic stress regime. This fractured area is more than nine times larger than projected. Overpressure in some wells may indicate a natural geothermal field capable of flowing under its own pressure. The developers plan to a 10 to 15 MWe feasibility demonstration, which will be expanded to commercial plants of 100 MWe or more.

### **Current DOE-Funded Laboratory Studies**

In addition to field projects, DOE is funding EGS research at several federal laboratories and universities. This research includes the following technology components: reservoir characterization and exploration, reservoir design and development, and reservoir operation and management.

#### **3.1.1.4. Technical Challenges and Barriers**

Resource characterization and exploration, reservoir design and development, and reservoir operation and management present major technical obstacles (Figure 3.3). A feasibility demonstration will require development of new technologies in these areas. Research on hydrothermal resources has developed relevant tools and technology, but EGS development has unique problems and challenges.

Reaching the 2011 goal will require preliminary economic evaluation. It may be technically feasible to create EGS reservoirs in many locations, but the economics of power production are highly site-dependent. GETEM, a simple cost-of-power model, does not yet permit detailed

analyses of development options. The model will be extended to model EGS reservoirs, and specific sites and technologies.

#### **3.1.1.4.1. Resource Characterization and Exploration**

Geological characteristics to depths of 5 km to 10 km are known on a regional basis from geological, geochemical, and geophysical studies, and from drilling by government and private entities. The U.S. Geological Survey, state geological surveys, and universities have produced regional and local geologic maps of rock types and geologic structure that provide a first-order method of assessing EGS resources by identifying areas of recent (< 1 million years old) magmatic intrusion and volcanic activity, deep sedimentary basins, granites that may have high heat production from natural radioactive elements, and other features of interest. Maps showing faulting, folding, and fracturing can help assess the stress state at the time structures formed, the present stress state, and the probability of the existence of permeable rocks at depth. Measurements of thermal gradient and heat flow provide regional knowledge of thermal conditions to similar depths. Although an overall assessment of the geothermal resource can be derived from these data, data at the local scale crucial to EGS development is limited.

The best EGS targets have high temperatures (> 200°C) at shallow depth (< 3 km) and a tectonic stress regime that keeps fractures open. Current technology cannot identify such sites without drilling. New and improved geological, geochemical, and geophysical techniques are needed to find shallow hot rock where there are no surface manifestations, and to predict crustal stress states prior to drilling.

#### **Geothermal Gradient and Heat Flow**

Borehole logging of temperature gradients in wells and thermal conductivity provides data on heat flow, which can be combined with geology to predict temperature at depth. Heat-flow measurements in areas where geologic data shows EGS potential are a high priority. For example, inexpensive gravity surveys can be used to find granitic bodies under Atlantic coastal plain sedimentary rocks, and subsequent shallow drilling to measure thermal gradient and heat flow can identify anomalously high heat flow from rocks heated by radioactivity, pinpointing areas for deeper drilling.

#### **Geologic Structure, Lithology and Tectonics**

The stress regime is an important factor in development of an EGS reservoir. Generalized stress-regime maps are needed to assess the resource base because rocks stressed by regional tectonics to form fractures that remain open are technically easier to develop systems in. Maps of large-scale tectonic stresses will be extended to priority areas identified by heat-flow information or presence of young igneous rocks. While stress determination currently requires a wellbore into the target area, it may be possible to combine geophysical or remote sensing techniques with surface geologic information to reliably predict stress state at depth, significantly reducing exploration and resource assessment costs.

#### **Induced Seismicity Potential**

Seismic events occur in geologically active areas worldwide, with frequency decreasing exponentially with increase in magnitude. Natural microearthquakes (microseisms) occur in hydrothermal reservoirs. Microseisms may be triggered whenever fluids are injected or produced. No seismic damage has ever been associated with geothermal development. Proper control of injection and production should prevent noticeable seismic activity, although developing control methods is a challenge. As a precaution, microearthquake risk will be included in resource assessments.

#### **3.1.1.4.2. Reservoir Design and Development**

Creating and mapping a reservoir is a major challenge. An appropriate zone must be identified and isolated for fracturing. Water is injected to create and propagate fractures, a process referred to as “hydraulic fracturing”, “hydrofracing” or “stimulation.” Fracturing progress is monitored by passive seismic and electrical geophysical techniques, and by pressure and pumping-rate measurements. After the desired volume has been fractured, circulation is tested between the injection well and a production well drilled into the fracture system. If there is adequate circulation, the loop would then undergo production testing.

##### **Fracture Mapping and In Situ Stress Determination**

The rock structure geometry must be known for modeling and designing a stimulation operation. Fractures can be mapped using geophysical well logs, but interpretation of logs to identify permeable and impermeable features is unreliable. Areas of research include improved high temperature logging tools, improved automated analysis and interpretation methods, and development of imaging methods that can better differentiate between permeable and impermeable fractures.

The in-situ stress state in the target area is critical in designing stimulation programs and predicting results. Tests used to determine stress states during and after drilling, such as detailed borehole geometry (breakout analysis) and mini-frac break-down, are slow and costly, and must be improved. Seismicity measurements while drilling, downhole strain metering, and other technologies will be improved to map the stress field in three dimensions.

##### **Isolating Stimulation Zones**

Target zones for fracturing are isolated by setting casing above the zone to be stimulated and then fracturing the section below. Pre-existing fractures are often preferentially enhanced, sometimes resulting in short circuits that prevent stimulation of less permeable zones. Borehole packers cannot be used to isolate zones in rocks above 175 °C. Research will be performed in setting and removing of packers, and alternative methods will be developed for isolating the treatment zone in high-temperature open holes.

##### **Reservoir Stimulation Design**

Because predictive modeling of stimulation results depends on assumptions about rock properties, the in-situ stress field, and fluid-flow properties which are largely unknown, modeling of the process and different stimulation options is unreliable. Capable, robust 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 system.

##### **Reservoir Stimulation**

The most important challenges in reservoir stimulation are (1) creating new, pervasive permeability rather than enlarging a few existing fractures, (2) avoiding short circuits and repairing them if they develop, (3) measuring the fractured rock volume and water-accessible fracture area, and (4) maintaining open fractures in unfavorable stress regimes.

Hydrofracturing technology developed by the petroleum industry has limited applicability to hard rock. Alternate technologies such as high-pressure gas fracturing, possibly using controlled-burn explosives, must be tested, and hydraulic fracturing techniques improved to provide fracturing methods for varying geological environments. Although large fractured volumes (several km<sup>3</sup>) have been created in experiments, circulating fluid through the full volume has proven difficult. Determining the location and geometry of the fractured volume during stimulation is also

problematic despite significant research. Microseismic monitoring is the best available technique, but the relationship between the microearthquake cloud and the fractures is not understood. New and improved real-time methods are needed to monitor fracturing progress and to indicate when and how to modify the stimulation program.

### **Fracture Propping**

Methods are needed to keep fractures open in unfavorably stressed regimes. Proppants used by the oil and gas industry to keep fractures open have not yet been successfully used in a geothermal setting. The temperature, stresses and high-volume circulation in many potential EGS reservoirs would destroy the most widely used proppants. Research is needed on high-strength propping agents such as advanced ceramics and coatings, or compositions that will reduce the risk of proppants dissolving rapidly.

#### **3.1.1.4.3. Reservoir Operation and Management**

Once a circulation loop has been created, the reservoir operation and management phase begins. Technology for operation and management of hydrothermal reservoirs can be extended into EGS. Standard reservoir engineering techniques must be modified to account for differences between EGS and hydrothermal reservoirs. New technologies for control of fluid flow between injection and production wells are required to mitigate short circuiting and fluid loss. Methods must be developed to keep pathways open and extend them. Technology must be developed to measure rock surface area, volume in contact with circulating fluids, and other parameters used in predictive models of reservoir performance and lifetime. Reservoir monitoring sensors and tools are also needed.

Heat production rate, thermal drawdown rate (i.e., reduction in temperature at a given flow rate), and expected reservoir lifetime, which can change as the reservoir develops, are important performance measures that depend on the reservoir volume, initial rock temperature, and reservoir surface area in contact with circulating fluids. Reactive chemical tracers can be developed to determine reservoir volume, effective fracture area, and thermal performance. Surface and down-hole geophysical, seismic, electrical, geochemical, and other techniques must be adapted for reservoir monitoring.

### **Reservoir Performance Monitoring**

Reservoir engineering methods and models must be adapted to the EGS environment, where permeability distributions are expected to be different from those in hydrothermal or petroleum reservoirs. Further improvement in modeling of fractured reservoirs is needed to ensure adequate monitoring and control. New pathways sometimes develop through mineral dissolution or through pressure and temperature effects, or close due to mineral precipitation. These effects must be incorporated in predictive models to evaluate changing reservoir properties. Tools for logging and recording pressures and temperatures during testing are needed for long-term, high-temperature deployment.

### **Hydraulic Management**

Controlling the pressure regime can be used to control reservoir fluid movement. Artificial lift (pumping) in production wells increases the pressure drop across the system without increasing injection pressures, which 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.

Reliable high-volume, high-temperature pumps are needed that can operate at temperatures above 200 °C. The depth limit for lineshaft pumps is about 2,000 feet, and such pumps are unreliable at high temperatures. High-volume electric submersible pumps can be set at almost any depth, but

they are designed to operate at less than 200°C. Because of low demand, there is little economic incentive for industry to increase the operating temperature range.

### **Short Circuit Mitigation**

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.

### **Fluid Loss Control**

Water loss has caused problems in some projects when large volumes of water were injected. In the western United States, water cost and availability can be a roadblock to development. Water loss can be controlled in large-scale systems by proper injection- and production-well siting and pressure-regime control. Water-loss management problems that must be solved are reliable predictive modeling, artificial lift in production wells, high-temperature fluid rheology control, and evaluation of alternative reservoir fluids.

### **Reservoir Properties Determination**

Chemical tracers, natural-fluid tracers, microseismic monitoring, active seismic surveys, and advanced forms of electrical geophysical methods have potential for determining heat exchange area and the useful volume of fractured rock, and for targeting new production and injection wells. Although downhole tools can measure temperature, pressure, flow and natural-gamma emissions on a short-term basis, these instruments cannot be used for long-term monitoring because of temperature limitations. Microearthquake monitoring tools are limited to 120 °C. Downhole tools must be developed to withstand temperatures above 200 °C for extended periods.

### **Fluid Chemistry and Permeability Control**

The economics of EGS depend on reservoir stimulation and operation techniques to provide a large heat-exchange area and allow high flow volume. Well productivity/injectivity (flow rate per unit pressure drop) and heat extraction must be balanced against each other. Closer fracture spacing may yield higher transmissivity and greater heat exchange area, but closely spaced fractures may be difficult to create and to prevent from forming short circuits. Reduction of skin effects or near-wellbore flow blockage could improve well productivity. Better targeting of production wells with optimal fracture spacing is another area for research.

Rock/water interactions 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.

#### **3.1.1.5. Barriers to EGS Commercialization**

The primary barrier to use of EGS resources is challenges to creating convective flowpaths in the geothermal reservoir rock. The current high costs of drilling and energy conversion further impede EGS commercialization. Research in these areas is described in Section 3.1.3, Systems Development.

The technical barriers to widespread EGS use are:

**A – Inadequate Stimulation (EGS Reservoir-Creation) Technology.** Research has demonstrated that reservoirs can be created, but the control required to create large volumes of fractured rock, free of short circuits, has not been achieved. Key requirements include improved

fracturing technology, rheologically controllable fracturing fluids, and high-temperature borehole packers for isolating fracture zones. Reliable numerical models and data are needed for planning and executing stimulation programs, and instruments and techniques are required for monitoring stimulation progress in real time.

**B – Inadequate Reservoir Management and Operation Technology.** Reservoir operation and management requires detailed knowledge of the geologic 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. Chemical tracer technology must be improved to determine reservoir volume and heat-exchanger surface area, and to detect thermal drawdown before it affects production wells. 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. Downhole pumps must be able to operate reliably at temperatures above 200 °C.

**C – Inadequate Resource Characterization and Exploration Technology.** Developers need a good estimate of the location, magnitude, and extent of the resource before they will risk an EGS project. Site selection requires mapping of stress fields, lithology, depth of overburden, and fracture patterns, among other parameters. Reliable heat-flow and geothermal-gradient data are mandatory. Data are available for some areas of the United States, but there are large areas with little access, or with vegetation cover, where data are sparse. New and improved technologies must be used to improve the exploration and resource characterization database and facilitate private-sector development.

**D – Inadequate Access to Field Research, Testing and Demonstration Sites.** The risk and cost of EGS deployment must be demonstrated through field testing of equipment and techniques. At present, the best option for field access is collaboration with geothermal operators, who are reluctant to allow testing in costly wells unless a clear benefit is available. A dedicated, DOE-operated field site would mitigate these problems, but at a high cost.

**E – Lack of a Viable EGS Industry Infrastructure.** Because of the limited profitability of the hydrothermal industry and the high risks and costs associated with EGS development, there is no EGS industry today. However, many components of an industry exist, and industry growth can be stimulated. Major energy companies with the capacity for large-scale EGS technology deployment appear to be the best potential partners.

**F – Loss of Technically Experienced Personnel.** Growth in the geothermal industry has leveled off, due to market pressure from conventional fuels. Since few new geothermal plants are being planned or built, valuable human resources are moving to areas with similar technical challenges such as oil and gas, mining, and waste management. New people rarely enter an industry that is not growing. Since government research funding has been level, universities not already involved have little incentive to participate in research. As geothermal veterans retire, expertise in the geothermal disciplines is declining.

#### **3.1.1.6. Technology Improvement Potentials**

Based on the challenges presented in Section 3.1.1.4 and the barriers to widespread EGS deployment identified in Section 3.1.1.5, TIPs that apply to both the short-term and long-term goals have been identified. Improvement is shown as a fraction of the total possible improvement for two primary metrics: flow per production well, and reservoir life. Two other metrics, exploration success and power-on-line, are indirectly affected by TIPs included in the EGS program. Improvement in temperature with depth accuracy is the only cross-program effect included in the EGS TIPs table.

The goal of the EGS research program is to improve the flow per production well by 29% and the reservoir life by 25% by 2011. By 2016, the total technology improvement over the base case for flow per production well is 33%. For reservoir life, a total of 100% improvement over the base case is planned.

**Table 3.3 - TIPs for EGS**

<b>Table 3.4 Technology Improvement Potentials (TIPs) for EGS</b>				
<b>Technology Improvement Potential</b>	<b>Metrics</b>	<b>2006</b>	<b>2011</b>	<b>2016</b>
<b>Resource Characterization and Exploration</b>				
Increase accuracy of target temperature prediction. Gradient and heat flow data over entire United States at data density needed for firm conclusions of EGS potential.	Exploration success rate in % (Success at achieving target temperature at target depth)	60% success rate 100 MW per discovery	40% inc. in success 400% inc. in MW  1.1% total cost improvement	47% inc. in success 500% inc. in MW  1.1% total cost improvement
<b>Reservoir Design and Development</b>				
Improved fracture methods, proppants and rheology for EGS reservoirs	Flow per production well in kg/s	332 l/s	13% inc. in flow per well  6.8% total cost improvement	23% inc. in flow per well  10.3% total cost improvement
Control of fracturing in EGS reservoirs New and improved borehole packers, especially open-hole packers, for isolation of stimulation zones	Flow per production well	332 l/s	5% inc. in flow per well  3.6% total cost improvement	15% inc. in flow per well  8.1% total cost improvement
Develop numerical models that accurately predict fracture growth and permeability development as a function of stimulation options and reservoir properties	Reservoir life in yrs	6 yrs	5% inc. in life of reservoir  0.8% total cost improvement	20% inc. in life of reservoir  3.2% total cost improvement
Ability to create a subsurface circulation system as designed and to control fracture growth and patterns for optimum fluid contact area and volume	Reservoir life in yrs	6 yrs	10% inc. in life of reservoir  1.5% total cost improvement	35% inc. in life of reservoir  4.6% total cost improvement
<b>Reservoir Operation and Management</b>				
Numerical models that explain reservoir performance and reliably extend predictions of performance into the future	Reservoir life in yrs	6 yrs	6% inc. in life of reservoir  1.0% total cost improvement	10% inc. in life of reservoir  0.8% total cost improvement
Artificial lift technology - Artificial lift equipment and methods with flexible setting depths which can produce 200°C fluid at target flow rate of 54 kg/s for at least 1 year	Flow per well l/s Cost of Pumps \$\$	332 l/s	10% inc. in flow per well 10% lower cost for pumps  6.8% total cost improvement	15% inc. in flow per well  8.4% total cost improvement
Improved short circuit mitigation methods - Successful short-circuit control for temperatures up to 200°C	Reservoir life yrs	6 yrs	10% inc. in life of reservoir  1.5% total cost improvement	30% inc. in life of reservoir  4.0% total cost improvement

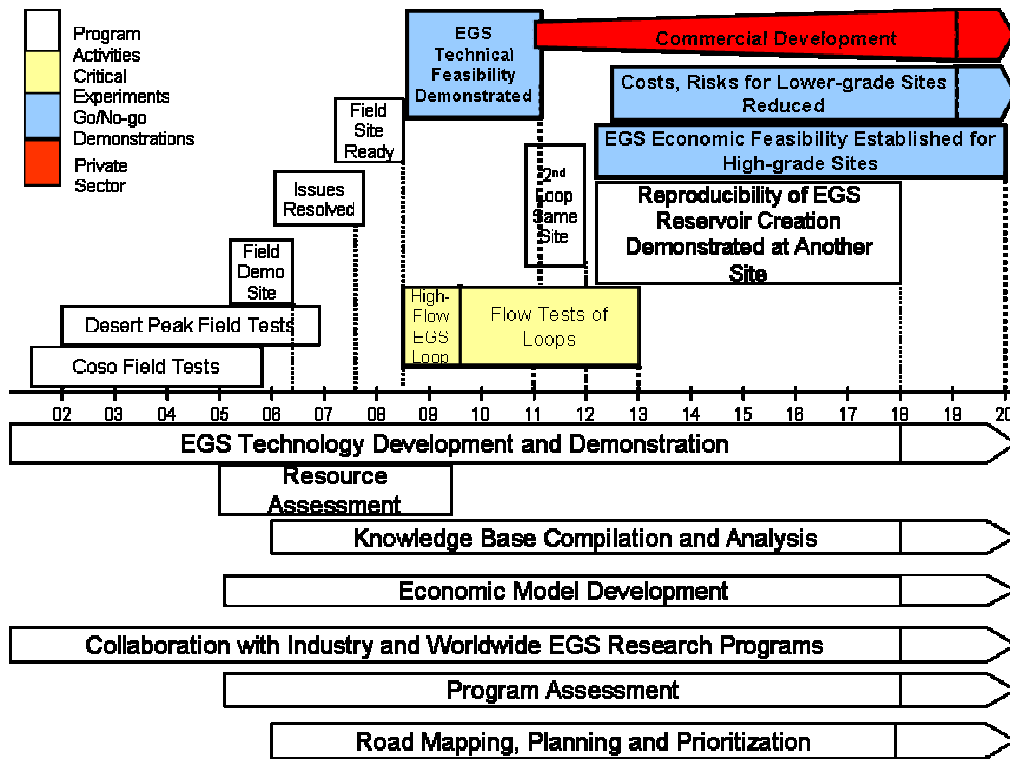
Table 3.4 Technology Improvement Potentials (TIPs) for EGS				
Technology Improvement Potential	Metrics	2006	2011	2016
<b>Systems Analysis</b>				
Assemble, analyze and interpret pertinent information on technologies relevant to EGS development from worldwide EGS research, petroleum reservoir development, mining operations, and other appropriate sources.	Flow per well l/s Reservoir life yrs	332 l/s 6 yrs	4% inc. in flow per well 3.3% lower cost for pumps  2% total cost improvement	5% inc. in flow per well   3.4% total cost improvement
Robust economic models to help guide EGS research and development	Updated models	GETEM model	EGS Prototype	EGS Advanced
<b>Technology Transfer</b>				
Collaborative relationships with industries large enough to move EGS development forward at desired rates to reach the 2040 goals. Involve at least one major energy company in the EGS program by 2009	Power on line MWe	0 MWe	0 MWe	60 MWe  0.9% total cost improvement

### 3.1.1.7. Technical Feasibility Task Plan

The technical tasks described for the proposed FY 2006 to 2011 EGS research program are designed to meet the 2011 objectives presented in Section 3.1.1.1, and to address challenges discussed in Section 3.1.1.4 and selected TIPs discussed in Section 3.1.1.6. The tasks are expanded on in Figure 3.6.

Figure 3.4 illustrates program elements and critical milestones. Above the timeline are field tasks leading to creation of a high-flow EGS circulation loop, with subsequent flow-testing to demonstrate production characteristics. If this succeeds, the technical feasibility of creating high-flow EGS reservoirs will be demonstrated and the 2011 goal will be met. The field effort then moves to creating a second reservoir and circulation loop at the same site, demonstrating reproducibility at a second site with different geology, and demonstrating economic feasibility at high-grade sites, all to be accomplished by 2016. Demonstrating economic feasibility will require cost and risk reductions in all aspects of EGS development, including exploration and resource characterization, drilling, reservoir creation and operation, and energy conversion.

A successful technical feasibility demonstration in 2011 is expected to increase private sector interest, leading to public-private partnerships to enable commercial development of high-grade resources in the 2011 to 2018 timeframe. The planned commercial feasibility demonstration in 2016 should further increase private sector interest and lead to commercial development. The program beyond this point will reduce costs and risks in lower-grade EGS resources that are lower in temperature (125 °C to 200 °C), deeper (>5 km), or both. Laboratory and field work will be needed beyond 2020 for EGS development to achieve its full potential.



**Figure 3.4 - EGS Critical Path**

Short-term and ongoing activities are illustrated below the timeline in Figure 3.4, including the tasks needed to improve EGS technology and develop new technologies. Prior to 2011, these efforts will develop technology to support feasibility demonstration. Afterward, they will reduce EGS project risks and costs with the 2040 goal of enabling EGS electricity generation at a cost of five cents per kilowatt-hour in 2004 dollars. A robust and comprehensive cost model will be developed and made publicly available. The USGS reassessment of geothermal resources will provide support. The Program will collaborate with the private sector, other government-funded programs, and the international EGS community. Ongoing program roadmapping, planning, and prioritization will be based on annual program assessments.

### 3.1.1.7.1. Task Overview

The tasks to be performed by 2011 are shown in Figure 3.6.

#### Task 1.0 Resource Characterization and Exploration

To attain the 2011 goal, aggressive thermal gradient and heat flow measurements must be made in boreholes of opportunity and, in critical areas, in new boreholes drilled for measurements. This task may be critical in selecting the first demonstration site, and will be critical in selection of the second site in 2012.

#### Task 2.0 Reservoir Design and Development

One or more sites will be selected for development, demonstration and testing of technologies, and for a critical experiment in developing a reservoir capable of producing thermal fluids at the high rates needed for commercial electricity generation. These field sites must be selected and negotiated for. Technologies to be developed and demonstrated include reservoir-engineering methods; fracturing and fluid-loss additives usable at temperatures above 200 °C; proppants to

keep fractures open; borehole packers for isolating stimulation zones; and numerical models incorporating rock and fluid properties and stress states, and capable of predicting the results of hydraulic fracturing or other stimulation options.

### Task 3.0 Reservoir Operation and Management

The EGS circulation loop created in Task 2.0 will be operated long enough to establish its production parameters. Associated research includes improving reservoir performance modeling, developing equipment and techniques for pumping production wells as a means of controlling the pressure regime in the reservoir, and developing techniques for controlling short circuiting and fluid loss.

### Task 4.0 Systems Analysis

The critical-path tasks in this area are to (1) review EGS technology and field experiments performed worldwide to date and assemble a database on the experiments for use by program researchers; (2) model the economic performance of EGS projects based on technology improvements and relevant market parameters; and, (3) perform program planning, roadmapping, and analyses to keep the program on the critical path.

### Task 5.0 Technology Transfer

Because EGS will be developed by the private sector, collaboration and technology transfer are essential. Some large petroleum companies are interested in EGS research and field experiments worldwide. The Program will elicit collaboration from large companies in the energy, mining and construction industries. The Program will also maintain and strengthen ties with other EGS research programs; sponsor workshops, symposia and conferences on EGS technology; and publish research results in peer-reviewed journals.

#### 3.1.1.7.2. Performance Targets

As indicated in Section 3.1.1.1, the EGS performance goals to be achieved by 2011 are to:

- Increase the net thermal power extracted to 35 MWt per production well, and
- Increase average reservoir lifetime to 7 years.

Net thermal power extraction and reservoir lifetime are functions of several variables listed in Table 3.4 along with their nominal, currently achievable values, and target values for 2011. These targets will be used to guide the program and measure progress. The power extraction and well lifetime goals will be achieved by some combination of improvements in these variables, but it may not be necessary to attain all of the target values. For example, if the production temperature is above the target value, the production rate can be lower or more water loss can be tolerated while still attaining the performance goals.

**Table 3.4 - EGS Reservoir Variables and Performance Targets**

Variable	Current	2011 Target
<b>Net Thermal Power Extracted, MWt</b>	<b>10</b>	<b>35</b>
Production Temperature at Surface, % of reservoir rock temperature	80	90
Mass Flow Rate, kg/sec	15	30
Pressure Drop, MPa	1.9	5.4
Lifetime to 10 °C Temperature Decline, years	< 1	<b>5-10</b>
Total Fractured Volume, km <sup>3</sup>	2.5	3
Short Circuit Index, dimensionless	11 E -6	3,300 E -6

Variable	Current	2011 Target
Water Loss, % of mass flow rate	10	1

Electricity generation is dependent on the temperature of the water or steam produced. Higher temperatures increase the energy extracted per unit of fluid and the energy conversion efficiency. The ideal (producing fluid at the reservoir rock temperature) can be approached in a fracture system in which the circulating fluids reach thermal equilibrium with the rock, although there is some temperature loss in the production wellbore. If the heat exchanger area is small relative to the mass flow rate, temperature equilibrium will not be attained and the production temperature will decrease. Development of reliable stimulation methods and models is a near-term goal. Poor stimulation results or short-circuiting can lead to an inadequate heat exchange area. The target is a production temperature that is 90 percent of the reservoir rock temperature.

The expected production-fluid temperature must be predicted early and accurately from knowledge of the initial reservoir-rock temperature, the inferred reservoir geometry, and the fluid-circulation characteristics within the reservoir. Fluid temperature is a critical variable in power plant design, but it cannot be measured directly until the circulation loop has operated for several months. Project costs could be reduced if the power plant were under construction while the subsurface reservoir is being created and tested.

The fractured volume and the rock temperature determine the accessible thermal energy in the reservoir, which affects reservoir and well lifetime. Fractured volume can be determined through chemical tracer tests. The surface area of the interface between the hot rock and circulating fluids is another important variable that cannot yet be determined reliably.



**Figure 3.5 - Geoscience researchers conduct tracer tests at The Geysers, northern California.**

Other variables to measure research progress include the mass flow rate (the production rate of thermal fluids, which equals the rate of circulation in the reservoir), which must be approximately 30 kg/sec per production well for temperatures near 200 °C for commercial heat production. A high pressure drop across the reservoir is desirable to increase production rate. The strategy for achieving the 2011 target is to use pumps in both injection and production wells. A high injection pressure is to be avoided to reduce short-circuiting, water loss from the loop, and the parasitic power needed to operate high-pressure pumps.

The useful reservoir life is a factor of the effective fracture surface area and the volume accessed by the circulating fluid, the amount of short-circuiting between injection and production wells,

and the amount of water lost to the surrounding rock. There are no methods to measure short-circuiting directly, although tracer testing can help determine its magnitude. In this plan, the metric for short-circuiting is the ratio of the volume of tracer-doped water injected prior to tracer breakthrough in a production well to the total effective reservoir volume. The larger this ratio, and the closer it is to the reservoir porosity (usually 1% to 7% for fractured hard rock), the less short-circuiting there is.

The ideal EGS system has little or no water loss. Water losses should be minimized because they imply excessive parasitic pumping power, and because makeup water is cooler than recirculated water, and hastens cooling of the rock. In some areas, makeup water may be limited in availability and costly. With appropriate control of the pressure regime, net water loss should be reduced to zero. The target limit is one percent.

### 3.1.1.7.3. Critical-Path Tasks and Milestones

The critical-path tasks and milestones for the 2011 EGS program are presented in Figure 3.6.

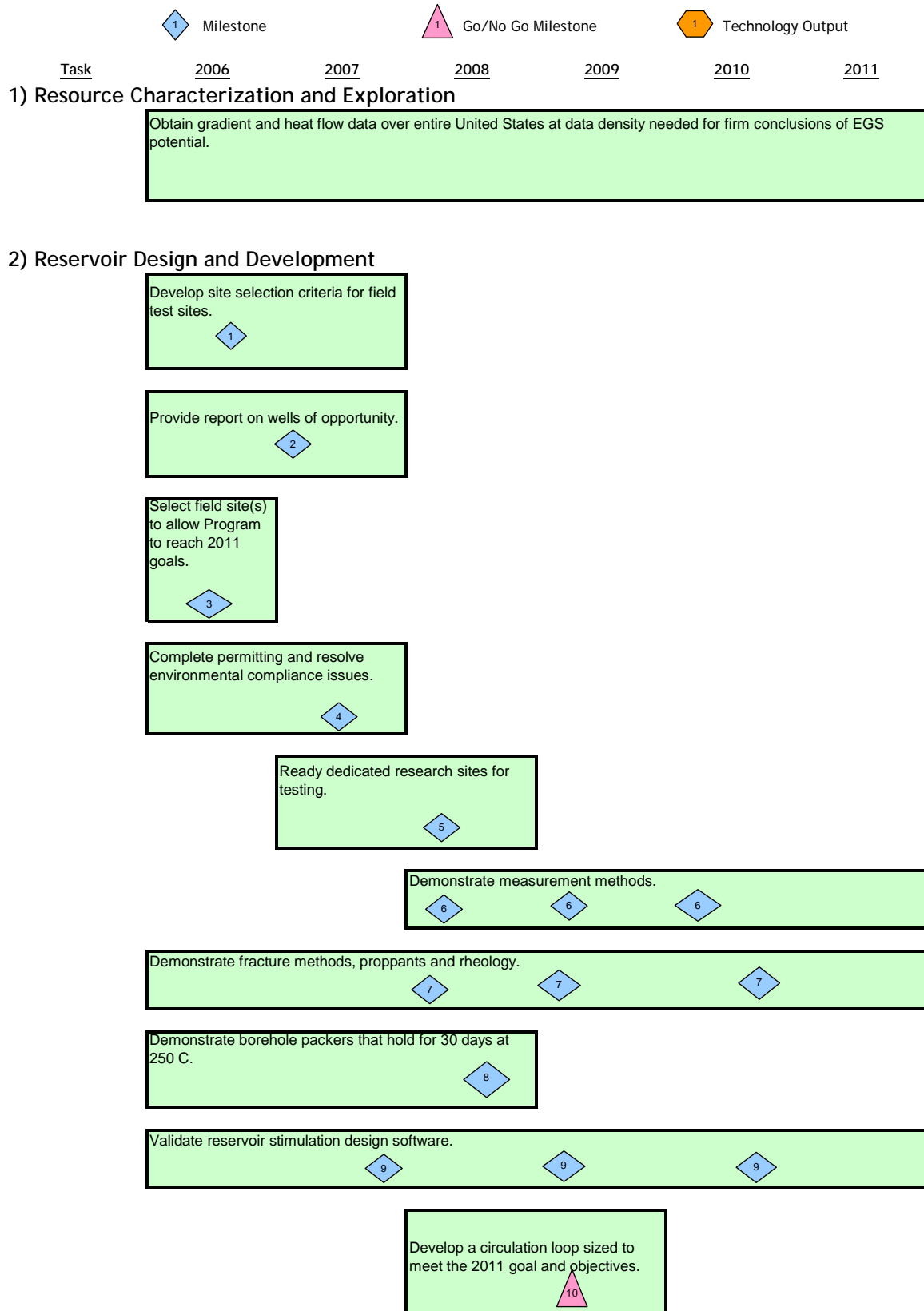
**Table 3.5 Technical Task Descriptions for EGS**

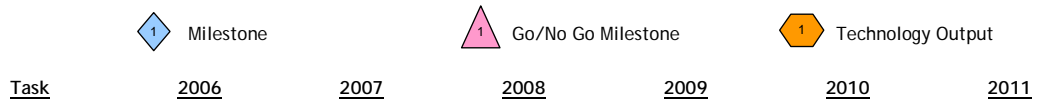
<b>Task</b>	<b>Description</b>	<b>Barriers</b>	<b>Duration in Years</b>
<b>Task 1.0 Resource Characterization and Exploration</b>			
<b>1.1-1.3</b>	<b>Heat-flow Mapping and Geology</b> <ul style="list-style-type: none"> <li>Continue gradient and heat-flow research, and related geologic studies</li> </ul>	C	5
<b>Task 2.0 Reservoir Design and Development</b>			
<b>2.1</b>	<b>Site Selection Criteria</b> <ul style="list-style-type: none"> <li>Develop criteria for selection of the best sites for EGS data collection, component equipment testing, and fracturing demonstration.</li> <li>Identify sites in different geologic settings with calculated cost of power at each site.</li> </ul>	D	1
<b>2.2</b>	<b>Wells of Opportunity</b> <ul style="list-style-type: none"> <li>Identify wells of opportunity that best meet Site Selection Criteria.</li> </ul>	C, D, E	2
<b>2.3</b>	<b>Field Site Planning and Design</b> <ul style="list-style-type: none"> <li>Plan the field site design and operations</li> </ul>	D	2
<b>2.4</b>	<b>Site Negotiation</b> <ul style="list-style-type: none"> <li>Make final selection of best site and negotiate for use or acquisition.</li> <li>Set up management team.</li> </ul>	D	1
<b>2.5</b>	<b>Permitting</b> <ul style="list-style-type: none"> <li>Acquire all permits needed to operate EGS research at site(s), including environmental permitting.</li> </ul>	D	2
<b>2.6</b>	<b>Preparation and Management</b> <ul style="list-style-type: none"> <li>Make arrangements as needed for site operation and management.</li> <li>Ensure availability of roads, power, water and other necessities at the site.</li> <li>Drill and complete injection well (if no well of opportunity is available)</li> </ul>	A, D	3


<b>Task</b>	<b>Description</b>	<b>Barriers</b>	<b>Duration in Years</b>
	<ul style="list-style-type: none"> <li>Drill and complete production well (if no well of opportunity is available)</li> <li>Install and test heat-rejection system.</li> </ul>		
<b>2.7</b>	<b>Measurement Techniques</b> <ul style="list-style-type: none"> <li>Develop and perform field tests of methods and techniques for designing, measuring and monitoring the EGS reservoir, including: <ul style="list-style-type: none"> <li>Improve geophysical methods for monitoring fracturing</li> <li>Develop and test transient pressure and other reservoir engineering tests for calibrating numerical reservoir models; other tests as appropriate and necessary.</li> <li>Develop and test methods for determining in-situ stress at reservoir depths.</li> </ul> </li> </ul>	A, B	5
<b>2.8</b>	<b>Fracture Methods, Proppants, and Rheology Control</b> <ul style="list-style-type: none"> <li>Test candidate methods for creating an EGS reservoir.</li> <li>Test candidate techniques for fracturing in the subsurface.</li> <li>Develop and test high-temperature proppants for the EGS environment</li> <li>Develop and test additives for controlling the rheology of fracturing fluids</li> <li>Develop and test methods of controlling short-circuiting and fluid loss.</li> </ul>	A, B	5
<b>2.9</b>	<b>Borehole Packers</b> <ul style="list-style-type: none"> <li>Develop and test new and improved borehole packers, especially open-hole packers, for isolation of stimulation zones</li> </ul>	A	3
<b>2.10</b>	<b>Reservoir Stimulation Design</b> <ul style="list-style-type: none"> <li>Develop new and improved numerical techniques for designing fracturing operations at EGS sites, including options for various fracturing methods that will lead to better fracturing results, higher mass flow rates and lower short circuit indices</li> </ul>	A, B	5
<b>2.11</b>	<b>Reservoir Stimulation – Critical Experiment</b> <ul style="list-style-type: none"> <li>Perform a reservoir fracturing operation and demonstrate the feasibility of creating EGS reservoirs that produce at commercial flow rates.</li> </ul>	A, B	4
<b>2.12</b>	<b>Create 2<sup>nd</sup> Loop</b> <ul style="list-style-type: none"> <li>Drill new injection and production wells and Install 2<sup>nd</sup> circulation loop at same site.</li> </ul>	A, B	5
<b>Task 3.0 Reservoir Operation and Management</b>			
<b>3.1</b>	<b>Reservoir Operation</b> <ul style="list-style-type: none"> <li>Operate EGS circulation loop for a sufficient length of time to demonstrate its production capacity and estimate its lifetime.</li> <li>Perform research measurements on the system and monitor its operation.</li> <li>Provide a least-cost system for rejecting produced heat while</li> </ul>	B	5

<b>Task</b>	<b>Description</b>	<b>Barriers</b>	<b>Duration in Years</b>
	supporting high heat rates.		
<b>3.2</b>	<b>Reservoir Performance Modeling</b> <ul style="list-style-type: none"> <li>Develop and validate reservoir engineering numerical models of the EGS circulation system.</li> </ul>	B	5
<b>3.3</b>	<b>Reservoir Research, Testing and Demonstration</b> <ul style="list-style-type: none"> <li>Gather data, perform research, test and demonstrate technologies for operating an EGS reservoir in an efficient fashion.</li> <li>Demonstrate artificial lift and its effect on production, short circuiting, fluid loss and other system parameters.</li> <li>Evaluate and develop short circuit mitigation methods which increase short circuit index toward target.</li> <li>Develop and demonstrate techniques for controlling fluid loss.</li> </ul>	A, B	5
<b>Task 4.0 Systems Analysis</b>			
<b>4.1</b>	<b>Review EGS Technology</b> <ul style="list-style-type: none"> <li>Assemble, analyze and interpret pertinent information on technologies relevant to EGS development from worldwide EGS research, petroleum reservoir development, mining operations, and other appropriate sources.</li> </ul>	A, B, C, D	3
<b>4.2</b>	<b>Program Assessment and Planning</b> <ul style="list-style-type: none"> <li>Perform critical path analyses of remaining research in light of results to date</li> <li>Modify the EGS research program as appropriate.</li> </ul>	A, B, C	5
<b>4.3</b>	<b>Economic Models</b> <ul style="list-style-type: none"> <li>Develop robust economic models to help guide EGS research and development</li> </ul>	A, B, C	5
<b>4.4</b>	<b>EGS Supply Curves</b> <ul style="list-style-type: none"> <li>Using resource assessment data and results of the other tasks in this plan, develop and update predictions for commercial EGS development.</li> </ul>	E	5
<b>Task 5.0 Technology Transfer</b>			
<b>5.1</b>	<b>Industry Collaboration</b> <ul style="list-style-type: none"> <li>Develop collaborative relationships with industries large enough to move EGS development forward at desired rates to reach the 2040 goals.</li> <li>Leverage DOE's limited research funds to the maximum extent possible.</li> </ul>	D, E, F	5
<b>5.2</b>	<b>International Participation</b> <ul style="list-style-type: none"> <li>Coordinate the program with and support other worldwide EGS research and field research programs.</li> <li>Encourage international participants in DOE's EGS program.</li> </ul>	D, E, F	5
<b>5.3</b>	<b>Information Dissemination</b> <ul style="list-style-type: none"> <li>Sponsor and participate in workshops, symposia and publications on EGS technology.</li> </ul>	F	5


**Figure 3.6 - Tasks and Milestones**








Create, complete and test second loop at commercial scale. 


### 3) Reservoir Operation and Management

Complete long-term reservoir flow test to meet 2011 goal and objectives. 


Validate predictive EGS models that actual reservoir history parameters of pressure and temperature with time within +10%. 






Demonstrate improved artificial lift equipment and methods with flexible setting depths which can produce 200 C fluid at target flow rate of 54 kg/s for at least one year. 


Demonstrate successful short-circuit control for temperatures up to 200 C. 




Conduct lab and field tests of loss control methods which allow reservoirs to operate with no losses. 

### 4) Systems Analysis

Report on EGS technology as a guide to further research. 

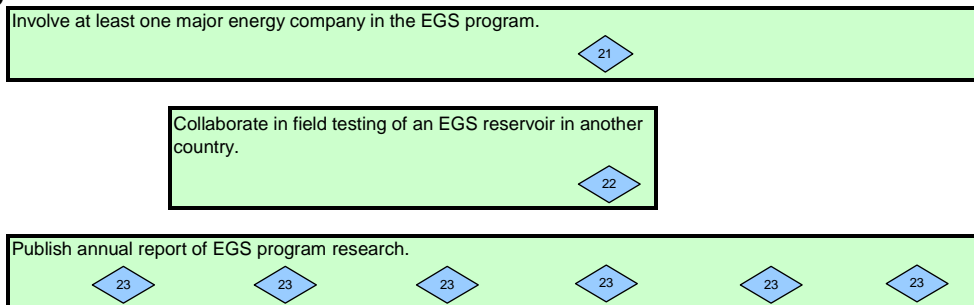
Update EGS research plan.     

Publish updated economic models.   

Update EGS supply curves.   



**5) Technology Transfer**



**Table 3.6 - Technical Task Milestones for EGS**

**1) Reservoir Design and Development**

1. Develop site selection criteria for field test sites. (December 2005 Milestone)
2. Provide report on wells of opportunity. (March 2007 Milestone)
3. Select a sufficient number of field sites to allow program to reach 2011 goals. (June 2006 Milestone)
4. Complete permitting and resolve environmental compliance issues. (June 2007 Milestone)
5. Prepare sites for testing. (March 2008 Milestone)
6. Demonstrate measurement methods. (March 2008, March 2009, September 2010 Milestones)
7. Demonstrate fracture methods, proppants and rheology. (March 2008, March 2009, August 2010 Milestones)
8. Demonstrate borehole packers that hold for 30 days at 250 °C. (March 2008 Milestone)
9. Validate reservoir stimulation design software. (October 2007, March 2009, August 2010 Milestones)
10. Develop a circulation loop sized to meet the 2011 goal and objectives. (March 2009 Go/No-go Milestone)
11. Create, complete and test second loop at commercial scale. (November 2011 Milestone)

**2) Reservoir Operation and Management**

12. Complete long-term reservoir flow test to meet 2011 goal and objectives. (September 2011 Go/No-go Milestone)
13. Validate predictive EGS models that actual reservoir history parameters of pressure and

temperature with time within +10%. (September 2010 Milestone)

14. Demonstrate improved artificial lift equipment and methods with flexible setting depths which can produce 200 °C fluid at target flow rate of 54 kg/s for at least one year. (September 2010 Milestone)
15. Demonstrate short-circuit control for temperatures up to 200 °C. (September 2010 Milestone)
16. Conduct lab and field tests of loss control methods which allow reservoirs to operate with no losses. (September 2011 Milestone)

### **3) Systems Analysis**

17. Report on EGS technology as a guide to further research. (July 2008 Technology Output)
18. Update EGS research plan. (August 2007, August 2009, August 2011 Milestone)
19. Publish updated economic models. (July 2006, July 2008, July 2010 Technology Outputs)
20. Update EGS supply curves. (August 2007, August 2009, August 2011 Milestones)

### **4) Technology Transfer**

21. Involve at least one major energy company in the EGS program. (September 2010 Milestone)
22. Collaborate in field testing an EGS reservoir in another country. (September 2007 Milestone)
23. Publish annual report of EGS program research. (December 2006, December 2007 Milestone)

## **3.1.2. Exploration Assessment and Technology**

### **3.1.2.1. External Assessment and Market Overview**

The risk of finding economic resources with current exploration capability is a significant barrier to geothermal development. Investors are reluctant to assume this risk (the probability of success is currently estimated to be 20%) because costs frequently exceed \$1 million per well, meaning that, on average, \$5 million must be spent per successful well. The cost of exploration varies widely from one location to another, adding to exploration risk.

Although the cost of exploration at a successful site is much less than the costs of drilling production wells and building power plants, the costs of many failed exploration projects must be amortized over the small proportion of successful projects. To minimize the overall cost of exploration, the geothermal industry requires technologies to remotely and reliably detect and image geothermal reservoirs before drilling. Most experts believe that a suite of methods will have to be used to locate hidden resources.

Because the geothermal industry does not have sufficient funding to independently develop exploration technology, the industry relies on modifying technology from the mining industry and the oil and gas industry.

U.S. geothermal exploration nearly stopped in the 1990s due to reduced domestic demand and an industry perception of greater returns on foreign projects. As a result, opportunities for field verification of new exploration methods were limited, and tools were developed for geologic environments that are not common in the United States, limiting their utility. As an example,

electromagnetic methods used successfully in volcanic geothermal environments in Indonesia may be useful in the Cascades, but may not be relevant to the Basin and Range.

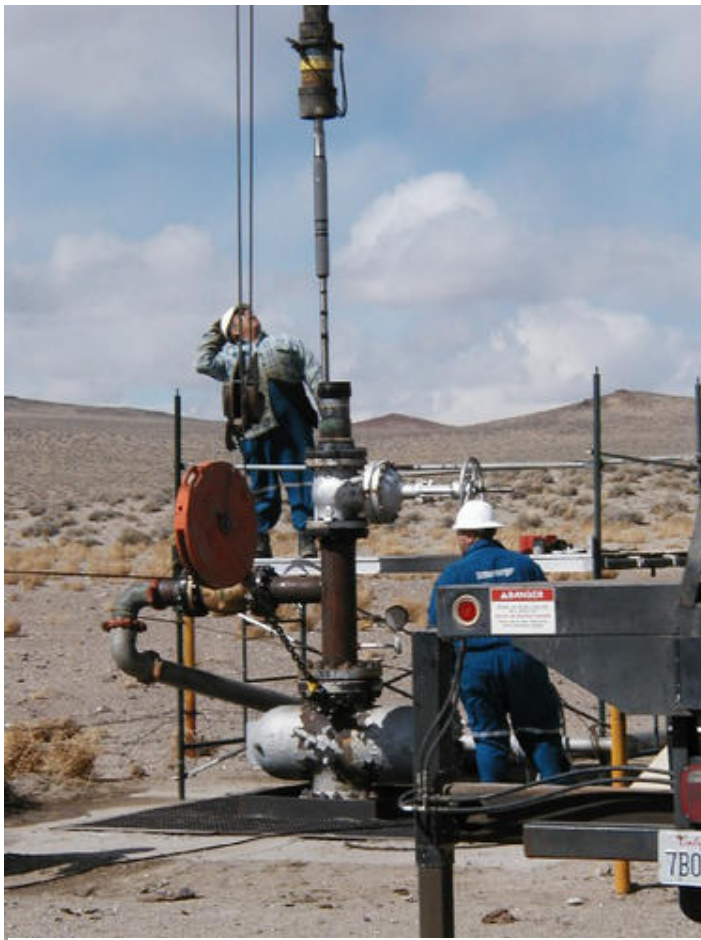
The status of geothermal exploration is similar to that of the oil industry of a hundred years ago. There has not been sufficient geothermal exploration to enable industry to identify resources without obvious surface manifestations. The oil and gas industry has a better understanding of the environment necessary for a developable site.

Only one out of five exploration wells at previously undrilled sites finds economic geothermal resources. Exploration techniques must be improved to increase the success rate.

### 3.1.2.2. Internal Assessment and Program History

Some technologies were set-aside during testing in the 1970s and 1980s because the state of the art did not provide enough resolution. Recent technical progress has led the program to re-evaluate some of these technologies. In addition, the database of hydrothermal reservoirs has grown and understanding of the resource has changed, making it possible to identify correlations between results and sites that were not previously detectable. DOE has initiated a review of exploration techniques and projects in order to develop current information on these techniques and the success rates of exploration and development.

Field-tested technologies have variable success rates, partly due to inadequate survey design, difficult geologic conditions, inadequate equipment or oversimplified numerical models, and/or primitive interpretation techniques. These problems reduce the resolution of resource maps.



**Figure 3.7 - Drilling exploration crew performing initial well logging tests at the Desert Peak site, Nevada.**

Relatively little information is available on the merits of many exploration methods due to inadequate record-keeping by both the industry and the Geothermal Technologies Program. Some methods have never been used at the same location, making direct comparisons difficult. These problems will be resolved by an exhaustive investigation of multiple methods at a single site, allowing direct comparison, identification of required improvements in both design and interpretation, and evaluation of the relative values of different methods. A joint field test will be costly, and the interests of field operators will have to be accounted for. The site must be selected equitably so that DOE is not providing one operator with a competitive advantage; the operator selected may want control over which tests are run; and the

operator may want to maintain some level of secrecy for the results. It may be possible to mitigate some issues by selecting a site where multiple operators have an interest, or by dealing with a consortium of companies.

Several methods are still at the evaluation, testing, and development stages. Methods that have not been adequately demonstrated include use of InSAR data to map fault strain on a regional scale; thermal imaging; integration of seismic, magnetotelluric (MT), and electromagnetic (EM) data for mapping deep fractures and permeability; isotopic geothermometry that can see through overprinting by shallower cooler systems; reactive transport modeling; and the use of surface reconnaissance tools such as soil gases to identify buried permeable faults and fault/fracture sets that affect the flow of fluid and heat on both regional and basin scales.

### **Remote Sensing**

Remote sensing is used to screen large areas inexpensively for sites for more intensive investigation. Because remote sensing techniques had insufficient resolution and sensitivity to routinely identify targets by surface reconnaissance, research was dropped from the program in the early 1980s. Improvements increasing resolution and sensitivity developed for other markets may now enable use of these techniques. The Program is field testing remote sensing methods to determine their utility in geothermal exploration. These methods will not be developed further if results are not good. Hyperspectral imaging, the first of the remote sensing tools being re-evaluated, is nearing commercial use.

### **Geology**

Geologic analysis of a system, combined with large-scale mapping of geologic attributes, improves the ability to locate similar systems elsewhere. Heat flow studies and other regional analyses are used to limit the area to be explored. Integrated maps can be used to overlay independent observations and rapidly compare properties among geothermal systems. Tectonic models allow development of guidelines for identifying present and past stress and strain regimes that are associated with hydrothermal systems. The program is developing GIS-based databases to assist in determining which attributes are necessary and sufficient to locate geothermal systems. These attributes and GIS databases are being utilized by industry to delineate exploration targets.

### **Geophysics**

Several exploration techniques were discarded during early research and field testing due to uncertainty in their results. Simple resistivity methods were found to be sensitive to non-geothermal signals and have been discarded. Geophysics can also be used to map the structure of a geothermal reservoir. Data on thermal anomalies detected during drilling, seismic imaging of fractures, gravity, magnetics, magnetotellurics (MT), and various electric methods (EM) can be used to image fluid circulation and alteration zones. Numerical models are required to interpret the data. Because each technique offers a different resolution and volumetric scope, integration of different methods can be used to develop a complete model of a reservoir.

A detailed aeromagnetic survey of the Dixie Valley field in the late 1990s showed that the technique provided excellent verification of field structure and was readily correlated with surface mapping and other data on the field. As a result, no further development of the technology is anticipated.

### **Geochemistry**

Recent improvements and new geochemical and isotopic techniques should significantly reduce the uncertainties associated with locating a new resource and defining the extent and potential of the resource prior to drilling and high-resolution subsurface geophysical imaging. While

geophysical regional analyses can sometimes be used to limit the area explored, chemical and isotopic methods are the only technology available for confirming the existence of hot fluids, quantifying reservoir temperatures, identifying the source of geothermal fluids and heat, and defining the geometry and extent of a resource and its potential. Preliminary work on helium isotopes suggests that they may be useful in determining which range fronts in the Basin and Range have deep fluid circulation with good geothermal potential.

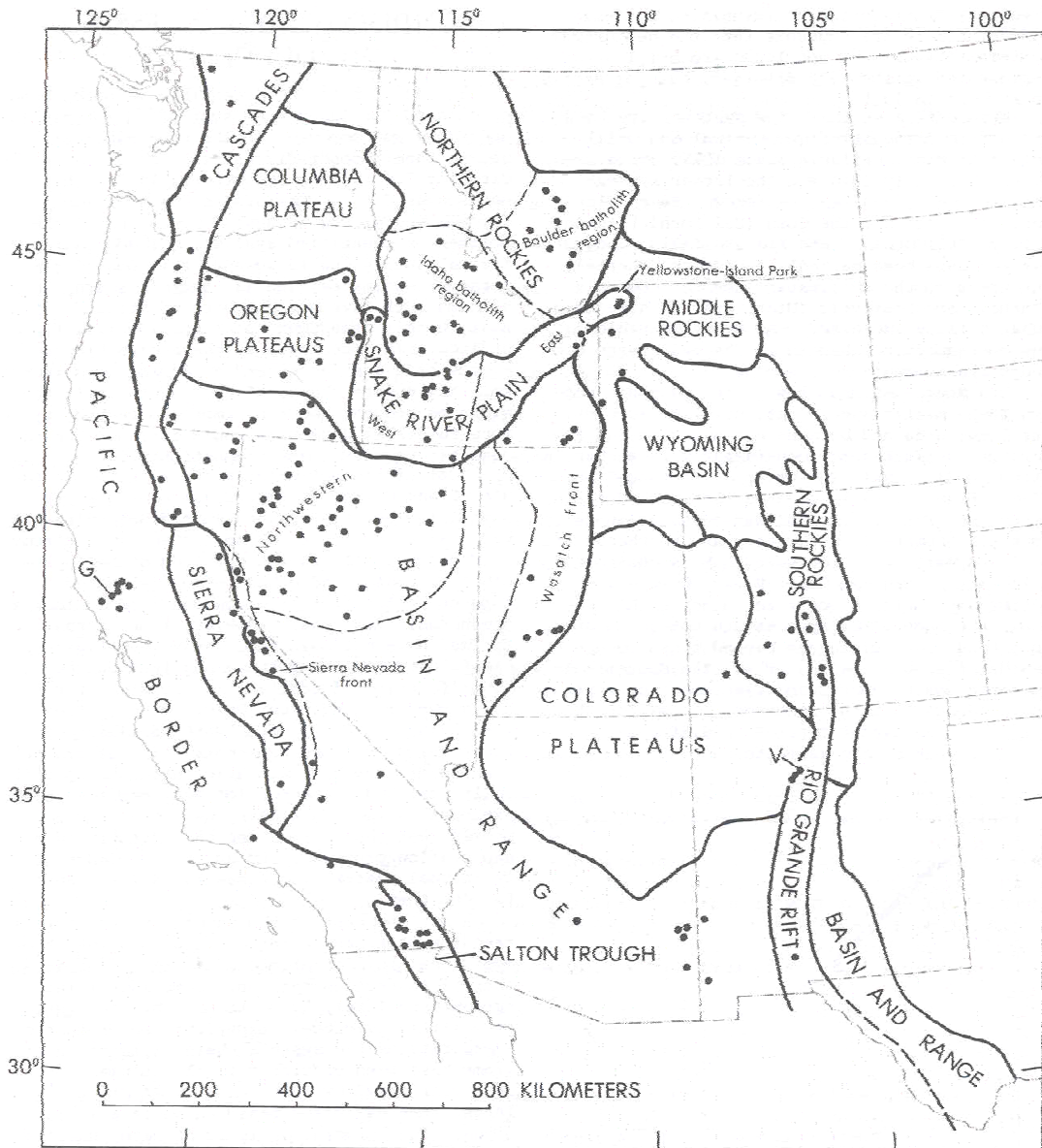
### **National Geothermal Assessment**

The Program undertook a major exploration effort in the 1970s and early 1980s. Resource assessments were developed by the USGS for high and moderate-temperature resources in 1978, geopressured resources in 1975, and direct use in 1982. The thermal energy associated with young volcanic rocks and conductive regimes was also estimated by the USGS in 1975 and 1978. These assessments are now considered obsolete due to the availability of new data and new interpretations of geothermal phenomena. The assessments projected that several systems would be much larger than is currently believed, and that many systems would be more productive than is currently believed. Subsequent research has shown that there are probably no other large Geysers-type systems in the United States, and that although there are probably numerous hidden systems they are likely to be relatively small (averaging 15 to 25 MWe, with some as large as 50 MWe).

The USGS estimated in 1978 that three geologic provinces contained the majority of undiscovered accessible hydrothermal resources: the Cascade Mountains, eastern Snake River Plains and the northwestern Basin and Range (see Figure 3.8). Only the northwestern Basin and Range, the focus of the greatest industry interest, has developed geothermal resources. The Cascade Mountains have one explored site (Newberry) with high temperature but low flow. Further exploration of the Cascades has been hampered by lack of access because of scenic and recreational values. The Snake River Plain might have a significant thermal anomaly, but it is masked by the cool water of the Snake River Plain aquifer. Exploration would be difficult and expensive. For those reasons, DOE has focused on techniques for Basin and Range exploration.

**Figure 3.8 Map showing geologic provinces of the western U.S.**

Dots indicate locations of identified hydrothermal convection systems with reservoir temperatures greater than or equal to 90 °C. G = Geyser; V = Valles Caldera. (USGS Circular 790)



Valid supply curves are needed to identify the types of geothermal systems with the greatest potential impact on U.S. energy production. Estimates of domestic geothermal resources are out of date, particularly for resources with the potential for EGS. Because the data is old, DOE is not able to construct accurate supply curves for the production of geothermal energy. New resource data is needed.

Mapping of the Nation's geology to determine the magnitude of easily-enhanced geological environments will make it possible to develop an EGS supply curve, and assist with identifying which technologies the program will need to prioritize to develop resources in these areas.

The Program is co-funding a multi-year effort headed by USGS to update and validate geologic data on geothermal resources, which were last documented by the USGS in 1978 in Circular 790.

The National Geothermal Assessment is being initiated in FY 2005 at the USGS with an assessment of the Basin and Range. A new assessment will provide an improved updated, peer-reviewed estimate of both known and undiscovered hydrothermal resources which can be used for DOE program planning and for Energy Information Administration estimates. The assessment will also provide a new, unbiased estimate of the regional potential for EGS.

### **3.1.2.3. Federal Role**

The Exploration Technologies subprogram accelerates development of geothermal resources and EGS by improving technology performance and reducing market entry costs to competitive levels. Most of the techniques under development will assist in targeting and developing both hydrothermal and EGS sites.

Individual geothermal systems are relatively small, and the profit margins are low on even the best systems. Many geothermal sites, both known and hidden, are believed to be nearly economic. These sites are not being developed because of the high risk of exploration, particularly in locating drilling sites that will produce economic quantities of fluid.

Due to size constraints, risk, and marginal economics, the industry cannot afford to conduct needed research, and trade organizations also have extremely limited resources. With the exception of California, the states do not have the resources to develop suitable research programs. California's program tends to conduct research applicable to problems specific to California fields that is not applicable to other states. The Federal government's research and development of exploration technologies mitigates these barriers to development.

This element complements research in the Fossil Energy Program, particularly in seismic tools. Other geophysical and geochemical tools are not as applicable or complementary to the oil and gas industry. The Program also works with the USGS geothermal program.

### **3.1.2.4. Approach**

The exploration technology subprogram develops technologies to detect and characterize hydrothermal systems and potential EGS, and works to assess the economic potential of geothermal energy in the United States. The Program transfers new technology to industry through presentation of results at industry meetings and cooperation with industry at selected field sites. This approach encourages industry to adopt new technology by decreasing financial risk.

In contrast with other renewable energy sources, geothermal resources are usually difficult to locate and characterize. The vast majority of developed resources are at sites with easily detected surface manifestations. The 1978 resource assessment conducted by the USGS posited that most resources are in "hidden" systems (i.e., systems which have no surface manifestations.) While the 1978 assessment is considered obsolete, research suggests that there may in fact be numerous hidden systems of moderate size (15 to 50 MW). The limitations of current technology prevent rapid, inexpensive screening for these resources. Because of the difficulty of locating geothermal systems, the program is developing exploration tools to reduce risk and increase the success rate of exploration from 20% to 40%.

The Program has another goal of reducing the levelized cost of electricity from hydrothermal resources. Exploration research reduces costs by enabling developers to maximize fluid productivity through optimal siting of exploration and development wells. The approach is to conduct applied research and validate it through industry cost-shared field applications.

The third approach involves a new national assessment of geothermal resources. This assessment will help the Program prioritize its research portfolio. Updated estimates of resource locations,

temperatures, and depths will enable calculation of the relative costs of exploration, wellfield development and energy conversion, which will be useful for setting program direction.

#### **3.1.2.5. Performance Goals**

The exploration subprogram is removing barriers to identification of hidden hydrothermal resources, improving techniques for collecting data used in modeling the economics of potential sites prior to drilling, and developing an updated supply curve for geothermal energy. The metrics used to measure progress are detailed in the discussion of Technical Targets in Section 3.1.2.8.

One goal is to improve the 20% success rate for finding economic resources at previously undrilled sites (i.e., drilling exploration wells that confirm the existence of an economically developable resource) to 40%. Achieving this goal would decrease the cost of drilling non-productive exploration wells by 50%. Reduction in exploration costs through fewer failed exploration wells and the selection of appropriate exploration tools will also decrease geothermal development costs. The subprogram objectives that will permit the achievement of this goal are:

- Develop new or improved methods for screening areas at the regional (100,000 sq. km.) and basin (1000 sq. km.) scales that will permit the identification of potential hidden hydrothermal resources (areas of hot, fractured, saturated rock) with 50% accuracy.
- Develop new or improved methods for screening sites on the reservoir (100 sq. km.) scale to improve pre-drilling estimates of reservoir production (well productivity and reservoir volume) to within 50% of the actual result.
- Improve methods for imaging subsurface permeability by using surface-based methods such as seismic, magnetotellurics, resistivity, and/or inexpensive shallow (hundreds of meters deep, rather than thousands) small diameter boreholes.
- Develop more reliable geochemical methods for identifying the source of fluids and heat associated with geothermal systems in order to estimate the locations of hidden systems.
- Develop methods for integrating and analyzing hydrogeologic, geophysical and geochemical data sets to construct best-fit conceptual and resource models of specific geothermal areas.

A second technical goal is the development of supply curves for both hydrothermal and EGS. Achieving this goal will help the Program optimize its research priorities, and will potentially affect the geothermal industry by drawing the attention of policy makers and other stakeholders. The objectives that will enable achievement of this goal are:

- Support the USGS update assessment of U. S. geothermal resources.
- Survey selected geological areas using advanced remote screening technologies in cooperation with industry to confirm resource estimates and identify sites for verification of advanced reservoir mapping technologies.
- Correlate resource characteristics with cost of energy.

#### **3.1.2.6. Strategic Goals**

Increasing the success ratio of geothermal exploration is a strategic goal. The Program will track the use of new and improved technologies, and will track the success rate of industry exploration.

#### **3.1.2.7. Market Challenges and Barriers**

- A. Exploration is affected by the small size of the geothermal industry and the lack of operators specializing in developing and using new resource exploration and

characterization technology. The industry cannot develop its own technology, and is reluctant to utilize technology that has not been verified.

- B. The industry has limited resources to track and implement advances in fields such as mineral and petroleum exploration that have potential geothermal applications. Many of these technologies must be modified for geothermal use. Many groups serving the geothermal industry are focused on exploration and reservoir characterization for the petroleum or mining industries, with little incentive to adapt technology for the small geothermal market.
- C. Geothermal leasing on federal land is delayed because geothermal development is not considered during land-use planning. Exploration affects this barrier, as does the GeoPowering the West subprogram, because inclusion of information on geothermal resources in land-use planning documents would shorten the time required for providing federal geothermal leases.

### **3.1.2.8. Technical Challenges and Barriers**

The costs of failed commercial exploration must be amortized by those commercial developments that are ultimately successful. To minimize unproductive drilling, the geothermal industry requires technologies to remotely and reliably detect and image geothermal reservoirs (as defined by the confluence of permeability, heat, and fluid) prior to drilling.

Better statistics about the success and costs of exploration and the benefits of specific exploration technologies are needed to develop geothermal supply curves and to better direct the future exploration research program. Although some information has been collected, the data was set aside as the U. S. industry moved its exploration efforts offshore. The old data will need to be reassembled and interpreted.

Current exploration techniques permit developers to find predicted temperatures about 50% of the time. Although temperature prediction can be improved, limited ability to detect permeability is the primary risk factor. The variability of subsurface permeability cannot be determined without drilling. Even in cases where initial wells are highly productive, subsequent wells sometimes are not, terminating development. While the ability to predict productivity before drilling would be highly useful, in the medium term, technical issues are expected to limit the odds of successful results from a first exploratory well to about 40%. Even this limited success rate is roughly double the rate achieved by the current state of the art.

It is difficult to find geothermal systems where there is little or no surface evidence. The sensitivity and resolution of current exploration techniques cannot consistently identify high quality resources. The industry is limited to exploring for resources with surface manifestations or where drilling for other purposes has found hot water. In order to expand the inventory of hydrothermal resources and exploration targets, DOE is developing regional databases of the geologic attributes of geothermal systems and geologic data that imply the presence or absence of geothermal resources. This data will be useful to the industry in selecting and exploring individual geothermal fields. Because geothermal systems are analogous to ore deposits, some mining techniques may be applicable, but the greater depth of geothermal resources will require improving the resolution of imaging techniques. Techniques developed for the oil and gas industries are often inapplicable to the geothermal industry or require modification for the geothermal environment. Because the geothermal environment is in rock types not common to the petroleum industry, new correlations must be developed to interpret signals in hotter environments with volcanic rocks.

An accurate and comprehensive supply curve for hydrothermal systems has not been developed. The 1978 USGS assessment was based on assumptions that are now known to be overly optimistic. A new assessment is needed to provide a realistic basis for research and development.

### **Technology-specific barriers**

#### **Remote Sensing**

Remote sensing methods rely on imagery obtained from aircraft and satellites. The high cost is generally mitigated by the regional nature of the data.

- A. The utility of some remote sensing technologies, such as InSAR and hyperspectral imaging, has not been tested or demonstrated. The program will validate these methods for use by the industry.
- B. Hyperspectral imaging is the most developed method under investigation, and several commercial firms are beginning to offer this service. Program research will be limited to development of more accurate methodology and interpretation methods. The principal barrier is acceptance by industry. DOE is providing examples of the use of this methodology to industry.
- C. Detecting the faint thermal signal of geothermal systems amid background thermal noise using remote methods is difficult.

#### **Geophysics**

Many geophysical methods utilized by the geothermal industry are also used by the mining industry, which operates in similar environments.

- D. The electrical methods important for geothermal exploration lack spatial resolution at the depth of most geothermal systems.
- E. Methods and models for interpreting data are imprecise and crude.
- F. Geothermal structures are more complex than most oil and gas environments and have larger velocity and reversing velocity contrasts, both of which make seismic interpretation more difficult.
- G. Seismic studies in geothermal areas are generally hampered by low signal-to-noise ratios. Equipment positioning and signal interpretation must be improved to achieve the same resolutions as oil and gas surveys.
- H. A barrier to the use of petroleum seismic technology is the fundamental difference between three-dimensional reservoirs and more two-dimensional geothermal fracture networks. The geothermal industry may benefit from increasing petroleum industry emphasis on fractured environments.

#### **Geochemistry**

- I. Geochemistry has not been widely used for regional exploration. Not enough samples are available to enable use of geochemistry for regional exploration.
- J. Geochemical interpretation methods for regional exploration have not been developed.

#### **National Geothermal Assessment**

The principal responsibility for assessing the Nation's geothermal resources lies with the U. S. Geological Survey (USGS).

- K. The USGS has not completed an assessment of the Nation's resources suitable for electrical development since 1978, and no assessment of resources suitable for direct use

has been performed since 1982. The lack of an up-to-date assessment of the nation's geothermal potential makes it difficult for land-use managers to plan for the needs of the geothermal industry, slowing development on federal land.

- L. Without a current resource assessment, prioritization of R&D activities is likely to be suboptimal.

**Exploration State of the Art**

- M. Adequate statistics and case histories are not available. Although lack of statistics and analysis of exploration methods is not a technical barrier, lack of validated information complicates program planning. Because the industry and the Program have not kept adequate records in the past, best practices and exploration statistics are largely anecdotal. This omission will be corrected in the near term to permit better measurement of the success of program R&D and assist in prioritization of program activities.

As exploration statistics are developed and preliminary reviews are conducted of the potential of exploration methods, technologies will be down-selected. Barriers will be ranked in order of importance, cost/benefit and likelihood of being overcome. This analysis will be used to plan future program direction. A method being developed in the fossil program that is based on risk analysis may be used.

**3.1.2.8.1. Technical Targets**

Table 3.7 lists TIPs planned through 2016.

**Table 3.7 - TIPs for Exploration**

Technology Improvement Potential	Metrics	2006	2011	2016
<b>Remote Sensing</b>				
Show utility of InSAR for remote detection of systems	Correlation of ground deformation profile with presence or absence of system	Identify baseline correlation for Basin and Range	-	-
Integrate hyperspectral imaging with geophysical data	Correlation of hyperspectral imaging data with presence or absence of system	Identify baseline correlation for B&R	-	-
Show utility of GPS in detecting candidate sites	Correlation of ground deformation profile with presence or absence of system	Complete baseline correlation for B&R		
Improve modeling of permeability using remote sensing data	Correspondence of modeled data with actual flow rate		Modeled data within 50% of actual flow rate	
<b>Geophysics</b>				

Technology Improvement Potential	Metrics	2006	2011	2016
Improve resolution of magnetotellurics (controlled source audio, computer analysis)	Improve scale of baseline accuracy and resolution	100 m accuracy at 1 km	25-50 m accuracy at 1 km	10-25 m accuracy at 3 km
Improve resolution of seismic (high frequencies, VSP, 3-D)	Scale of resolution	10 m accuracy at 1 km	10 m accuracy at 3 km	
Integration of geophysical techniques (joint inversion modeling)	Scale of resolution	10 m accuracy at 1 km	5 m accuracy at 3 km	5 m accuracy at 6 km
<b>Geochemistry</b>				
Verify use of isotopes for identifying fluid source and deep permeability	Accuracy of fluid source determination and thermal potential	Source and extent of permeability determined with 50% probability	Source and extent of permeability determined with 75% probability	Source and extent of permeability determined with 90% probability
Verify use of gases to identify hidden geothermal systems	Correlation of gases with presence of geothermal systems	Identify baseline correlation		
Couple isotope and geochemistry data in transport models	Accuracy of derived fluid flow models and resource definition	Accurate to within 30%	Accurate to within 20%	Accurate to within 10%
Correlate geochemical interpretation with geophysical and geologic models	Verifiable exploration toolbox for the Basin and Range	Accurate to within 30%	Accurate to within 20%	Accurate to within 10%
<b>National Geothermal Assessment</b>				
Updated national geothermal assessment including EGS	Level of available data included in assessment	10%	90%	
Develop a supply curve for hydrothermal systems based on USGS assessment	Uncertainty in resource estimate	60%	20%	10%
Develop a supply curve for EGS based on USGS assessment	Uncertainty in resource estimate	Within 500%	100% (factor of 2)	50%
Maintain exploration data	Enter all data annually	Ongoing	ongoing	Ongoing

### 3.1.2.9. Strategies for Overcoming Barriers and Challenges

The strategy of the Exploration subprogram is to conduct research to improve existing technology and develop tools to increase exploration success and decrease geothermal development costs.

This will be done by reducing exploration costs, which reduces wellfield development costs by decreasing the number of wells required during both exploration and field development.

The exploration portion of the program impacts barriers A-J; well productivity is related to barriers C-H; and the national geothermal assessment and exploration statistics provide strategies for overcoming barriers K-M.

## **Metrics**

The principal metric is the reduction in exploration risk, measured as the rate of drilling economic wells in new geothermal fields. The program is re-evaluating the success rate because limitations in the data available to the program have raised concerns about the measurability of this metric.

The Program will monitor exploration efforts to determine whether research increases the rate of success at new sites, measured by the reduction in the number of dry holes drilled. Decreasing the number of wells needed for geothermal development will reduce the levelized cost of power. This cost reduction can be estimated in economic models.

Improvements in tools to improve the targeting of reservoir productivity by characterizing fractures will be measured by increases in resolution of the techniques and correlation of industry drilling results with exploration tools used. Increased well productivity reduces wellfield costs nearly in proportion to the productivity increase.

## **Strategies related to barriers**

### Market barriers

#### A. Industry size and reluctance to use new technology

Two strategies are being used to overcome this market challenge. The Program conducts research that a larger industry would fund in-house. The Program also shares costs with industry in initial deployment of the technology to decrease the risk of new technology in geothermal environments.

#### B. Limited technology transfer from other industry

The Exploration subprogram reviews technology developments in the mining and petroleum fields and researches promising techniques in conjunction with both geothermal operators and service companies. The Program also tests selected technologies such as hyperspectral imaging to demonstrate their usefulness to industry, and evaluates technologies jointly with industry.

#### C. Federal leasing delays

As part of the environmental process associated with federal geothermal leasing, geothermal operations must be discussed in the context of land-use planning documentation. Often leasing is delayed because land use managers did not consider geothermal operations, necessitating amendments to land-use plans. If land management agencies had better knowledge of geothermal development potential, they could include geothermal operations at an earlier stage of land-use planning, which would speed the issuance of leases. The strategy is to assist the USGS in assessment of geothermal resources for use by land management agencies in land-use planning.

### Technical barriers

Technical barriers are addressed through targeted technology research projects. Table 3.8 lists the projects and related technical barriers.

#### **3.1.2.10. Tasks**

Exploration techniques include remote sensing, geophysical techniques, geochemical techniques, and regional resource assessments. Remote sensing involves use of satellite or airborne data for

identification of geothermal prospects. Geophysics research includes detection of thermal anomalies, advanced seismic imaging, 3-D magnetotellurics (both surveys and system development), integration of different survey methods to improve accuracy, and the development of algorithms, models, and methods for interpretation of survey results. Geochemistry research is focused on soil mineral anomalies, botanical anomalies related to faults and geothermal phenomena, radioisotopic dating to identify young rocks, gas emissions, and water chemistry. Regional resource assessments involve application of surveying techniques to develop a complete picture of the country's resource base.

Tasks 1-5 and 8-10 will develop exploration techniques that will increase the success rate for geothermal exploration. Tasks 6 and 7 will verify the usefulness of the methods and allow explorers to select the most cost-effective package for exploration. Tasks 5-10 will reduce costs of geothermal development by helping industry select better drilling targets, thus improving well productivity. Tasks 1-4 will have a smaller effect on productivity. Task 11 supports increasing geothermal production by enabling industry to more rapidly access federal lands for development and by delineating areas with potential for hidden resources. Task 12 collects data on the performance of the program and the status of the industry.

**Table 3.8 - Technical Task Descriptions for Exploration**

<b>Task</b>	<b>Description</b>	<b>Barriers</b>	<b>Duration in Years</b>
<b>Remote Sensing</b>			
<b>1</b>	<b>Evaluation of Regional Remote Sensing Technologies (InSAR, Hyperspectral, IR, GPS)</b> <ul style="list-style-type: none"> <li>Assess resolving power and information content</li> <li>Relate to occurrence of known geothermal resources</li> <li>Develop and evaluate new regional technologies</li> </ul>	A, B, C	2
<b>2</b>	<b>Evaluation of Potential Basin Scale Technologies (Hi-Res Hyperspectral and IR, GPS, Soil Gases)</b> <ul style="list-style-type: none"> <li>Verify signals acquired remotely</li> <li>Integrate geophysical information (e.g. local heat flow anomalies) with geochemical soil gas signatures</li> <li>Apply evaluations to two field sites: one with a known resource, the other void of known resources</li> <li>Make Go-No Go decision on the various technologies and modify MYPP</li> <li>Integrate surface reconnaissance toolset</li> </ul>	A, B, C	3
<b>3</b>	<b>Synthetic Aperture Radar Interferometry (InSAR)</b> <ul style="list-style-type: none"> <li>Apply and verify InSAR to Basin and Range for detection of strain anomalies</li> </ul>	A	2
<b>4</b>	<b>Hyperspectral Imaging</b> <ul style="list-style-type: none"> <li>Apply and verify hyperspectral airborne and QuickBird satellite imagery to Basin and Range to develop screening methods using soil types, mineralizations, springs, and hidden faults</li> </ul>	A, B	1
<b>Geophysics</b>			
<b>5</b>	<b>Evaluation, Development, and Integration of Reservoir Scale Geophysical Technologies (EM, 3-D Seismic, etc.)</b> <ul style="list-style-type: none"> <li>Refine integrated generic geothermal models for exploration and resource assessment in the Basin and Range</li> </ul>	D, E	5

Task	Description	Barriers	Duration in Years
	<ul style="list-style-type: none"> <li>Apply and verify integrated modeling approach using 3D magnetotelluric, seismic, and gravity data with log, geochemical, and flow data from a geothermal field</li> <li>Evaluate and develop new geophysical imaging technologies that will lead to detailed 3-D map of subsurface permeability</li> <li>Develop improvements in resolution of geophysical methods.</li> <li>Determine best method of integrating multiple sets of exploration data to find best fit geothermal/geologic/hydrologic resource model by comparing deterministic, stochastic, or other methods' capabilities</li> <li>Develop geothermal exploration toolboxes integrating petrophysical, geophysical, hydrological, geochemical, and geomechanical technologies for each scale: Regional, Basin (Valley), and Reservoir</li> </ul>		
6	<b>Integrated Field Study #1 (Targeting Known Resource)</b> <ul style="list-style-type: none"> <li>Apply, improve, and verify integrated geothermal exploration models on the basin (valley) and reservoir scales</li> <li>Evaluate TIP 6 and modify MYPP based on results</li> </ul>	E	3
7	<b>Integrated Field Study #2 (Targeting "Hidden" Resource)</b> <ul style="list-style-type: none"> <li>Apply, improve, and verify integrated geothermal exploration models on the regional, basin (valley) and reservoir scales</li> <li>Evaluate TIP 6 and modify MYPP based on results</li> </ul>	E	3
8	<b>Seismic</b> <ul style="list-style-type: none"> <li>Investigate seismic techniques developed for oil and gas or other disciplines for application to geothermal exploration including single and multi-component VSP, 2D, 3D, and 4D methods</li> <li>Assess the use of reverse-time migration and refraction surveys</li> </ul>	F, G, H	5
9	<b>3. Evaluation of Natural Fractures in Cores and Outcrops</b> <ul style="list-style-type: none"> <li>Analyze core fractures from test sites and compare with wellbore stress indicators</li> <li>Characterize related outcrop fractures and assess local and regional stress</li> <li>Synthesize into semi-quantitative fracture model and integrate with tectonic stress model</li> </ul>	E	3
<b>Geochemistry</b>			
10	<b>Regional Geochemistry (He Isotopes, Isotope Geothermometry, etc.)</b> <ul style="list-style-type: none"> <li>Complete Basin and Range data collection and geochemical mapping</li> <li>Investigate new chemical and isotopic geothermometers for seeing through shallow low-temperature water-rock equilibration events that overprint deeper higher temperature resources.</li> <li>Synthesize data and integrate into regional tectonic and geophysical models</li> </ul>	I, J	3

<b>Task</b>	<b>Description</b>	<b>Barriers</b>	<b>Duration in Years</b>
	<ul style="list-style-type: none"> <li>Integrate relevant methods into regional and basin scale exploration tool boxes</li> </ul>		
<b>National Geothermal Assessment</b>			
<b>11</b>	<b>National Geothermal Assessment (with USGS)</b> <ul style="list-style-type: none"> <li>Conduct Basin and Range, Cascade, and other non-Basin and Range assessments</li> <li>Determine energy content and temperature of identified and undiscovered resources</li> <li>Correlate resource quantity with cost of energy</li> </ul>	K, L	5
<b>4. Exploration State of the Art</b>			
<b>12</b>	<b>Exploration State of the Art Study and Statistics</b> <ul style="list-style-type: none"> <li>Determine status of current geothermal exploration technologies</li> <li>Determine success statistics of historic exploration</li> <li>Utilize results to modify MYPP</li> </ul>	A, E, M	5

#### **Milestones and Decision Points**

Figure 3.9 shows the interrelationship of milestones, tasks, and technology program outputs for the Exploration program element from 2006 through 2011.

**Figure 3.9 - Tasks and Milestones**

**Legend**



Milestone



Go/No Go Milestone



Technology Output

2006

2007

2008

2009

2010

2011

**Remote Sensing**

**Task 1**

Identify correlation of regional remote sensing techniques with exploration success. Complete evaluation of technologies.



**Task 2**

Reassess remote sensing technologies for continued development as basin scale tools.



Complete assessment of basin scale technologies.



**Task 4**

Complete InSar testing and evaluation.



**Task 5**

Complete application of hyperspectral and associated imagery.



**Geophysics**

**Task 6**

Development of improved magnetotelluric resolution to 100 m at 1 km.



Complete integrated study using existing field data.



Complete integrated geothermal model.




Complete integrated exploration methodology (toolbox).



Develop improved resolution magnetotelluric to 25-50 m at 1km.



 Milestone

 Go/No Go Milestone

 Technology Output

2006

2007

2008

2009

2010

2011

**Task 7**

Complete Integrated field test 1.



**Task 8**

Begin second integrated field test.



Complete integrated field test 2.



**Task 9**

Improve seismic resolution to 10 m at 1km.



Improve seismic resolution to 10 m at 3 km.



**Task 10**

Interim report on natural fractures.



Complete evaluation of natural fractures.



**Task 11**

Complete data collection to validate selected new geochemical methods.



Complete study of innovative geochemical methods.



**Task 12**

Complete Basin and Range assessment.



Complete Cascade assessment.



Complete assessment of undiscovered resources and non-hydrothermal resources.



**Table 3.9 - Technical Task Milestones for Exploration**

<p><b>5. Remote Sensing</b></p> <ol style="list-style-type: none"><li>1. Correlate regional remote sensing techniques with exploration success. Complete evaluation of technologies. (September 2006 Technical Output)</li><li>2. Reassess remote sensing technologies for continued development as basin scale tools. (September 2006 Go/No Go Milestone)</li><li>3. Complete assessment of basin scale technologies. (September 2008 Go/No Go Milestone)</li><li>4. Complete InSar testing and evaluation. (September 2007 Technical Output)</li><li>5. Complete application of hyperspectral and associated imagery. (September 2006 Technical Output)</li></ol> <p><b>6. Geophysics</b></p> <p>Task 6</p> <ol style="list-style-type: none"><li>6. Develop improved magnetotelluric resolution to 100 m at 1 km. (September 2007 Milestone)</li><li>7. Develop improved resolution magnetotelluric to 25-50 m at 1km. (September 2011Go/No Go Milestone)</li><li>8. Complete integrated study using existing field data. (September 2007 Milestone)</li><li>9. Complete integrated geothermal model. (September 2007 Milestone)</li><li>10. Complete integrated exploration methodology (toolbox). (September 2008 Milestone)</li></ol> <p>Task 7</p> <ol style="list-style-type: none"><li>11. Complete Integrated field test 1. (September 2009 Technology output and Go/No Go Milestone)</li></ol> <p>Task 8</p> <ol style="list-style-type: none"><li>12. Begin second integrated field test. (October 2008 Go/No Go Milestone)</li><li>13-14. Complete integrated field test 2. (September 2011 Technology output and Go/No Go Milestone)</li></ol> <p>Task 9</p> <ol style="list-style-type: none"><li>15. Improve seismic resolution to 10 m at 1km. (September 2006 Milestone)</li><li>16. Improve seismic resolution to 10 m at 3 km. (September 2011 Milestone)</li></ol> <p>Task 10</p> <ol style="list-style-type: none"><li>17. Interim report on natural fractures. (February 2007 Technology Output)</li><li>18. Complete evaluation of natural fractures. (September 2008 Technology Output)</li></ol> <p>Task 11</p> <ol style="list-style-type: none"><li>19. Complete data collection to validate selected new geochemical methods. (March 2007 Milestone)</li><li>20. Complete study of innovative geochemical methods. (September 2011 Technology</li></ol>
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<p>Output)</p> <p>Task 12</p> <ol style="list-style-type: none"> <li>21. Complete Basin and Range assessment. (September 2007 Technology Output)</li> <li>22. Complete Cascade assessment. (September 2008 Technology Output)</li> <li>23. Complete assessment of undiscovered resources and non-hydrothermal resources. (September 2009 Technology Output)</li> </ol>
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### 3.1.3. Systems Development

The Program’s research on technologies and systems required to extract energy from a geothermal resource and convert it to electric power is managed as a single Systems Development subprogram. Systems Development research is subdivided into technology for extraction of energy, referred to as Wellfield Construction, and Energy Conversion technology affecting power generation systems.

#### 3.1.3.1. Wellfield Construction

##### 3.1.3.1.1. External Assessment and Market Overview

Wellfield Construction research makes geothermal drilling and related wellfield construction cheaper and more reliable. Drilling is involved in almost all aspects of geothermal development (exploration, production and injection, and well maintenance). It is expensive relative to other cost elements; and is largely an upfront cost incurred before revenue streams begin. In hydrothermal development, the cost of the production and injection wellfield can be as much as 50% of the total capital investment.

Although much of the equipment for geothermal drilling comes from the oil and gas industry, the drilling is qualitatively different. Because rocks are hard, abrasive, fractured, and hot, and formation fluids are often highly corrosive and underpressured (the pore pressure is less than that of an equivalent column of water), many of the tools used to reduce cost in oil and gas drilling cannot be used in geothermal reservoirs. Because geothermal wells must produce large volumes of fluid, they are larger in diameter than equivalent oil and gas wells. These factors drive the cost of typical geothermal wells much higher than oil and gas wells of comparable depth.

Oil and gas drilling and completion technologies are currently used wherever possible. New and evolving technologies from the oil and gas, mining, and water well industries, can be more widely used once modified and proven for geothermal applications. Because the number of new geothermal wells is limited and the risks associated with use of new or unproven technologies are significant, maximum use must be made of every opportunity for field verification.

Many geothermal drilling needs are unique, requiring development of novel technologies. The Program takes maximum advantage of conventional and new oil and gas technologies in creating and implementing these geothermal-specific technologies.

##### 3.1.3.1.2. Internal Assessment and Program History

The Wellfield Construction program developed as an offshoot of oil and gas drilling activities after the energy crises of the 1970s. Although some DOE Fossil Energy program funding (and, to a limited extent, other funding such as that from the California Energy Commission supporting horizontal drilling R&D) has leveraged Program research, the Program has evolved to address problems unique to drilling in geothermal environments. The Program provides unique, extensive data and technical analysis capabilities not available elsewhere.

## **Historical contributions**

The Wellfield Construction program has developed award winning drilling technologies and tools that have reduced geothermal drilling costs. The Program's work on high-temperature acid resistant cements, acoustic telemetry technologies and a Low Emissions Atmospheric Metering Separator won R&D 100 awards. PDC drill bit development received a DOE Energy 100 Award. As a result of fundamental research on PDC cutters, PDC bits are now used for two-thirds of all oil and gas drilling.

The Program's systems analyses over the past 25 years have enabled development of well-cost modeling methodologies to identify high-payoff projects by identifying areas of high costs and analyzing advanced drilling concepts to determine their cost reduction potential.

Fit-to-purpose concepts resulted in slimhole methodologies to reduce the cost of geothermal exploration. This technology was transferred to industry by publication of a slimhole drilling handbook.

High temperature electronics research, with a goal of reliable operation for long periods at 300°C, has resulted in development of numerous high-temperature logging tools, including well logs that function at 260°C without heat shielding. Four different service companies are commercializing these tools.

Recently developed technologies now being adopted by the service industries include acoustic telemetry methods for real-time, wireless downhole data retrieval and Diagnostics-While-Drilling.

The Program researches emerging technologies and technologies used in other drilling industries (e.g., mining and water well) that can be cost-effectively adapted and demonstrated for the geothermal industry. Successful examples have included Dual-Tube Reverse-Circulation (DTRC) drilling, tremmie pipe cementing, insulated drill pipe, a robust rolling float meter, new grout placement methodologies for lost circulation mitigation, and nitrogen foam cementing.

Tools and research developed by the program have become the basis for drilling industry work, including the PDCWEAR computer code (widely used in PDC bit development); the GEOTEMP computer code (for wellbore temperature analysis); high temperature mud programs; determination of how lost circulation materials (LCM) seal loss zones, development of methods for testing LCM, and ranking of LCM for geothermal applications; and field testing and modeling of the effects of drillstring dynamics on rate-of-penetration and bottom hole assembly wear.

The Program has provided unique analysis capabilities to the geothermal industry that are not available in the private sector.

## **Current Activities**

Current activities of the Wellfield Construction program are summarized below. Section 3.1.3.1.6 describes these activities in greater detail.

Geothermal drilling and well completion technologies, while unique in many ways, complement those of other industries. Oil and gas drilling is conducted worldwide, and wells are going deeper, hotter, and into harder formations. The mining industry does extensive drilling into hard rock. The Program is leveraging rapidly-growing demand for high-temperature electronics by working with the military, NASA, and the aircraft and automobile industries. Geothermal technologies are used in other industries, and technologies from other industrial programs are adapted to meet geothermal needs. The Program seeks to maximize technology transfer and perform R&D that is unique to geothermal requirements, avoiding duplication of effort.

**Well Cost Database and Systems Analysis.** The Program collects and analyzes drilling cost and performance data, develops drilling-cost models and integrates them into general geothermal models, and analyzes the potential of advanced drilling concepts.

**High-Temperature Electronics.** The Program tests and evaluates high-temperature components and develops prototype high-temperature tools to support industry. Field demonstrations of high-temperature electronic technology are being conducted in geothermal wells. Successful demonstrations encourage manufacturers to continue development of high-temperature components, and help persuade geothermal operators to consider using the technology. In a recent demonstration test of high temperature electronics within a geothermal well, a downhole tool based on Silicon-on-Insulator (SOI) technology operated successfully for over 450 days at a well temperature of 193° C (379° F).

**Diagnostics-While-Drilling.** Diagnostics-While-Drilling (DWD) has undergone proof-of-concept testing. A major milestone in FY05 demonstrated DWD technology in a high-temperature geothermal well. Although current activities are not researching other advanced, or new, drilling diagnostics tools, new diagnostics capabilities will be required as improved drilling technologies are developed.

**Hard-Rock Drill Bits.** Rock reduction and removal activities include parametric design and material optimization for PDC & TSP cutters, developing and/or testing advanced cutter materials, and field tests and production drilling qualification of improved bit designs in conjunction with DWD field tests. Drillstring dynamics issues are addressed by computationally modeling drillstring/bit and bit/rock interactions and developing a Prototype Controllable Damper. The Program is considering development of an advanced Drilling Dynamics Simulator for future laboratory-scale testing. Recent testing demonstrating the state-of-the-art PDC drill bits was done in the field through Cooperative Research and Development Agreements with four bit manufacturers.

**Wellbore Integrity.** The Program evaluates methods and materials to avoid or mitigate lost circulation, and develops them as needed to support the industry. Enabling technologies to drill to the next casing point are being evaluated. High-temperature grouting technology to mitigate lost circulation economically in geothermal wells is being tested in laboratory and field demonstrations. After a well at Rye Patch was temporarily abandoned because of seemingly unsolvable lost-circulation problems, the Program responded to an industry request to try reactive plugging techniques being developed by a national laboratory. This field verification of polyurethane grout also led to the demonstration of an alternative approach to drilling with lost circulation – DTRC. DTRC is a technique common in water well drilling but not in geothermal drilling. Over nine subsequent geothermal wells have been drilled with this technique.

**Acid Resistant Cements.** Research on cost-effective, acid-resistant cement systems for wellbore completions in corrosive geothermal environments is focused on bond durability at interfaces between cement and casing, corrosion inhibitors for chemically foamed lightweight cement, and monitoring of advanced cement emplaced in geothermal wells.

**Advanced Concepts.** The Program is seeking opportunities for application or development of advanced drilling system technologies to dramatically reduce drilling costs. Examples include design of deep current-technology wells, and DTRC drilling.

#### **3.1.3.1.3. Federal Role**

In order for geothermal energy to realize its potential, wellfield construction costs and risks must be substantially reduced, particularly for EGS.

Few geothermal wells are being drilled, so the opportunities for natural evolution of geothermal drilling technology are limited. Most of the potential resource base is not yet cost competitive. That resource base will extend across the western half of the country, and throughout much of the eastern United States, as EGS resources become accessible, significantly increasing national energy production.

#### **3.1.3.1.4. Performance Goals**

##### **Goal**

The goal is to develop and transfer to industry technologies that will lower the cost and risk associated with drilling geothermal wells. Commercialization of these technologies will sustain the industry and enable expansion into more challenging EGS resource areas.

##### **Objectives**

The hydrothermal systems objectives are:

1. By 2011, develop and implement improvements to drilling processes to reduce costs by 20% (relative to costs in 2005), e.g., for the 150°C hydrothermal binary air-cooled 1525 m (5000 ft) reference well, reduce drilling costs from \$802/m (\$244/ft) to \$640/m (\$195/ft).
2. By 2011, develop and implement advanced technology solutions to reduce the risk of lost or unproductive (due to drilling problems) wells by 25-50%.

The EGS objectives are:

1. By 2011, demonstrate and implement drilling, completion, and maintenance technologies that support successful first-generation EGS demonstrations.
2. By 2020, develop long-term revolutionary drilling advances to allow drilling to twice today's depths for the same cost.

##### **Metrics**

The primary metric is the levelized cost of energy in cents/kWh, on a constant dollar basis. While detailed reference plant configurations must be defined for calculation of levelized costs, preliminary analyses have been performed to guide research.

Secondary wellfield construction-specific metrics are used to guide technical efforts. Meters/hour (or feet/hour) drilling rate is an engineering metric independent of economics that includes many factors beyond simple rate-of-penetration, e.g., flat time, trouble time, etc. To incorporate the different costs of various technologies (and because it has been used historically as the metric for drilling), \$/meter (or \$/ft) will be used. Constant dollar analyses must be used or costs must be adjusted for inflation.

Because every well is different (lithology, depth, diameter, causes of trouble, wellbore fluids, necessary completion technologies, etc), "actual" well cost varies. To enable tracking of performance improvements, wellfield-cost models use reference wells for which typical cost, performance, and risk values, validated with field data, are used to calculate \$/m and cents/kWh average costs.

##### **Technical Targets**

The fraction of levelized cost of electricity of a geothermal attributable to wellfield construction varies on a case-by-case basis, often reaching as much as 30% of the total cost. Estimating the effect of wellfield construction on levelized cost of electricity requires translating the total cost of the wellfield to cents/kWh by modeling production flows and temperatures, energy conversion efficiencies, financial conditions, etc. Initial calculations have been done for several wellfield scenarios, including:

- A near-term (2011), shallow (1525 m) binary hydrothermal system (with average drilling costs of \$640/m); and
- A near-term (2011), relatively shallow (4000 m) Basin & Range EGS system capable of demonstrating the feasibility of EGS in a first-generation or test phase.

These cases represent the GETEM reference cases used to estimate potential improvements in levelized cost of electricity for the TIPs discussed in Section 0.

Target parameters for these model systems are summarized in Table 3.10. To determine the targets for the primary Wellfield Construction parameters of drilling cost (average \$/m) and well depth, improvements in various parameters were projected (e.g., bit life, rate-of-penetration, trouble time, pumps, piping, O&M reduction, etc.), and the effect of those improvements was calculated. The cost of energy is calculated using the GETEM model.

**Table 3.10 - Technical Targets for Wellfield Construction**

Cost Factor	Reference System	
	2011 Binary Hydrothermal	2011 Initial EGS
Average plant production (MW)	30	38
Average drilling cost (target, \$/m)	640	984
Average Depth (typical, m)	1525	4000
Well Construction Cost (\$)	0.98M	3.93M
Well Construction contribution to levelized cost of electricity (cents/kWh)	0.66	4.10
Surface equipment (piping, etc.) levelized cost of electricity (cents/kWh)	0.19	0.92
Expected O&M (target, cents/kWh)	0.23	2.84
<b>Calculated Target Wellfield Cost of Energy (cents/kWh)</b>	<b>1.08</b>	<b>7.86</b>

### 3.1.3.1.5. Strategic Goals

One strategic goal is to assure the availability of essential high-temperature components. The electronics industry must be able to produce high-temperature components for required downhole geothermal instrumentation. The program supports the industry with cooperative programs, development of standards, participation in working groups and regular conferences, provision of early markets and development opportunities, and technical support. The program tracks the number of high-temperature components available from industry and component operating temperatures and lifetimes.

### 3.1.3.1.6. Approach

While no single element of wellfield creation has the potential to dramatically reduce total cost, a combination of improvements in all activities associated with creating the wellfield can achieve the objectives.

Activities will be prioritized and quantitatively ranked by systems analysis, permitting selection of activities with the highest payoff. Coordination with reservoir developers will assure that technologies being researched respond to their needs, and the Program will leverage

complementary technology development in related industries, such as oil and gas and mining. Progress and results will be documented in journals, conference papers, and laboratory technical reports.

The program develops both tools and techniques, and improved technologies. While it is impossible to predict which specific technologies will be developed in future years, the following examples are representative of the types of technologies under consideration.

### **Develop tools and techniques**

The Program develops tools and techniques to diagnose, assess, and improve drilling system performance through:

- Systems Analysis
- Creation and utilization of “Smart Development” Capabilities, including Numerical Simulation, Laboratory Testing, and Field Testing
- Development of Advanced Diagnostics, including High-Temperature Electronics, Diagnostics While Drilling, and other advanced instrumentation systems
- Infrastructure Engineering

Systems analysis activities include analyses of wellfield system requirements, costs, performance, limitations, needs, and R&D priorities. They support:

- Development, improvement, and validation of drilling cost/performance sub-models for incorporation into geothermal system cost and performance macromodels.
- Tracking industry needs and trends through regular, structured interactions with industry and industry groups.
- Identifying and applying/adapting technologies to develop interest, cost-sharing, and markets beyond the geothermal industry such as oil & gas; high-temperature electronics applications for the Department of Defense, NASA, and others; and grout materials for the mining industry.
- Integration of wellfield development with requirements of other geothermal applications (EGS, exploration, direct use and geothermal heat pump drilling, etc.)
- Quantitative assessment of R&D cost, risk, and payoff to help prioritize R&D activities.

“Smart development” capabilities are designed to improve understanding of the drilling process.

- Numerical Simulation activities involve development and application of computational models of drillstring dynamics for predictive and control applications (akin to stockpile stewardship in DOE’s nuclear weapons program).
- Laboratory testing includes expansion of laboratory capabilities for testing and validation of drilling system components to simulate drillstring dynamics, rock/bit interactions, and other concepts, using a Drilling Dynamics Simulator (DDS); a high-temperature, high-pressure autoclave; and related components.
- Testing and field validation of promising components and systems is used to validate progress, assess needs, and guide development.

Computer models allow testing and evaluation of capabilities before committing to hardware, and provide the basis for advanced controls. Promising options can be tested and improved in the laboratory, and field qualification tests emphasize successful early demonstrations (avoiding false negatives). Laboratory and field testing validates and provide feedback to the modeling process. This development system reduces the time to market for advanced technologies, and provides a historical database for evaluation of new technologies.

Advanced diagnostics for understanding, controlling, and optimizing the drilling process are critical to achieving cost goals. High-temperature electronics systems and the design tools must be developed and qualified. High-temperature batteries must be developed to allow operations that do not need downhole wireline power systems. Advanced diagnostic systems include the Diagnostics-While-Drilling tool now being developed to improve understanding of dynamics at the drill bit, and new tools required by reservoir developers (e.g., long-term high-temperature, high-pressure monitoring; seismic monitoring for EGS applications; and special applications such as resistivity, flow, sampling, and very high temperatures).

Infrastructure engineering is a low-cost, high-payoff activity to assure availability of the capabilities and understanding to use new or improved technologies. The Program is supporting development of a “geothermal friendly” high-temperature electronics industry, and commercial manufacturing capabilities for specialized tools needed by the industry. The program will help the industry establish a web-based best-practices information clearinghouse to encourage their industry-wide adoption of state-of-the-art technologies.

### **Develop improved drilling technologies**

The Program develops improved drilling technologies to lower the cost and risk of geothermal development. Both near-term evolutionary advances and longer-term revolutionary technologies are necessary to meet cost goals. Activities conducted in conjunction with industry include cost-shared competitive procurements, pre-competitive consortia, cooperative research and development agreements (CRADAs), and cooperative in-house laboratory R&D. Cost and risk reductions are being pursued across all aspects of wellfield construction:

- Site-specific well design optimization for type, depth, lithology, maintenance, flow, etc..
- Rock reduction and removal to increase rate of penetration (ROP) and bit life using improved cutters, bits, operating procedures, and novel technologies.
- Wellbore integrity improvements to reduce incidences of trouble and increase efficiency and cost-effectiveness of mitigation of lost circulation, water intrusion, wellbore stability, and related problems.
- Well construction/completion using novel casing, lining, cementing, and other technologies, and designs and procedures to limit formation damage and lost wells and to improve well productivity.
- Wellfield operations and maintenance using improved designs, pumping technologies, materials, and procedures optimized for well and fluid conditions.

Technologies will be selected for research based on reservoir developers’ needs, projected benefits, and estimated development costs and likelihood of success.

### **Technology Status**

**Systems Analysis.** Data from 32 geothermal wells have been incorporated into a well-cost database, providing information needed for cost assessment. An improved well-cost model has been developed and used to assess costs for a variety of “standard” conditions and to update drilling cost metrics. A short list of advanced technologies has been compiled and assessment has begun. Detailed cost and cost-improvement models will help identify high-priority R&D activities most likely to meet objectives.

**Smart Development Capabilities.** A limited numerical modeling activity supports understanding of drillstring dynamics and other issues, and a suite of laboratory capabilities allows testing of cutters, bits, prototype downhole controllable damping, and high-temperature electronics and instrumentation. Dynamic modeling is addressing characterization of rock/cutter interaction for drill bits including bit performance, force predictions and wear rates; prediction of instabilities in the drilling process that lead to deleterious vibrations; and validation of new

hardware for field deployment. Results are validated with field results whenever possible. Utilizing this suite of “smart development” capabilities will improve the cost-effectiveness of R&D and bring advanced technologies to the market quickly.

**High-Temperature Electronics.** The emerging high-temperature electronics industry is attempting to identify the market and the role of various component manufacturers. Future purchasers are seeking high-temperature components to build complete commercial systems. Long-term field demonstrations show excellent performance. Additional high-temperature systems, particularly supporting DWD, are being developed to meet program and industry needs. The improved understanding of downhole conditions provided by high-temperature instrumentation will contribute to meeting cost-reduction objectives, especially for EGS.

**Development of Advanced Diagnostics.** A working DWD system for low-temperature applications has demonstrated the validity of the approach and gained the support of industrial partners. The Program will provide a commercially available tool,

demonstrate the value of extensive real-time downhole data, and improve understanding of drillstring dynamics issues to spur development of improved drilling tools and processes. Additional activities will be planned based on new technology developments and establishment of advanced diagnostics priorities.

**Engineering the Needed Infrastructure.** The Program is promoting development of a high-temperature electronics industry standard. Technology transfer of DTRC drilling and tremmie pipe cementing has resulted in demonstrated cost reductions in geothermal applications.

**Well Design.** Well design work helps minimize cost and define diameter and depth intervals within which rock-reduction research must reduce cost. Designs have been completed for 3650 and 6100m wells. Concepts such as monobore wells and expandable casing are being analyzed to determine their cost reduction potential. Modeling of the mechanical, thermal, and thermal/mechanical life cycle of a well can be used to forecast subterranean environmental changes from spud through completion. The results of these analyses, coupled with drilling material and method developments, will enable development of designs which could reduce life cycle costs by reducing raw material consumption.

How Current Activities Fit the MYPP Structure	
MYPP Structure	Current Program Structure
<b>Tools and Techniques</b>	
<ul style="list-style-type: none"> <li>• Systems Analysis</li> </ul>	<ul style="list-style-type: none"> <li>• Well Cost Database</li> <li>• Advanced Concepts</li> </ul>
<ul style="list-style-type: none"> <li>• “Smart Development” Capabilities, including Dynamic Modeling, Laboratory Testing, Field Testing</li> </ul>	<ul style="list-style-type: none"> <li>• Wellbore Integrity</li> <li>• Hard Rock Drill Bits</li> <li>• Advanced Concepts</li> </ul>
<ul style="list-style-type: none"> <li>• Development of Advanced Diagnostics</li> </ul>	<ul style="list-style-type: none"> <li>• High-Temperature Electronics</li> <li>• Diagnostics-While-Drilling</li> </ul>
<ul style="list-style-type: none"> <li>• Engineering the Needed Infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>• High-Temperature Electronics</li> </ul>
<b>Improved Drilling Technologies</b>	
<ul style="list-style-type: none"> <li>• Well design</li> <li>• Rock reduction &amp; removal</li> <li>• Wellbore integrity</li> <li>• Well construction/completion</li> <li>• Wellfield operations and maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Wellbore Integrity</li> <li>• Acid Resistant Cements</li> <li>• Hard-Rock Drill Bits</li> <li>• Advanced Concepts</li> <li>• Diagnostics-While-Drilling</li> </ul>

**Rock Reduction and Removal.** PDC cutter performance can be improved by an order of magnitude by variations in geometric design and material properties. Laboratory tests have validated improved fracture toughness for TSP cutters produced using proprietary treatments. Joint CRADA-based field tests with industry partners have yielded extended hard-rock bit runs at high penetration rates for “best effort” drag bits operated with DWD. Laboratory tests of a Prototype Controllable Damper have demonstrated improved drilling stability. Improved rock-reduction efficiency, bit life, and advanced rock-reduction technologies will provide major contributions to meeting cost reduction objectives.

**Wellbore Integrity.** High-temperature polymer grouts have been demonstrated in the lab. A new technology using silicates to form high-temperature plugs has been demonstrated in the lab to >300°C. These grouting methods are drawing the interest and support of industrial partners. Modifying drilling plans by an operator to anticipate lost circulation, combined with tremmie pipe-assisted cementing has decreased drilling time and costs in side-by-side wells.

**Well Construction/Completion.** Well construction and completion assure that drilling addresses the entire system and meets underground access requirements for engineering the reservoir. This work includes approaches such as 1) fit-to-purpose rigs, e.g., DTRC drilling; 2) application of advanced casings, e.g., expandable tubulars and advanced materials; and 3) incorporating technology to allow deep setting of pumps. Acid resistant cements have increased corrosion resistance of the casing/cement system, potentially decreasing well life-cycle costs for geothermal brines with moderate pH. Improved resistance is being developed for very low pH, and less expensive formulations are being investigated. Industry has identified near-term pump design research involving water intrusion into cable and potheads; replacement of heavy lead cladding that protects copper cable from H<sub>2</sub>S corrosion; improved high-temperature epoxy potting compounds for motor windings; an oil recovery system for pump bearings; and water-lubricated pump bearings.

Improvements in this area will increase the drilling success rate relative to drilling-caused problems. Twenty percent or more of wells are not successfully completed or are re-completed as observation or injection wells. Wells are lost or production is impaired due to twist-offs, lost tools, casing failures, bad cement jobs, loss of wellbore integrity, and other mishaps which cannot be corrected. Formations damaged by inappropriate mud systems result in lost production, and neighboring wells can be damaged by loss of drilling fluids and cement, adding to project development costs. Improving the success rate will reduce costs by eliminating problems that cause well failure. Cutting the number of unsuccessfully completed wells in half could decrease wellfield costs by as much as 10%.

**Well Maintenance.** Well maintenance addresses brine chemistry and rock deformation that reduces the lifetime of wells, requiring workovers or well replacement. Many wells must be prematurely replaced due to material failures. Titanium liners prevent corrosion, but at high cost. Recent advances in material science have enabled reevaluation of advanced materials for downhole use. Additional work on designs to minimize well maintenance costs is needed.

### **3.1.3.1.7. Market Challenges and Barriers**

#### **Cross-Cutting Barriers**

**A. Well Access.** Short-term operator costs associated with hosting development tests limit the availability of wells for validation of laboratory and numerical predictions, high-temperature electronics and DWD testing, and evaluation of wellbore integrity solutions (e.g., grouts, cements, etc.) Additional funding is required to offset these costs. Because many wells are available, access to “hot” oil and gas wells will be substituted for geothermal wells.

- B. Field Testing Costs.** Field tests are costly and often difficult to interpret. They are risky for developers, which makes finding sites problematic. Modeling and laboratory simulations are used to minimize field testing and maximize the probability of success, but some field tests are required to validate progress, guide future development, and convince industry of the potential of new technologies.
- C. Small Markets.** Geothermal markets are so small that it is difficult to justify commercial production of high-temperature grouts, cements, muds, and other technologies. The oil and gas industry, NASA, the military, and the commercial aviation and auto industries can provide the necessary markets for high-temperature electronics.
- D. Transparent Telemetry.** A fast data link is needed for reliable downhole tools and controls. The current DWD system uses a wireline system as the data carrier. Cost-effective telemetry systems less intrusive to the drilling process are required for widespread acceptance of high-speed, real-time drilling diagnostics.

#### Systems Analysis

- E. Well Data.** The number of geothermal wells being drilled is few, and those being drilled are in resources already under development. Drilling data on undeveloped resources, including EGS, is limited. Existing data is not necessarily representative of future drilling.
- F. Mechanical-Drilling Lithologic Data.** Generic approaches to drilling are costly. Quantitative data on drilling of undeveloped resources, including EGS, is speculative. Data from exploration activities and sampling and testing will define the mechanical-drilling lithology for specific resources.
- G. Unpredictable Economics.** The most cost-effective drilling technologies must be identified. Well costs are highly dependent on unpredictable economic factors: discount rate, inflation, competing demand for oil/gas rigs, logging components and well completion materials.

#### 3.1.3.1.8. Technical Challenges and Barriers

##### Smart Development Capability

- H. Model Complexity.** Dynamic models of processes such as drillstring dynamics, drillstring/bit interactions, and rock/bit interactions are complex, requiring extensive development. Extensively instrumented laboratory testing and field tests are used to collect data for validation/modeling guidance.
- I. Material Properties Characterization.** Characterization of rock behavior at elevated pressures and temperatures is necessary for adequate rock/bit interaction models.
- J. Laboratory System Capabilities.** Today's laboratory capabilities (Sandia's Hard-Rock Drilling Facility and Linear Cutter Test Facility) are not able to simulate key dynamic issues.
- K. Laboratory Testing at High Pressures and Temperatures.** Time-consuming, expensive testing at high pressures and temperatures is required to represent the properties encountered in field drilling.

##### Development of Advanced Diagnostics

- L. Lack of High-Temperature Components.** There are not enough high-temperature components on the market for service companies to build high-temperature logging and drilling tools required for deep drilling.
- M. High-Temperature Electronics Cost.** No single service company can afford to build/maintain its own custom high-temperature electronic devices. Common standards can enable use of similar components across many industries.

- N. **No High-Temperature Battery:** Approximately 70% of drilling and logging tools require high-temperature batteries. No battery technology operates above 200°C.
- O. **DWD Testing Cost.** The cost associated with fielding DWD systems is high compared to the benefits shown in prototype tests. Further DWD development is needed to make the technology a standard tool in the geothermal drilling environment.
- P. **System Durability.** The utility of the DWD system has been proven in an R&D environment, but acceptance by industry will require a more robust commercial tool.
- Q. **Need Identification.** Systems analysis will be used to prioritize advanced diagnostic needs. Timely development of diagnostics capabilities will require coordination with other program areas.

#### **Engineering the Needed Infrastructure**

- R. **Information Availability.** State-of-the-art information is not always readily available to users (especially small users). Well-publicized, continually updated, on-line databases could help users adopt new technologies and follow trends in drilling.
- S. **Outreach/Direct Communication.** Technology transfer requires communication with industry to identify challenges and problems and to demonstrate solutions. Determining root causes of problems may require first hand experience, and solutions may be perceived as risky until they become common practice.

#### **Well Design**

- T. **Adequate Flow Capacity.** Economic geothermal production requires large diameters to prevent choking of flow. Geologic issues, unanticipated borehole stability problems, cold water influx, etc., can be mitigated through additional casings, but this reduces flow capacity or requires overly expensive large initial diameters (excessive design contingencies).
- U. **Casing Material.** Casings should ideally have a combination of properties that do not coexist: strength and ductility of metal, lightness and strength of non-metals, high temperature resistance, and the cost of mass-produced construction materials.
- V. **Design Optimization.** Mechanical, thermal, and thermal/mechanical response of the casing-cement-rock system should be optimized for the predicted life-cycle of a well through trade-off studies.

#### **Rock Reduction and Removal**

- W. **Penetration Rate.** The ROP of current rollercone and drag bits in typical geothermal production sites is too low. Better cutters and bits are needed that can survive in hot, hard, abrasive, and fractured environments.
- X. **Bit Life.** The severe conditions encountered during geothermal drilling accelerate bit wear and impact damage. Improved materials, drilling techniques, and/or process controls are needed for extended bit runs.
- Y. **Cost.** The cost of geothermal drilling with current synthetic-diamond drag bits is too high due to the combination of large initial cost and limited ROP and bit life. New cutter and bit technologies are needed to reduce the normalized bit cost per meter of drilled hole.

#### **Wellbore Integrity**

- Z. **Hot, Highly Fractured Formations.** Geothermal formations are typically highly fractured, resulting in severe lost-circulation and wellbore integrity issues. Higher temperatures create additional challenges for lost-circulation materials.
- AA. **Operator/Industry Acceptance of New Drilling Technology.** Operator/Industry practices are difficult to change, even in the face of potential improvements and cost savings.

Additional funding is required to offset operator costs during the evolution of new drilling practices.

### **Well Construction/Completion**

- BB. Pumping.** Pumping is frequently required to achieve adequate flow rates. Current technology requires excessively large well diameters to set pumps deep.
- CC. EGS Reservoir Completion/Intervention.** Intervention will be required to manage EGS reservoirs. Whereas oil and gas wells are completed with tubing inside the casing to provide intervention/completion options, tubing would unacceptably choke flow in geothermal wells. Economic geothermal completions include open-hole and slotted liners, which have problems in systems requiring permeability enhancement. Short-circuiting problems may require high-temperature grout placements.
- DD. Cement Capabilities.** Current cements are not suitable for use in hot, corrosive geothermal wells. New cements must be economically competitive and proven over a range of conditions.
- EE. Severe Geothermal Conditions.** Wells are lost or production is impaired due to twist-offs, lost tools, casing failures, bad cement jobs, loss of wellbore mechanical integrity, and other mishaps which cannot be fixed, and formation damage by inappropriate mud systems results in lost production. These problems are exacerbated in typical geothermal environments.
- FF. Geologic Variability and Complexity.** Experience can usually be used to minimize drilling costs. Variability among geothermal resources is high, and the number of wells drilled at a given site is low, making it difficult to reap the benefits of learning.
- GG. Unknown Target.** Drilling success requires intersecting productive zones within the reservoir and orienting the well relative to the in situ stress, and hence is subject to the success of exploration technologies. These are relatively unknown before drilling.

### **Wellfield Operations and Maintenance**

- HH. Brine Chemistry & High Temperature.** High temperatures, brine chemistry, and pH make corrosion and scaling a major challenge. Inexpensive anti-corrosion and anti-scaling materials are hard to develop.
- II. Tectonic Activity.** Geothermal resources are often in tectonically active areas. Improved designs must be resilient to deformation, but cannot stop movement of the earth. Maintenance options must be developed for these situations.

#### **3.1.3.1.9. Strategies for Overcoming Barriers and Challenges**

While the technical challenges of Wellfield Construction are similar to those of the oil and gas industry, there are key differences. Geothermal formations are typically hard, abrasive, fractured, and hot. Formation fluids are often highly corrosive and underpressured. Because of the high flow rates, wells are also substantially larger in diameter than oil and gas wells. To make a large geothermal resource base cost-effective, these wells must be drilled for less than half of current costs with high reliability.

#### **Technology Improvement Potentials**

Table 3.11 includes estimates of the potential impact of the TIPs on levelized energy cost (rolled up to the activity level, e.g., Well Design). While the 2016 column is beyond the scope of this MYPP, future directions help explain program activities over the next five years.

These impacts are preliminary, based on estimates of relative cost savings expected for each of the activity areas and the goal of drilling cost savings of 20% by 2011 (detailed well cost modeling has not yet been completed). Projected savings have been incorporated into the

Improved Drilling Technologies areas, with Tools and Techniques activities considered “enabling technologies” for the expected improvements. Two 2011 GETEM reference cases were used as a basis for the calculations (the cases discussed under Technical Targets in Section 3.1.3.1.4). The Binary case is a 1525 m (5000 ft) deep, 150°C reservoir and a binary air-cooled conversion plant. The EGS case is a 4000 m (13123 ft) deep, 200°C reservoir, also with a binary air-cooled plant.

The estimated savings ranges incorporate potential cost savings ranges for the activity and a range of success in other elements in meeting cost projections (from zero to complete success). The total cost savings from Wellfield Construction for these reference cases range from 0.12 to 0.42 cents/kWh for the Binary case to 0.55 to 5.25 cents/kWh for the EGS case.

**Table 3.11 - TIPs for Wellfield Construction**

Title/Description	Metric	2006	2011	2016
<b>Systems Analysis</b>		Potential Savings: Enabling (incorporated below)		
Cost model predicting the impacts of drilling technology improvements (input into greater $\phi$ /kWh model).	Scope and detail of technologies modeled.	Existing technologies; simplified model	Emerging & advanced concepts; detailed model	
<b>Numerical Simulation</b>		Potential Savings: Enabling (incorporated below)		
Rock/bit interactions understanding	Accuracy predicting bit performance for rock reduction	60%	80%	95%
Drilling instability understanding	Accuracy predicting instability of bit/ drillstring interaction	20%	40%	80%
Drilling system performance and reliability understanding	Hardware performance/ reliability in field deployments	80%	95%	99%
<b>Laboratory Testing</b>		Potential Savings: Enabling (incorporated below)		
Drilling Dynamics Simulator capabilities	Degrees of Freedom Simulated	1	3	6
Autoclave testing capabilities	Temp (°C), Pressure (MPa)	325°C, 10MPa		
<b>Field Testing</b>		Potential Savings: Enabling (incorporated below)		
Field validation tests successfully supporting smart development efforts	% successfully supporting modeling efforts	25	40	60
<b>High-Temperature Electronics</b>		Potential Savings: Enabling (incorporated below)		

Title/Description	Metric	2006	2011	2016
Successful demonstrations of geothermal tool electronics	# of HTE devices Temp (°C)	15 300	150 250	200 300
Increased availability of high-temperature services to the geothermal industry	# of HT logging and drilling tools offered	1	5	20
<b>Development of Advanced Diagnostics</b>		Potential Savings:		Enabling (incorporated below)
DWD availability and functionality in geothermal temperature regimes	°C Increased functionality	225 Drillstring dynamics	250 BHA & lost circulation measurements	250 Resource confirmation
Increased bit life through real-time trouble avoidance	% Bit life improvement	0	50	100
Mean-time to Failure of DWD system electronics	Hours	200	1000	10,000
Adaptation of non-wireline telemetry technologies for DWD	Number of technology options	1	2	3
Flat-time reduction	% Reduction	5	10	15
Adaptation of DWD capabilities to support new drilling technologies	Time to implement new diagnostic capability (yr)	2	2	1
Real-time telemetry/ look ahead technologies to locate and drill to targets cost effectively.	Proof of concept tests	Concept plans	Plugging back and redrilling	Plugging back and redrilling not required
<b>Engineering the Needed Infrastructure</b>		Potential Savings:		Enabling (incorporated below)
Commercially available high-temperature electronics components (a gauge of the number of new high-temperature component manufacturers)	Number of new components	1	5	10
<b>Well Design</b>		Potential Savings (¢/kWh)		0.04 – 0.15 0.28 – 1.88 Binary EGS
Well designs optimizing steel and cement use through site-specific analyses	% life-cycle raw material cost savings	1	3	5
Well designs minimizing steel through lean designs (e.g., monobore technology)	Number casing strings.	Existing designs with deeper set points	One less string	One string more than required for ES&H
<b>Rock Reduction &amp; Removal</b>		Potential Savings (¢/kWh)		0.05 – 0.15 0.14 – 1.13 Binary EGS
Rate of Penetration – granite (ROP)	m/hour (rollercone (RC) or PDC)	5 (RC)	10 (PDC)	20 (PDC)

Title/Description	Metric	2006	2011	2016
Bit life (run distance)	meters	50	150	300
Normalized Rock Reduction Cost	\$/m	400	300	150
<b>Wellbore integrity</b>		Potential Savings (¢/kWh)		Binary EGS
			0.01 – 0.06 0.05 – 1.50	
Flat-time reduction	% reduction	5	10	15
Shortened drill & completion time	% cost savings	5	10	15
<b>Well Construction/Completion</b>		Potential Savings (¢/kWh) (no credit for submersible pumps)		Binary EGS
			0.02 – 0.06 0.09 – 0.75	
Economic acid resistant cements	Synthesis/Characterizations	Durability studies	Field demos	Commercial
Adaptation of DTRC drilling for use on generic rigs.	Demonstrations	Engineering studies	Two demonstrations	Common practice
Wellbore/pump designs/deployment allowing pumps to be set at any depth without increasing casing diameter	Temperature (°C) Flow rate (m <sup>3</sup> /hr) Service Life (hr) Diameter (m) Depth (m)	150 23 4000 0.27 3000	250 46 8000 0.24 6000	
Shoe-to-shoe drilling without stopping to plug each lost circulation zone	Demonstrations	Engineering plans	Two demos for total lost circulation	Two demos for cross flow
<b>Wellfield O &amp; M</b>		Potential Savings (¢/kWh)		TBD pending additional analysis
New corrosion-resistant casing materials/coating systems to reduce well life-cycle cost	Material designs/testing	In-house validation tests	Field validation tests	Commercialization
<b>Potential Impact of TIPs for Wellfield Construction</b> (based on 7/21/05 GETEM runs, not including submersible pumps and O&M)		Total Potential Savings (¢/kWh)	0.12 – 0.42 0.55 – 5.25	Binary EGS

### 3.1.3.1.10. Tasks

The Technical Task Descriptions for Wellfield Construction are presented in Table 3.12. Each task shows the associated barriers and task durations.

**Table 3.12 - Technical Task Descriptions for Wellfield Construction**

Task	Title/Description	Barriers	Duration In years
<b>Tools and Techniques</b>			
<b>1</b>	<b>Systems Analysis</b>		
	<ul style="list-style-type: none"> <li>Develop cost models of evolutionary, emerging (technology being developed elsewhere by industry but not yet tested for geothermal drilling) and advanced (revolutionary technology) concepts. Integrate with overall geothermal models. Assess on an ongoing basis the potential of various advanced technologies, their projected costs, and</li> </ul>	B,E,G	6

Task	Title/Description	Barriers	Duration In years
	<p>their impact on other technologies.</p> <ul style="list-style-type: none"> <li>• Gather well-cost and mechanical-drilling lithology data to update the well-cost database and calibrate system cost models.</li> <li>• Develop capability to model life-cycle mechanical, thermal, and thermal/mechanical response of the casing-cement-rock system to optimize life-cycle cost/benefit of well component-completion options.</li> <li>• Develop capability to model life-cycle production of various completion options (large single-leg vs. slim multi-leg, open hole vs. cased hole, etc.) to determine life-cycle cost/benefit of drilling-completion options.</li> <li>• Prioritize/choose advanced concepts to evaluate progress in the development of geothermal drilling technology against programmatic metrics, and to prioritize R&amp;D directions.</li> </ul>	<p>E,F,G</p> <p>E,F,G, CC,DD</p> <p>A,B,E, G,H,T, U,V</p> <p>B,E,F,G</p>	<p>6</p> <p>3</p> <p>3</p> <p>1</p>
<b>2</b>	<p><b>Smart Development Capability – Numeric Simulation</b></p> <ul style="list-style-type: none"> <li>• Continue development of rock/bit interaction codes to facilitate development of advanced bits and introduction of new rock-reduction technologies.</li> <li>• Continue computational modeling effort to characterize the mechanisms contributing to drillstring vibrations.</li> <li>• Develop and apply physical performance models (including flow rate, pressure-drop modeling) to determine technical feasibility of advanced drilling concepts. Use these engineering models coupled to economic analyses to direct research investment.</li> </ul>	<p>H,I</p> <p>H,I</p> <p>B,H,I,K</p>	<p>6</p> <p>2</p> <p>3</p>
<b>3</b>	<p><b>Smart Development Capability – Laboratory Testing</b></p> <ul style="list-style-type: none"> <li>• Continue testing in existing Sandia facilities (Hard-Rock Drilling Facility and Linear Cutter Test Facility) to develop unique data for modeling the cutter/rock interaction process and evaluating new technologies for subsequent field testing.</li> <li>• Develop the Drilling Dynamics Simulator, a research facility to allow an improved understanding of the factors contributing to drillstring vibrations and the development and validation of downhole tools to mitigate these. Vibrations. The capabilities of this facility will be available to industry as needed.</li> <li>• Develop a high-temperature, high-pressure autoclave capability to prove full-scale viability of prototype developmental hardware before committing to field trials. The capabilities of this facility will be available to industry as needed. This task will in turn support most of the tasks outlined in Tasks 4, 5, 6 and pump-related aspects of 11 below.</li> </ul>	<p>H,I</p> <p>H,I,J,K</p> <p>A,B,J, K,L,M, N,O,P, BB</p>	<p>1</p> <p>6</p> <p>1</p>
<b>4</b>	<p><b>Smart Development Capability – Field Testing</b></p> <ul style="list-style-type: none"> <li>• Perform field validation of promising drilling systems in support of laboratory and analytical/numerical prediction of drillstring behavior. The validation efforts will validate progress, assess additional needs, and help guide development.</li> <li>• Perform field tests of active subs to suppress deleterious drillstring</li> </ul>	<p>A,B,K</p> <p>J,K</p>	<p>6</p> <p>3</p>

<b>Task</b>	<b>Title/Description</b>	<b>Barriers</b>	<b>Duration In years</b>
	dysfunctions. Tests will be performed with complementary diagnostic technologies (e.g., DWD) to provide necessary feedback for suppression sub development.		
<b>5</b>	<p><b>Development of Advanced Diagnostics – High-Temperature Electronics</b></p> <ul style="list-style-type: none"> <li>Conduct public domain demonstrations of commercial off-the-shelf high-temperature electronic components within geothermal wells to encourage industry confidence in HIGH-TEMPERATURE technology, creating market pull; increase the number of qualified high-temperature components; reduce the risk of high-temperature tool development for the service companies; and ensure that the emerging high-temperature electronics market meets geothermal requirements</li> <li>Ensure the largest possible number of qualified high-temperature components, the largest possible market, and lowest cost for new high-temperature electronic components by “standardizing” the general requirements of all HT industries, including commercial aircraft, US military, deep fossil energy drilling, and geothermal.</li> <li>Develop high-temperature batteries through a competitive procurement for high-temperature battery development with a 50% cost-share from industry.</li> </ul>	<p>C,K,L, M</p> <p>C,K,L, M, O,P</p> <p>N</p>	<p>6</p> <p>6</p> <p>3</p>
<b>6</b>	<p><b>Development of Advanced Diagnostics – DWD and Advanced Diagnostics</b></p> <ul style="list-style-type: none"> <li>Expand DWD capabilities for drilling in the severe environments associated with geothermal wells. Continued system development will focus on making appropriate diagnostic measurements with increased temperature capabilities and improved robustness. The interface between the driller and the system will evolve, as will real-time analysis tools to aid the drilling process.</li> <li>Develop a surface drilling “sub” to provide real-time, portable measurements of surface-based drilling parameters (e. g., surface measurements of weight-on-bit, torque, mud flow rate, temperature, etc.). The system will be integrated into the DWD system but also be capable of providing stand-alone measurements. Comparison of surface and DWD data correlation will be used to assess whether surface-only measurements (if appropriate in detail and frequency) could be adequate if available.</li> </ul>	<p>A,D,H, K,O,P</p> <p>A,H,O</p>	<p>5</p> <p>4</p>
<b>7</b>	<p><b>Engineering the Needed Infrastructure</b></p> <ul style="list-style-type: none"> <li>Support creation and expansion of a high-temperature electronics industry to support geothermal by establishing an on-line, web-based database of high-temperature electronics best practices and learning curves.</li> <li>Develop a technology transfer mechanism between industry and research rooted in first hand experience.</li> </ul>	<p>C,L,M, N</p> <p>A,B,C, R,S</p>	<p>3</p> <p>6</p>
<b>Improved Drilling Technologies</b>			
<b>8</b>	<b>Well Design</b>		

Task	Title/Description	Barriers	Duration In years
	<ul style="list-style-type: none"> <li>Analyze technical challenges of advanced well design options, including detailed design, prototype construction, and field testing of most promising options.</li> </ul>	B,T,U, V	4
9	<b>Rock Reduction and Removal</b> <ul style="list-style-type: none"> <li>Field test and qualify improved bit designs for production drilling in conjunction with DWD.</li> <li>Develop and demonstrate additional downhole tools and BHA components (e.g., hard-rock underreamer).</li> <li>Develop, fabricate, and laboratory test a controllable damper system to mitigate drillstring/bit vibration issues, with design based on modeling results. If results continue to be promising, initiate field tests in cooperation with industry.</li> </ul>	A,M,O, B,R,Y	4
		W,X,Y	5
		D,O,W, X,Y	6
10	<b>Wellbore Integrity</b> <ul style="list-style-type: none"> <li>Demonstrate new silicate grout capabilities in a large lab demo. The silicates have been demonstrated to flash set into a competent grout material that is thermally stable for all geothermal conditions. Define the adhesion characteristics of silicate grout systems to rock in hot water-flowing environments using the thermally encapsulated/activated silicate hydrate grout system in bench-scale evaluations.</li> <li>Field demonstrate the silicate-based grout system by placing the thermally encapsulated/activated silicate hydrate grout in a geothermal well, arresting lost circulation, and allowing drilling to continue.</li> <li>Demonstrate polymer grout technology, with temperature capabilities recently extended to &gt;260°C, in a high-temperature geothermal well to enhance industry acceptance of the method.</li> <li>Develop and test advanced high-temperature drilling muds. Working with available technology within industry, a silicate-based mud coupled with glass fibers will be developed, tested, and fielded for geothermal well applications.</li> <li>Develop advanced grout/cements suitable for low pH environments and to meet EGS issues yet unidentified, addressing lost circulation, water shut off, well completion needs, etc.</li> <li>Evaluate, as part of advanced wellbore stability research, advanced options for eliminating the need for steel (e.g., by increasing the strength / fracture gradient of the rock or using other materials). Lab and field test promising options.</li> </ul>	A,C,Z	1
		A,C,Z, AA,CC	2
		A,Z	1
		A,X,Z	4
		Z,EE	5
		A,U,Z, AA	4
11	<b>Well Construction/Completion</b> <ul style="list-style-type: none"> <li>Develop advanced DTRC rig design modifications to allow DTRC utilization on a more common basis (particularly for otherwise undrillable/uneconomic resources). Demonstrate in a field environment if promising.</li> <li>Validate available advanced, cost-effective, high-temperature drillable packers to more economically allow placement of polymer plugs and facilitate water shut off for EGS reservoir management.</li> <li>Initiate efforts to improve downhole/submersible pumping</li> </ul>	A,Y,Z, EE	3
		A,Z,EE	2
		BB	6

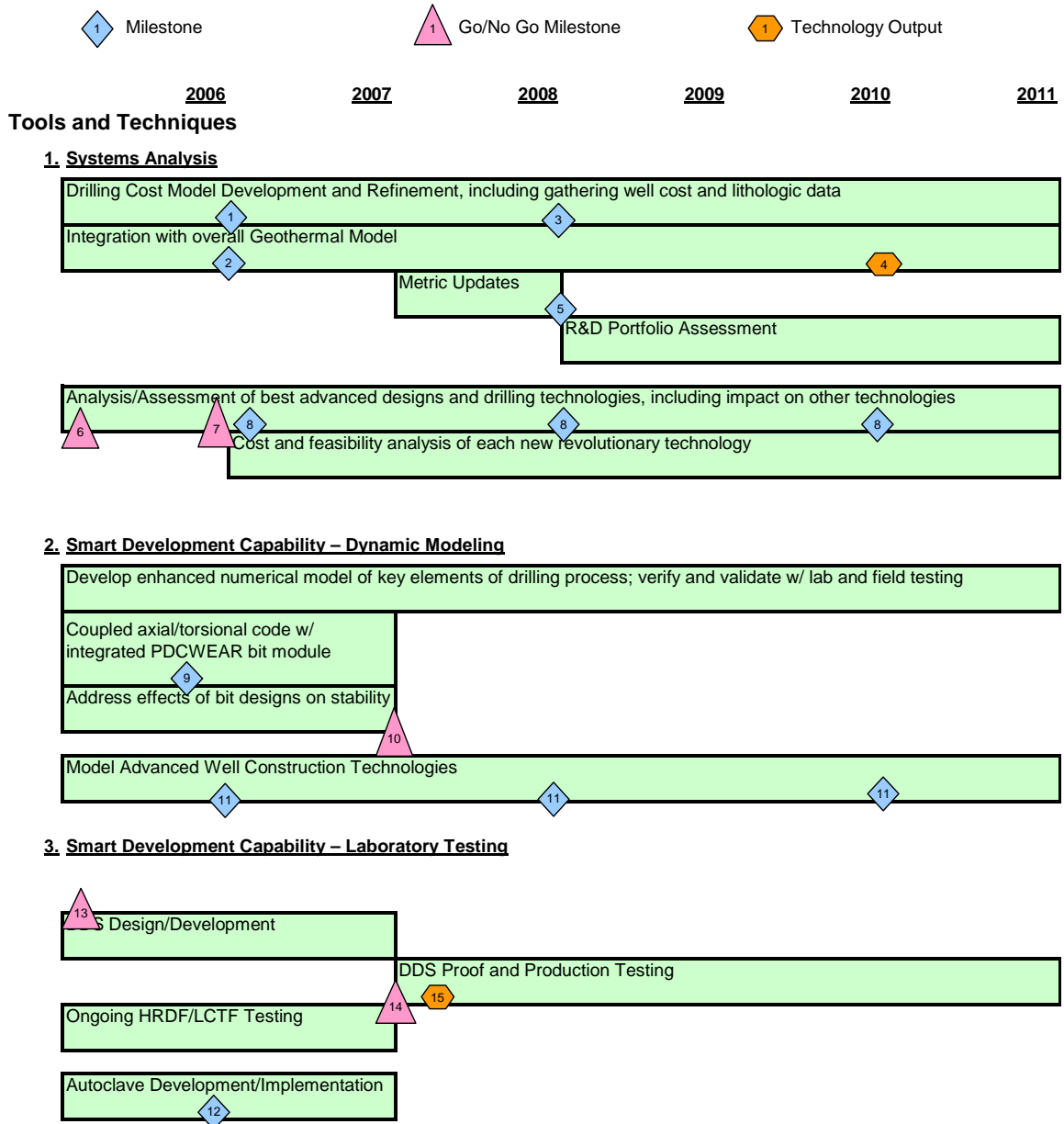
Task	Title/Description	Barriers	Duration In years
12	<p>technologies, including conversion of large pumps to DC (to reduce power conductor number and cost); to set pumps in casing, not tubing; and to develop pumping technology for deep wells.</p> <p><b>Wellfield Operations and Maintenance</b></p> <ul style="list-style-type: none"> <li>Evaluate other design and well-construction options that could lead to reduced well-maintenance needs. Partner with industry on an O&amp;M cost reduction study to evaluate and document maintenance costs and key issues, and implement improved design and material demonstrations to reduce O&amp;M needs.</li> </ul>	HH	6

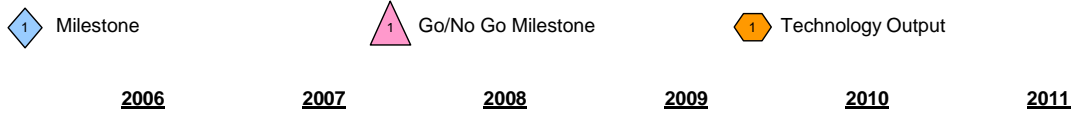
### 3.1.3.1.11. Milestones and Decision Points

#### Technology Development Paths

Figure 3.10 shows the interrelationship of technical tasks, milestones, input from other programs, and technology program outputs for Wellfield Construction from FY06 through FY11. Milestones are summarized in Table 3.13.

**Figure 3.10 - Technology Development Paths for Wellfield Construction**

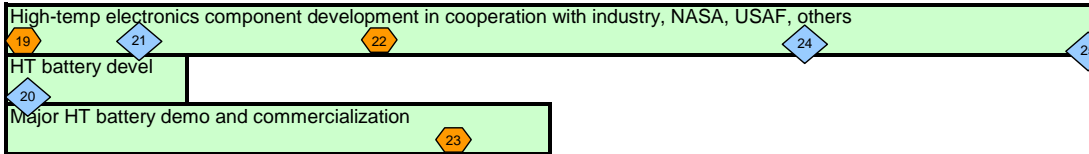




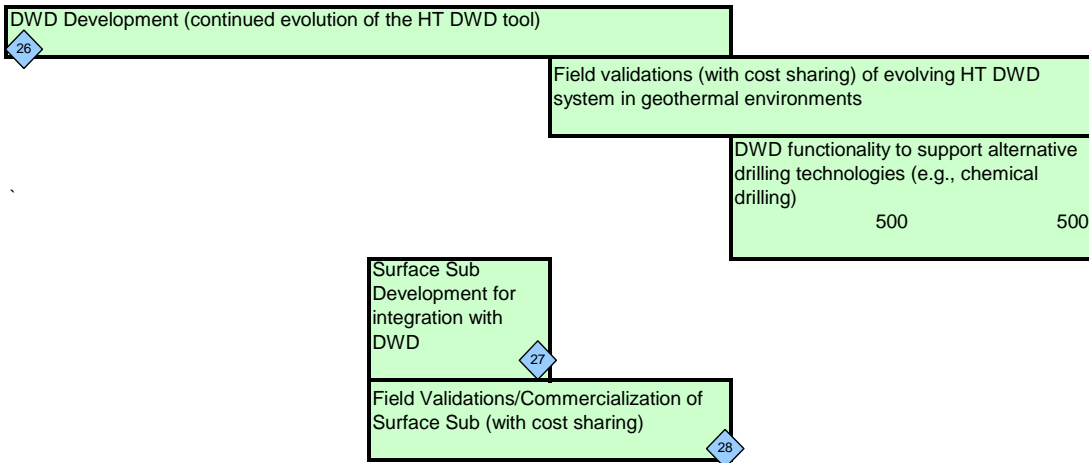
**4. Smart Development Capability – Field Testing**



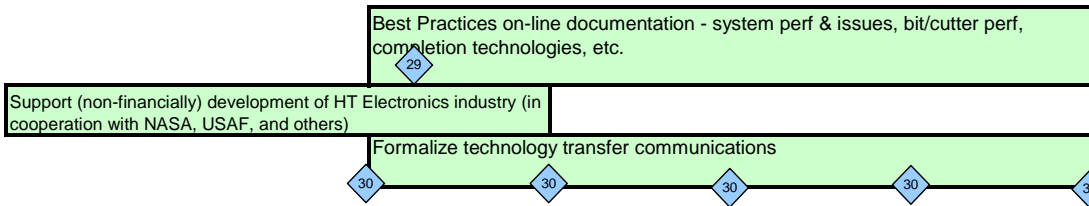
**5. Development of Advanced Diagnostics -- High-Temperature Electronics**



**6. Development of Advanced Diagnostics -- Diagnostics-While-Drilling and Advanced Diagnostics**

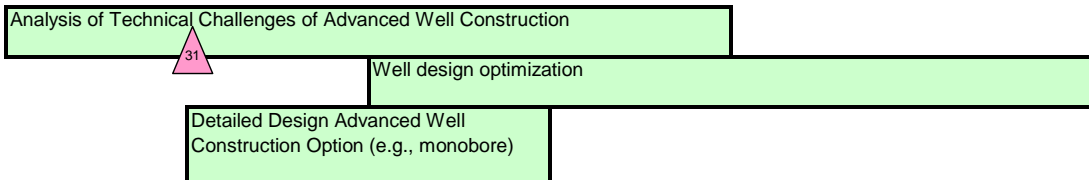


**7. Engineering the Needed Infrastructure**



**Improved Drilling Technologies**

**8. Well Design**





Milestone



Go/No Go Milestone



Technology Output

2006

2007

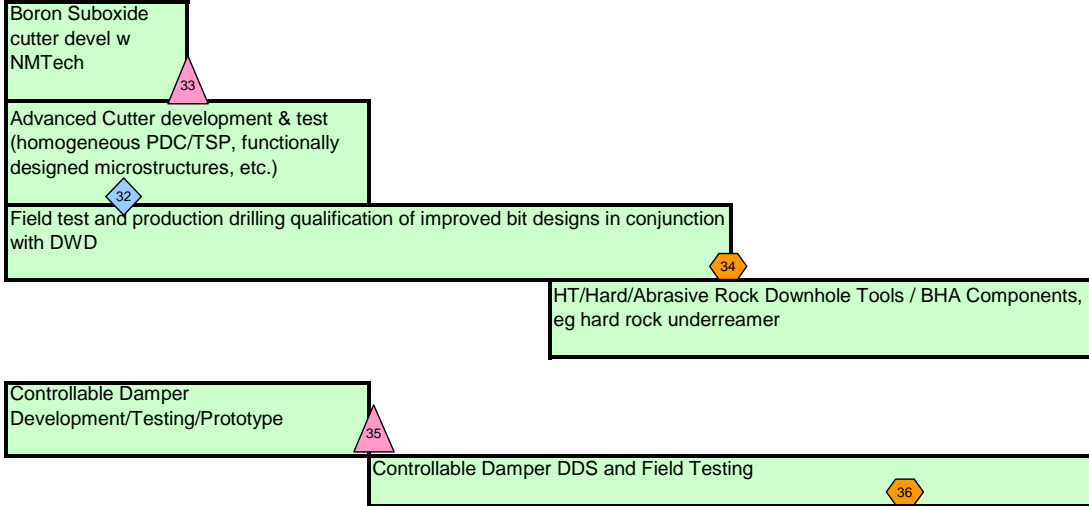
2008

2009

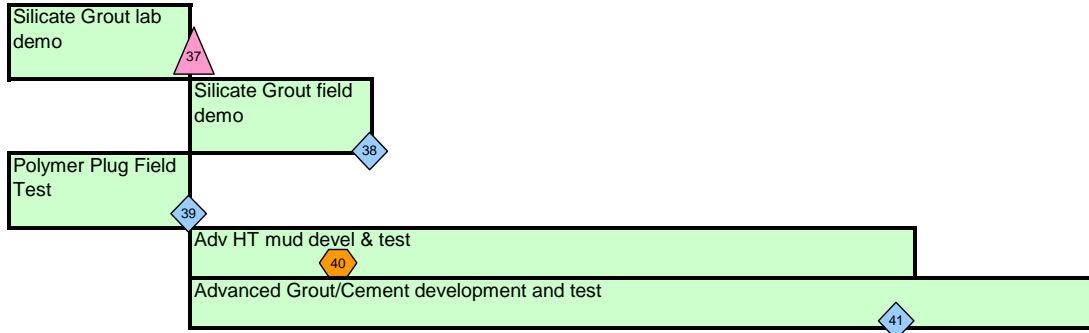
2010

2011

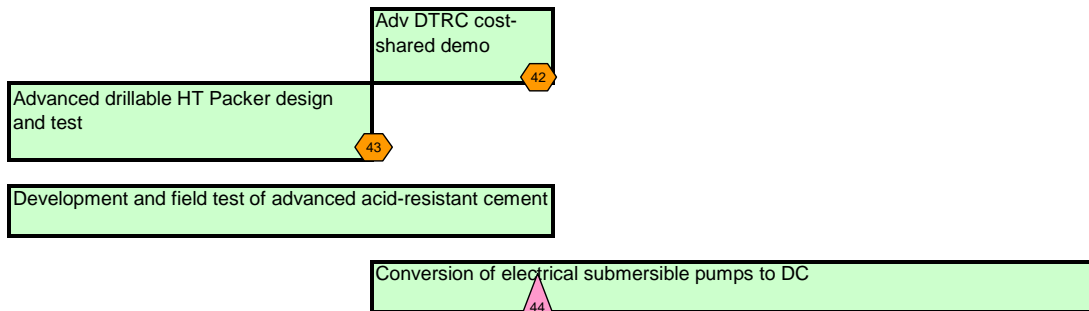
**9. Rock Reduction & Removal**



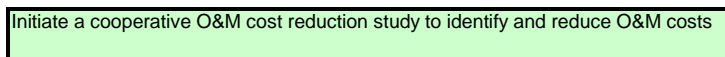
**10. Wellbore Integrity**



**11. Well Construction / Completion**



**12. Well Maintenance**



**Table 3.13 - Technical Task Milestones for Wellfield Construction**

<b>Tools and Techniques</b>
<b><u>1. Systems Analysis</u></b>
1. Provide complete first-generation cost modeling and analyses of existing drilling work. (September 2006 Milestone)
2. Establish Well Construction, Reservoir, Power Conversion, and EGS Interfaces. (September 2006 Milestone)
3. Acquire missing well cost and EGS lithology data. (September 2008 Milestone)
4. Complete system analyses of advanced drilling concepts needed for EGS. (September 2010 Technology Output)
5. Update program metrics as required (September 2005, 2008 Milestones)
6. Select top priority “emerging technology” target (additional “emerging technology” targets recommended as appropriate). (September 2005 Go/No-Go Milestone).
7. Select top priority “revolutionary technology” target (additional “revolutionary technology” targets recommended as appropriate). (September 2006 Go/No-Go Milestone).
8. Update system analyses of “emerging” and “revolutionary” technologies as appropriate. (September 2006, 2008, etc. Milestone)
<b><u>2. Smart Development Capability – Numerical Simulation</u></b>
9. Integrate coupled Axial/Torsional code with PDCWEAR bit module. (June 2006 Milestone)
10. Address effect of bit designs on stability. (September 2007 Go/No-Go Milestone)
11. Update physical analyses of “emerging” and “revolutionary” technologies as appropriate. (September 2006, 2008, etc. Milestone)
<b><u>3. Smart Development Capability – Laboratory Testing</u></b>
12. Develop Autoclave capability. (September 2005 Milestone)
13. Determine Drilling Dynamics Simulator feasibility with prototype fixture. (September 2005 Go/No-Go Milestone)
14. Proof test Drilling Dynamics Simulator. (September 2007 Go/No-Go Milestone)
15. Initiate proof testing of fieldable components in Drilling Dynamics Simulator (e.g., Prototype Controllable Damper). (January 2008 Technology Output).
<b><u>4. Smart Development Capability – Field Testing</u></b>
16. Provide field test services in support of modeling and laboratory findings. (2006 Milestone)
17. Validate in the field promising drilling systems, e.g., rock reduction technologies. (September 2008 Milestone)
18. Perform field tests of active subs to suppress deleterious drillstring dysfunctions. (September 2010 Technology Output)
<b><u>5. Development of Advanced Diagnostics – High-Temperature Electronics</u></b>
19. Demonstrate a 300°C pressure tool for deep EGS flow testing and hydrofracing. (January 2005 Technology Output)

20. Select private industry HT battery developer. (March 2005 Milestone)
21. Report on testing of new HT components at HiTEC (High-Temperature Electronics Conference). (August 2006 Milestone)
22. Demonstrate in the laboratory 250°C firmware reprogrammable high-temperature universal tool electronics. (September 2007 Technology Output)
23. Make high-temperature battery commercially available. (May 2008 Technology Output)
24. Demonstrate a 250C, 150 component firmware reprogrammable high-temperature universal tool electronics. (May 2010 Milestone)
25. Identify 5 new HT logging or drilling tools for use within the geothermal industry. (September 2011 Milestone)

#### **6. Development of Advanced Diagnostics – Diagnostics While Drilling**

26. Demonstrate the use of the DWD system in a geothermal well. (September 2005 Milestone)
27. Develop and fabricate a portable surface sub for acquiring important surface-based drilling parameters. (September 2007 Milestone)
28. Validate the utility of the portable surface sub. (September 2009 Milestone)

#### **7. Engineering the Needed Infrastructure**

29. Working with industry and other government developers, establish an on-line “best practices” web site supporting the high-temperature electronics industry. (January 2006 Milestone)
30. Enhance technology transfer communications by participating actively in national and international geothermal meetings. (Annual Milestone)

#### **Improved Drilling Technologies**

##### **8. Well Design**

31. Analyze technical challenges of advanced well design options (e.g., expandable tubulars, monobore well). (September 2006 Go/No-Go Milestones)

##### **9. Rock Reduction and Removal**

32. Document PDC cutter parameter study results. (June 2006 Milestone)
33. Decision to continue R&D for boron suboxide cutters. (September 2006 Go/No-Go Milestone)
34. Field test and qualify improved drag-bit designs for geothermal production drilling in conjunction with DWD. (September 2009 Technology Output)
35. Decide whether or not to proceed with development of field-ready controllable damper. (September 2007 Go/No-Go Milestone)
36. Adopt controllable damper by industry. (December 2010 Technology Output)

##### **10. Wellbore Integrity**

37. Complete and report on Silicate Grout Lab Demo. (August 2006 Go/No-Go Milestone)
38. Complete and report on Silicate Grout Field Demo. (September 2007 Milestone)
39. Complete Polymer Grout Field Test. (August 2006 Milestone)
40. Report on Advanced HT mud development & testing. (August 2007 Technology Output )

41. Report on Advanced Grout/Cement development. (August 2010 Milestone)

**11. Well Construction/Completion**

42. Complete demonstration of advanced DTRC capabilities. (September 2008 Technology Output)

43. Complete field testing of advanced drillable packer. (September 2007 Technology Output)

44. Decide whether or not to proceed with development of DC downhole pumps. (September 2008 Go/No-Go Milestone)

**3.1.3.2. Energy Conversion**

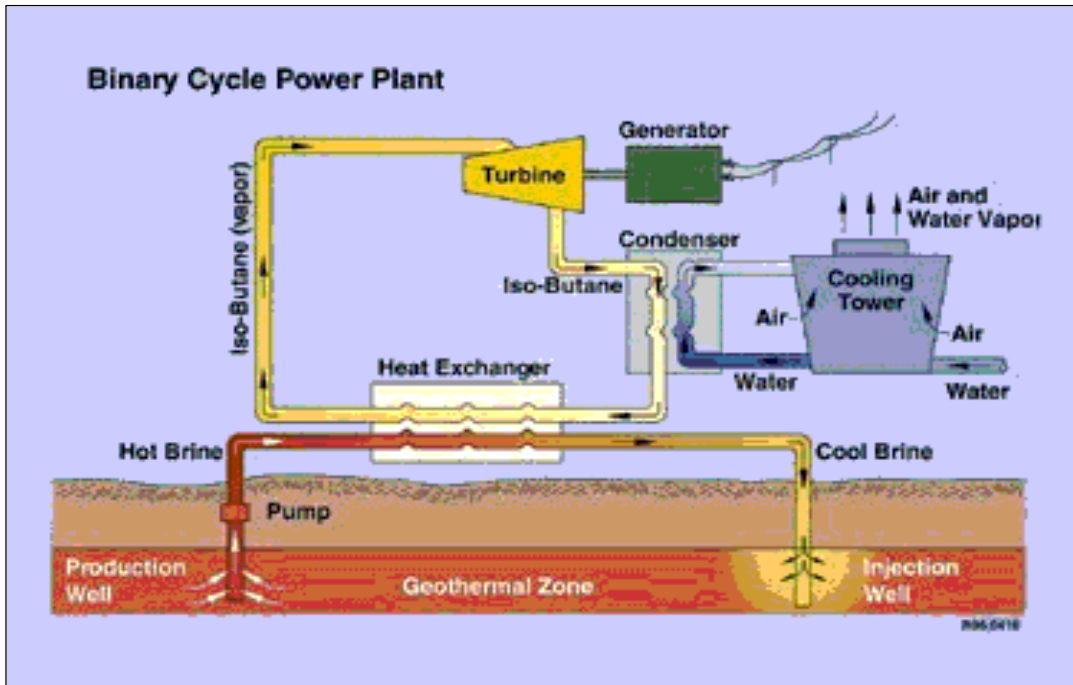
**3.1.3.2.1. External Assessment and Market Overview**

Energy conversion represents technologies used to convert thermal energy into electrical power. Current geothermal conversion systems technologies are Carnot-limited Rankine type cycles. Geothermal energy conversion is economically viable for resources producing large quantities of high enthalpy fluids. The type and size of conversion systems used depends on the temperature of the geothermal resource, with larger plants (up to 100 MWe) associated with higher temperature resources.

Direct steam resources with pressurized, superheated steam that can be used directly with conventional condensing steam turbine technology to produce electricity (such as The Geysers in Northern California) are very rare. Many hydrothermal resources are hot ( $>175^{\circ}\text{C}$ ) and are liquid-dominated. These resources are exploited using flash-steam power cycles where the pressure of the fluid is lowered until the water flashes (vaporizes to steam). The steam is separated from the resulting two-phase mixture and converted to electricity via conventional condensing steam turbine technology. Un-flashed liquid is injected back into the reservoir.

Lower temperature ( $<175^{\circ}\text{C}$ ) hydrothermal resources are typically converted to electricity using binary cycles in which the energy in the geothermal fluid is transferred to a secondary working fluid in one or more heat exchangers. The working fluid vaporizes, and the pressurized vapor drives a turbine generator to produce electricity, and is condensed before being pumped back to the heat exchangers to close the cycle. The cooled geothermal fluid is reinjected to maintain the supply of working fluid. Binary cycles typically do not release components from the geothermal fluid to the ambient air.

**Figure 3.11 - Binary Power Plant Schematic**



Geothermal conversion technology offers significant opportunities for improvement. The surface plant may represent as much as two-thirds of the total investment in a hydrothermal system, and improvements in conversion efficiency, reductions in initial investment, or reductions in operating and maintenance costs enhance competitiveness. Conversion efficiency affects other investments, including drilling. Higher efficiencies reduce wellfield costs by reducing the number of wells required. Improved efficiencies also increase the life of the resource or, for a given lifespan, extract more energy.

Early conversion plants were either direct steam or flash plants. More recent plants have been binary cycle plants, and the binary conversion technology will be most used for future hydrothermal and EGS development because binary technology is best for lower temperature resources.

Binary conversion technology has other potential uses, including:

- Waste heat recovery for electricity generation. A typical application is conversion of heat from compressors for natural gas pipelines.
- Combined heat and power cycles.
- Bottoming cycles on existing, higher temperature Rankine power cycles.
- Low temperature renewable energy conversion, such as concentrating solar energy plants using trough technology and hybrid cycles with the spectrum split for direct conversion using photovoltaic devices and thermal conversion for electricity production.

#### **3.1.3.2.2. Internal Assessment and Program History**

The first geothermal plants were simple flash plants with water-cooled exhaust steam condensers for high temperature brines. This low first-cost approach leads to depletion of the water working fluid and reduced output as reservoir pressures fall.

The thermal efficiency of the flash cycle falls with temperature, so other conversion cycles were developed for lower temperature geothermal resources. The Department of Energy developed the first successful proof-of-concept dual-pressure binary cycle geothermal power plant at Raft River, ID. Most recent projects have used binary technology. The major industry players are the Ormat Corporation, Bibb and Associates (earlier as Ben Holt Company) and The Industrial Company.

Activities are performed via public-private partnerships. There are numerous opportunities for improvement of basic technology, engineering design, and construction of geothermal plants.

### **Advanced Conversion Cycles**

Advanced cycles significantly increase conversion efficiency while reducing investment. The Program is examining advanced cycles, with evaluation of the most promising concepts, and initiated several projects for demonstration of economic benefits for improved technologies for generating electricity from hydrothermal resources. Energy conversion field verification projects include the Empire, NV project to confirm the advantages of mixed vs. single component hydrocarbon working fluids; namely, a 4% enhancement in plant output at no additional cost.

Once the process is optimized, the gains may be as great as 12%. Other projects include innovative conversion cycles at Chena Hot Springs, AK and Salt Wells, NV. The Advanced Direct Contact Condenser applied by Calpine at The Geysers gained an additional plant output of 5% with an attendant hydrogen sulfide abatement chemical cost reduction.

#### **Innovative Component Development**

Innovative components enhance performance, reduce investment, and reduce O&M costs. The Program is evaluating both tabbed and vortex generator fins for heat exchangers, and is working in partnership with industry to field-test membrane units.

#### **Plant and Operation & Maintenance Costs**

Plant operating and maintenance costs can be reduced by improved materials, instruments and controls systems, and operating strategies. The Program is developing and field-testing instruments for H<sub>2</sub>S, steam quality and particulate monitoring in collaboration with industry.

The Program is working with universities and industry to develop bio-oxidation of H<sub>2</sub>S for cooling tower emission abatement.

The Program is working with the coatings industry and with the geothermal industry to develop polyphenylene sulfide and organometallic polymer (OMP) coatings with special properties, and flame-sprayed metal coatings.

The Program's commercialized Energy Conversion technologies have received three R&D100 awards since 2000, including "doped" polyphenylene sulfide (PPS) coatings, an advanced direct contact condenser (ADCC), and coproduction of silica.

PPS coatings can be used in geothermal applications such as condenser tubes, as well as applications in the oil and gas refining and chemical industries. A specialized coating plant has been built to supply PPS-coated tubing and equipment.

An ADCC can increase the output of a plant with high non-condensable gas loadings on its direct contact condensers by about 5%, and reduces the cost of chemicals for treatment of hydrogen sulfide emissions from the cooling towers.

The silica extraction process has the potential to add another revenue stream to a geothermal power plant, effectively reducing the levelized cost of electricity. Geothermal fluids can be used for solution mining because the circulating hot water is in equilibrium with geological formations. Removal of silica reduces operating challenges because silica often causes scaling on process equipment. This technology could capture a significant portion of the commercial silica market.

The Program is working in partnership with the California Energy Commission and the Ormat Corporation to examine the technical feasibility and economic viability of producing by-product silica.

### **Advanced Engineering Design and Construction**

Value engineering with advanced engineering design and construction techniques, such as use of modular subsystems, can reduce engineering and construction costs and accelerate development. The Program is using state-of-the-art modeling tools and is validating the resulting cost prediction models via industry.



**Figure 3.12 – At the Mammoth Geothermal plant, three air-cooled binary units generate a total of 28 megawatts of electricity and release essentially no emissions to the atmosphere or land surface.**

#### **3.1.3.2.3. Federal Role**

Improved geothermal conversion cycles are necessary to achieve Program goals. Synergies with combined heat and power, waste heat recovery, and conversion of other renewable energy forms, such as concentrated solar thermal heat, will significantly enhance the return on the federal investment.

The Program performs relatively high risk research that private industry cannot afford to conduct without Federal government assistance. While the Program can leverage state funds, the cost is too great for state governments. The public-private partnerships employed by the Program will enable efficient achievement of the goals via a mechanism that ensures technology transfer.

#### **3.1.3.2.4. Approach**

Conversion systems for geothermal power production are selected based on the fluids produced by the resource. High temperature, high enthalpy fluids (>175°C) primarily utilize steam and

flash steam conversion cycles. While these cycles have material, chemistry and abatement issues that will be researched, the technology is well understood. The top priority of energy conversion will be technology development for lower-temperature hydrothermal and EGS resources.

The program prioritizes technology development by targeting resource temperature ranges. This prioritization is shown in Table 3.14, where 1 is the highest priority and 5 is lowest. The highest priority temperature range is between 130° and 175°C. Priority is given to these resources because they are on the margin of economic feasibility. Unless a technological breakthrough allows significant, cost-effective performance improvement, the cost of power will be reduced incrementally. In the near term (through 2011), the target will be reducing the cost and improving the performance of binary cycle conversion systems.

**Table 3.14 - Prioritization of Technology Development Resource Type**

Resource Temperature Range	Research Priority thru 2011 (1 = highest; 5 = lowest)	Research Priority thru 2016 (1 = highest; 5 = lowest)	Notes
175° - 200°C	3	3	Out-year priority will increase if applicable to EGS
150° - 175°C	1	2	Current development range: range for achieving <5 cent power by 2011
130° - 150°C	2	1	Marginal resources: development needed to expand resource base; >130°C will be needed for EGS
100° - 130°C	4	4	Small power projects; will require favorable site conditions
<100°C	5	5	Lowest priority; small scale power; require minimal well field costs; more suited to direct use

The development of the binary cycle and the use of downhole pumps to increase production has enabled commercial development with resource temperatures down to approximately 160°C at sites with favorable conditions (low well field development costs), or favorable power sales agreements. This temperature range (150° to 175°C) will be targeted in order to enable development of resources with higher well field costs (deeper resources).

Though generating power for 5 cents per kWh from 130° to 150°C resources by 2011 is a challenge, a high priority is being placed on technology development for this class of resources. These resources are not commercially viable unless there is minimal well field development cost or they receive very favorable power prices. Reduced power plant costs will increase the amount of viable resource in this temperature range. This range also represents the lower temperatures that might be produced from EGS resources.

Technology development will focus on sensible heat rejection from binary cycles (air-cooled condensers) because:

- Hydrothermal resources are typically found in the western United States, where make-up water for evaporative heat rejection systems is limited, and
- EGS plants will probably use air-cooled condensing in order to minimize water losses from the subsurface heat exchange loop.

The final priority is lowering the cost of power from air-cooled binary power plants in the resource temperature range with the highest priority through 2011. Though directed towards binary plants and resource, the results will be at least partly applicable to other conversion systems and resource types.

Analysis of all aspects of power plant design, construction, and operation is used to identify opportunities for improving conversion efficiency and reducing the levelized cost of electricity. Innovations for a given energy conversion technology are analyzed, starting with those with the greatest potential to affect capital costs, operating costs and cycle performance. These innovations are researched and evaluated through field testing in partnership with industry, and the technological goals are refined in concert with partners in research and industry.

This public-private partnership approach leverages Program funds with those from the private sector and prioritizes R&D activities with industrial partners.

The technical approach will include:

Analysis:

- Develop analytical tools. Process simulators and cost estimating tools will provide the core methods used to evaluate performance improvements and cost-benefit tradeoffs of innovative concepts. Other analytical methods will be developed as necessary to assess specific technology areas.
- Identify innovative concepts/technologies. This involves working with industry and reviewing literature for innovations, including relevant advances in other technology areas, and identifying problem areas and potential solutions.
- Evaluate potential benefits using established metrics.
- Identify technology/economic barriers and define approaches to overcome those barriers.
- Evaluate the costs and benefits of different approaches to overcoming barriers and select the most promising concepts.

Research:

- Perform bench-scale testing to address resolution of barriers.
- Solicit industry participation.
- Evaluate progress towards resolving barriers and achieving benefits; decide which activities warrant continued work.

Field Validation:

- Solicit industry participation.
- Support industry to perform field testing to validate cost and performance benefit.
- Transfer technology to the private sector for commercialization.

Laboratory testing will be performed at the national laboratories or by industry under the direction of a laboratory Project Investigator. The Program will solicit industry participation in

continued research and subsequent field validation as technologies develop and benefits become better defined. Industry may lead the development process in some cases, for example, an industry-led effort to improve the efficiency of turbines, where the objective is to develop manufacturing expertise and resources.

The Program will prioritize research based on the potential for cost of power reduction, and on industry priorities.

The top priority areas are Advanced Conversion Cycles, Innovative Component Development, Plant and Operation & Maintenance (O&M), and Advanced Engineering Design and Construction Methods.

Advanced Conversion Cycles increase conversion system efficiency. Higher priority is being given to binary cycle improvements and defining innovative conversion techniques. Innovative cycles can enable the low temperature power plants needed to expand the economically viable hydrothermal and EGS resource base.

Analyses have indicated that mixed working fluid binary plants can extract heat more efficiently than the single component (pure) hydrocarbon plants now used by industry. The non-isothermal phase changes of mixed working fluids in Rankine cycles reduce the inefficiency associated with heat transfer during both boiling and condensation. Mixtures can also reduce the energy lost to fluid leaving the plant. Mixed hydrocarbons and ammonia-water mixtures have potential for generating energy at lower temperatures, but further research is necessary to demonstrate technical and economic viability.

Some early binary plants used CFC refrigerant working fluids that became environmentally unacceptable. Newer refrigerants with superior heat transfer coefficients may be usable as alternative working fluids to increase performance or permit reductions in component or system costs. These refrigerants may provide performance equivalent to those of hydrocarbons. If these fluids have the required heat transfer properties, it will be possible to reduce costs by using smaller heat exchangers.

Supercritical cycles, where the working fluid vaporizes above its critical pressure, can reduce irreversibilities in the heat addition process and minimize energy loss to reinjected fluid. Variants of the trilateral cycle and the total flow cycle can also decrease heat transfer irreversibilities. Cycles that use heat pumps to elevate input temperatures or depress heat sink temperatures may also increase performance (increased temperature differences increase conversion efficiency).

The conversion cycles most likely to provide economic benefits will be determined by public/private analysis and research work. The most promising concepts will be field tested and validated in partnership with industry, with the expectation that industrial partners will consider the benefit worth the risk.

In addition to innovative cycles, some state-of-the-art technologies generate electricity directly from thermal energy, including thermophotovoltaic, thermoelectric, thermoionic, ferroelectric and ferromagnetic. If these devices can operate efficiently at low source temperatures, and if issues associated with heat transfer into the device can be resolved, they may provide a competitive alternative to conventional power cycles.

Innovative Component Development seeks to improve the performance and/or cost of individual power plant components.

Enhancements to air-cooled condensers can reduce costs by decreasing the size of the condenser. The efficiency of air-cooled condensers is limited by the airside heat transfer. Enhanced condenser designs minimize this thermal resistance. These condensers can account for 20 to 30% of the plant cost, making this a promising target for research.

Hybrid air/water cooling systems, such as evaporative precooling of the air entering an air-cooled condenser, can increase plant power output by 100% or more on hot summer afternoons when electricity is highly valued. These technologies will be developed collaboratively with industry.

Using more efficient non-condensable gas removal systems will increase conversion efficiency. These gas removal systems are based on low-energy membrane separation technology, which continuously removes non-condensable gases from binary plant condensers.

Increased efficiency of rotating equipment (turbines, liquid pumps, compressors, fans, etc.) improves performance and plant output. Increased turbine efficiency improves binary cycle performance, and could make total-flow cycles viable. Reducing inefficiencies increases power output and reduces the heat rejection load. The benefits are estimated as up to 5% increase in power with a 1% to 2% reduction in heat load. Industry will lead this development effort, with DOE support through competitive selection of concepts during the initial phases.

Plant Operation & Maintenance (O&M) Cost reductions improve the viability of geothermal power production. Technology developments that reduce O&M costs may also improve cycle performance, increase revenue, or decrease capital costs. Validation of technologies addressing O&M issues and costs require field testing cost-shared with industrial partners.

Labor costs associated with operation of power plants, especially smaller plants on lower temperature resources, represent a significant portion of the facilities' O&M costs. These costs can be reduced by developing technology to automate operations, enable remote monitoring and control to optimize plant performance, and integrate plant and well field operations.

Innovative process monitors target chemical species such as hydrogen sulfide and hydrogen chloride, or conditions such as steam quality and microbial activity, that hinder performance and, in some instances, environmental compliance. Existing technology usually does not allow cost-effective continuous measurement of these species and conditions. To mitigate their impact, plants have cost-intensive abatement systems or use expensive measures to prevent corrosion. Continuous measurement reduces costs by optimizing use of expensive chemicals or by eliminating the need for procedures such as steam washing and throttling, which adversely affect performance.

Silica fouling adds to costs and reduces performance. Controlling silica precipitation and fouling reduces cleaning costs and minimizes thermal resistance caused by heat exchanger fouling, which enables reductions in heat exchanger size and cost. Controlling silica precipitation also allows the fluid to be cooled more without causing scaling, enabling greater energy extraction for a given pumping power and wellfield expenditure.

Antifouling coatings applied to low-cost carbon steel can eliminate the need for more expensive metals such as titanium. Alternative materials such as doped polyphenylene sulfide or organometallic polymers will also reduce operating costs by reducing equipment repair or replacement.

The Program will identify and evaluate cost-effective design strategies. While performance improvements will enhance viability of lower temperature resources, cost reductions may have a greater impact. In conventional binary plants, installation and indirect costs account for 50 to 65% of the total installed costs.

Advanced Engineering Design and Construction Methods can reduce the cost of electricity by reducing the cost of the power plant through economies of scale, accelerating and simplifying plant design, and leveraging experience with a given design. Most existing plants are custom designs, with a typical design cost of about 8% of the plant investment. Installation (construction of the plant) typically costs about 1.6 to 1.8 times the cost of the equipment. One way to reduce

these costs is through a modular approach, with modules defined at either the subsystem or the system level.

Standard design tools for various cycles will be developed, with the basic data and the accuracy of the design techniques and tools verified through either laboratory or field testing.

A set of near-optimal modular subsystems will be designed that are near optimal, reducing design costs. Any reductions in performance will be more than justified by the engineering cost savings. Robust designs for components and subsystem modules will have flat performance curves over a wide range, allowing rapid power plant design using modules. This “plug and play” approach will require detailed engineering only at subsystem interfaces and to accommodate site specific requirements.

The modular subsystems or even a system (for a small plant) can be factory assembled and tested as subsystems or large parts of subsystems prior to shipment. The size of the preassembled modules will be limited only by shipping requirements. The modules will be joined in the field to create the system, with much less effort than assembling individual components. This “plug and play” approach will reduce construction costs.

Improved plant designs can improve operational flexibility, increasing power production when the plant is at an off-design operating point, allowing load-following, increasing availability and capacity, and extending the life of the resource. Systems can be designed to allow working fluid composition to be adjusted to optimize net power output. Variable frequency drives that allow pumps, fans, and compressors to operate efficiently across a wide range of geothermal and ambient conditions, enabling optimization of net power output, can be incorporated into binary cycle and EGS power conversion systems.

### **3.1.3.2.5. Performance Goals**

#### **Goal**

The goal of the Energy Conversion subprogram is to develop technologies that reduce the cost of electricity by increasing conversion efficiencies, reducing power plant costs, and reducing operations and maintenance costs.

#### **Objectives**

The objectives are:

1. By 2011, increase the conversion efficiency of low temperature (binary cycle) conversion systems by 11%, relative to 2006 technology.
2. By 2016, increase the conversion efficiency of low temperature (binary cycle) conversion systems by 20%, relative to 2006 technology.
3. By 2011, reduce the levelized cost of electricity by 0.59¢/kWh via a combination of improvements in cost, performance and efficiency, relative to 2006 costs.
4. By 2016, reduce the levelized cost of electricity by 2.11 ¢/kWh via a combination of improvements in cost, performance and efficiency, relative to 2006 costs.

#### **Metrics**

As innovative concepts are identified, metrics are used to gauge their potential. The ultimate metric is cost of power. Because the cost of power benefit may not be easily analyzed, intermediate metrics will be used. The intermediate metrics include:

- Plant, system, or component installed capital cost (\$/kW)

- Operating and maintenance cost (\$ per year)
- Cycle performance improvement, which can be expressed as either increases in the brine effectiveness (net power per unit mass flow rate of geothermal fluid), or increases in the thermodynamic Second Law efficiency. Projections of performance improvements must be normalized with assumed heat source and sink temperatures.
- Increased annual revenue (\$ per year)

Improvements will be measured against a reference plant configuration for which each of these metrics has been established, and used to establish the contribution of the power plant to the cost of power.

### 3.1.3.2.6. Strategic Goals

A strategic goal of energy conversion activities is to leverage developments in other technology areas for geothermal applications, and to make improved geothermal technology available for use in other applications such as:

- Efficient technologies for combined heat and power, which is also a goal of the DOE Industrial Technologies Program.
- Generation of electricity from recycled energy (waste heat).
- Bottoming cycles to enhance conventional generation cycle efficiency.
- Conversion cycles for other renewable thermal applications, such as concentrating solar power.

### 3.1.3.2.7. Market Challenges and Barriers

Large-scale field validation of new technology is a market challenge. While it is easy to forecast performance and cost gains from advanced conversion cycles, plant operators and developers are unwilling to accept the risk associated with an industrial scale installation.

At present, DOE cannot perform small-scale validation of conversion cycles, and no field test site is dedicated to validating the cost and performance of innovative cycles. DOE must accept sufficient risk to induce power plant operators and developers to serve as a field validation site. While this market barrier is most significant for innovative cycles, it also affects individual components, operating changes such as advanced control and monitoring systems, and use of advanced engineering design and construction methods.

### 3.1.3.2.8. Technical Challenges and Barriers

The challenges associated with power generation are to efficiently capture the lower-grade energy content of geothermal fluids, and to reduce the costs of converting this energy to electrical power.

#### Technical Barriers

##### A. Low Energy Conversion Efficiencies for Geothermal Systems

Because relatively low geothermal fluid temperatures reduce the thermodynamic potential to convert the energy to electrical power, the conversion systems are more equipment intensive and costly than similarly sized fossil-fired generation plants. Both conversion system cost and the required fluid production rate per kW increase with declining resource temperature.

Development of EGS resources will face challenges similar to those of lower temperature resources. EGS resources may have a relatively rapid temperature drawdown, necessitating development of plants that can accommodate falling fluid temperatures. Recycling of fluid may

affect production fluid chemistry. If concentrations of dissolved chemical species increase with time, conversion system designs should accommodate the increased potential for corrosion and/or scaling, although this may also provide an opportunity for extracting marketable byproducts from the dissolved minerals and metals. Submersible pumps capable of long-term operation at elevated fluid temperatures can increase fluid productivity and power output with no increase in well costs.

### **B. Inadequate Heat Rejection Systems**

Because of the relatively low temperature, the performance of a geothermal conversion cycle is sensitive to the temperature of the heat sink, which is typically the temperature of the air. If the air temperature rises from 20°C to 40°C, the power theoretically obtainable from a conversion system operating with a 150°C resource falls by approximately 30%.

Evaporative heat rejection systems lower the heat sink temperature to the ambient wet bulb temperature and reduce the impact on power generation. This type system uses water, and requires a ready supply of make-up water. Where water is scarce, hybrid air/water heat rejection systems can significantly boost performance on hot summer afternoons when electricity is highly valued and minimize the total annual water consumption. The scarcity and cost of water supplies due to the fact that hydrothermal resources are predominantly located in semi-arid regions, combined with public dissatisfaction with condensation plumes associated with evaporative systems, drives plants to use air cooling systems. Air-cooling is even more important for EGS systems.

Air a poor heat transfer medium, and because of low conversion efficiencies, up to 90% of the heat extracted from the geothermal fluid must be rejected. As a consequence, large heat exchanger areas and very large volumes of air are required. The corresponding capital costs and fan power requirements impact project economics, especially for lower temperature resources. Fundamental research will define optimal heat exchanger surfaces and enhance heat transfer rates while minimizing parasitic power losses.

### **C. Lack of industry support for mixed working fluids**

Commercial binary plants typically use pure, or single component, working fluids. Binary cycles using mixed working fluids can increase conversion system performance. Though benefits of mixed working fluids have been identified, industry has not adopted the technology due to risk. Industry concerns must be addressed by a working demonstration. Air-cooled condenser mixtures are used for heat rejection in these cycles, and vaporizing mixtures at subcritical pressures. The mixtures' effect on heat transfer coefficients must be researched so that heat exchangers will be properly sized.

### **D. Corrosive Fluids**

Geothermal fluids contain dissolved species that cause corrosion and mineral deposition issues. More chemicals are dissolved at higher temperatures, so corrosion and mineral deposition issues become more pronounced. Corrosion in systems, components and piping can be minimized by expensive materials, and precipitation can be minimized by restricting energy extraction, but this increases the levelized cost of electricity. Costly abatement is sometimes necessary to meet regulatory emissions requirements (hydrogen sulfide), or to protect plant equipment.

### **E. High Component Costs**

Conservative component design increases capital costs. Knowledge of heat transfer coefficients and heat exchanger surface fouling can reduce design conservatism.

## **F. Existing instrumentation technology**

Due to elevated fluid temperatures and chemistry, certain plant process parameters cannot be continuously measured with existing technologies. When these parameters affect performance, component reliability, or operating cost, plant operators mitigate impacts through conservative operating practices (e.g., chemical overuse, excessive system pressure reductions). New control technologies can assist operators in optimizing mitigation processes and reduce associated costs and performance impacts. Instruments for continuous, accurate monitoring of regulated chemical species will ease geothermal power plant permitting and enhance operation.

## **G. Control Techniques and Automation/O&M Cost Reduction**

Automating plant operation minimizes labor cost and optimizes net plant output due to geothermal fluid, ambient condition and market demand changes. While it is difficult to automate existing facilities, automated operation should be encouraged for new projects through cost-shared DOE/industry partnerships. Modern control theory and equipment supports eliminating or substantially reducing operator numbers. Information technology provides a control system capable of learning and improving with experience. Modern high-speed data transmission techniques allow remote monitoring and multiple power plant control from a single central location.

## **H. Design Practices**

Currently, every plant is custom designed, since each resource has a unique temperature, flow, and brine composition. Because no design standards exist, each supplier designs from individual experience. Equipment is ordered piecemeal, with auxiliary items (e.g., instrumentation) separate from base equipment, leading to inefficiencies in the system. Future design engineers should be able to choose equipment designs from a catalog to create a near optimal design with little effort.

## **I. Construction Techniques**

Construction is performed one piece of equipment at a time – a costly and slow process. Subsystem modules could reduce construction cost by minimizing component interfaces.

## **J. Changing Geothermal Conditions**

Geothermal resources change constantly due to brine chemistry and the mismatch between the thermal extraction rate and the thermal recharge rate. Plant designs should be flexible to allow efficient, cost-effective operation over a range of conditions, not just optimal performance at a specific design point.

### 3.1.3.2.9. Technical Targets

**Table 3.15 - Technical Targets for Energy Conversion**

Cost Factor	Reference System		
	2006 Base Case	2011 Enhanced Binary	2016 Developed Binary Plant
<b>Average Plant Production</b>	30MW	30MW	30MW
<b>Conversion Brine Efficiency</b>	4.63 Watt-hr/lb	5.14 Watt-hr/lb, reducing LCOE by 0.42 ¢/kW-h	5.56 Watt-hr/lb, reducing LCOE by 0.27 ¢/kW-h
<b>Power Plant O&amp;M Reduction (non-labor)</b>	0%	30%, reducing LCOE by 0.17 ¢/kW-h	60%, reducing LCOE by 0.16¢/kW-h
<b>Power Plant Power Plant Operating Labor Cost Reduction</b>	0%	0%	60%, reducing LCOE by 0.42 ¢/kW-h
<b>Power Plant Design Cost Reduction</b>	0%	0%	50%, reducing LCOE by 0.20 ¢/kW-h
<b>Power Plant Construction Cost Reduction</b>	0%	0%	22%, reducing LCOE by 1.06 ¢/kW-h
<b>Total Reduction in Levelized Energy Cost</b>	<b>0¢/kW-h</b>	<b>0.59¢/kW-h</b>	<b>2.11 ¢/kW-h</b>

This table defines electricity cost reductions for power plant design, construction and operation changes and shows the magnitude of the combined reductions in relative terms.

### Technology Improvement Potentials

TIPs represent opportunities to work with industry to conceptualize, research, develop, field validate and commercialize power plant equipment and operating changes that significantly reduce costs. The foundations are being developed to achieve cost reduction goals in 2016 and on, beyond the scope of this MYPP.

**Table 3.16 - Energy Conversion TIPs**

Technology Improvement Potentials	Metric	2006	2011	2016
Mixed Working Fluid Plants	Power Plant Output, MW	Validation plant designed	4% increase in plant MW output	Commercialization
Other Innovative Cycles	Power Plant Output, MW	Conceptual studies underway	Field validation underway	5% increase in plant MW output

<b>Technology Improvement Potentials</b>	<b>Metric</b>	<b>2006</b>	<b>2011</b>	<b>2016</b>
Innovative Cycles	Power Plant Output, MW	Test plans developed	Field validation underway	5% increase in plant MW output
Non-Turbine Cycles	Power Plant Output, MW	Conceptual studies underway, test plans developed	Field validation underway	8% increase in plant MW output via a bottoming cycle
Alternative Working Fluids (non-hydrocarbons) with Improved Heat Transfer Characteristics	Power Plant Output, MW	Conceptual studies underway, test plans developed	Field validation underway	5% increase in plant MW output
Advanced Air-Cooled Condensers	Power Plant Output, MW	Basis completed for a field test of enhanced air-cooled condensers	4% increase in plant output due to reduced turbine back-pressure	5% increase in plant output due to reduced turbine back-pressure
Hybrid Cooling Systems	MW-h/yr	Model developed, information transferred to industry	Validate a 30% increase in annual plant output for a high desert location	Commercialization
Improved Non-Condensable Gas Removal Subsystems	Power Plant Output, MW	Testing underway at geothermal power plants	3% increase in binary plant output via use of a membrane system	Commercialization
Increased Turbine Efficiency	Power Plant Output, MW	Conceptual studies underway	Establish limits turbine efficiency can be increased	Demonstrate prototype-scale efficiency approaching 90% (corresponds to a 5% increase in power)
Innovative Process Monitors	Reduction in O&M costs, \$/yr, expressed as LCOE reduction, ¢/kW-h	Basis developed and field tests underway	Field testing and technology transfer	Reduce LCOE by 0.15¢/kWh, commercialization

<b>Technology Improvement Potentials</b>	<b>Metric</b>	<b>2006</b>	<b>2011</b>	<b>2016</b>
Chemistry and Physics of Geothermal Brines	Reduction in O&M costs, \$/yr, expressed as LCOE reduction, ¢/kW-h	Joint work underway with Ormat and CEC to define production of silica	Field validation with industrial partner	Reduce LCOE by 0.05¢/kWh through better inhibitors, process knowledge
Innovative Materials	Reduction in O&M costs, \$/yr, expressed as LCOE reduction, ¢/kW-h	PPS commercialized and being improved	Other innovative materials under test	Reduce LCOE by 0.1¢/kWh via coatings, commercialization
Cost-effective Plant Design and Construction Strategies	Reduction in plant capital costs, \$, expressed as LCOE reduction, ¢/kW-h	Basis defined for approach	Projects with industry to validate cost reductions	Reduce LCOE by 0.2¢/kWh, commercialization
Automation to Reduce Operating Labor	Reduction in operating labor, \$/yr, expressed as LCOE reduction, ¢/kW-h	Task basis defined	Projects with industry to define and validate systems	Reduce operating labor by 60% and LCOE by 0.5 ¢/kW-h

### 3.1.3.2.10. Strategies for Overcoming Barriers and Challenges

The strategy is to analyze energy conversion systems to characterize potential improvements based on industry needs, addressing the highest priorities first. The Program and industry will jointly define priorities based on:

- Industrial need,
- Potential cost reduction and/or process improvement, and
- Difficulty and cost.

The work is performed and technology transfer occurs via public-private partnerships. As the work matures through field verification projects, industry involvement will increase to the point of commercialization and widespread application.

### 3.1.3.2.11. Tasks

The Technical Task Descriptions for Energy Conversion and the associated barriers are presented in Table 3.17.

**Table 3.17 - Technical Task Descriptions for Energy Conversion**

Task	Description	Barriers	Duration in years
<b>1.0</b>	<b>Advanced Conversion Cycles</b>		
<b>1.1</b>	<p><b>Characterize Mixed Working Fluid Plants</b></p> <ul style="list-style-type: none"> <li>Quantify performance gains possible with working fluid mixtures for resource temperatures between 100° and 160°C, and project probable impact on conversion system cost.</li> <li>In conjunction with industry, verify that technical barriers limiting use of mixtures are associated with designing heat exchangers that produce the non-isothermal phase changes (boiling and condensation). Of particular concern is the design of horizontal, in-tube condensers.</li> <li>Develop research plans to address these barriers; including integration of work done in related industries (i.e., petrochemical).</li> <li>Validate design methods that allow heat exchangers to be built and operated that produce the non-isothermal phase changes required to produce the project performance gains.</li> <li>Identify cost effective means to continuously monitor and, if desired, adjust fluid chemistry. If existing technologies are inadequate, develop new technologies.</li> </ul>	A, C, K	4
<b>1.2</b>	<p><b>Evaluate Other Innovative Cycles</b></p> <ul style="list-style-type: none"> <li>Study the use of pure ammonia working fluid with a regenerator for lower-temperature resources.</li> <li>Investigate the use of sub-atmospheric flash.</li> <li>Evaluate the best concepts in total flow expanders.</li> <li>Analyze various hybrid geothermal plant configurations; such as geothermal hydrogen generation plants that use high-temperature electrolyzers that can benefit from geothermal power plant reject heat, thus maximizing system efficiency.</li> </ul>	A, C, K	3
<b>1.3</b>	<p><b>Field Tests of Innovative Cycles</b></p> <ul style="list-style-type: none"> <li>Perform field validation of innovative cycles to positively verify cost and performance gains, and to provide a technical basis for additional improvement</li> </ul>	A, C, H, I, K	5
<b>1.4</b>	<p><b>Evaluate Non-Turbine Cycles</b></p> <ul style="list-style-type: none"> <li>Investigate current state-of-the-art ways to generate electricity directly from thermal energy, including thermophotovoltaic, thermoelectric, thermoionic, ferroelectric and ferromagnetic.</li> </ul>	A	2

<b>Task</b>	<b>Description</b>	<b>Barriers</b>	<b>Duration in years</b>
<b>1.5</b>	<p><b>Evaluate Alternative Working Fluids (non-hydrocarbons) with Improved Heat Transfer Characteristics</b></p> <ul style="list-style-type: none"> <li>Evaluate refrigerants.</li> <li>Identify working fluids for higher temperature binary cycles (&gt;175°C) that might be required for EGS resources.</li> </ul>	A, B, C, K	2
<b>2.0</b>	<b>Innovative Component Development</b>		
<b>2.1</b>	<p><b>Develop Advanced Air-Cooled Condensers</b></p> <ul style="list-style-type: none"> <li>Field validate the tabbed fin concept to enhance the airside heat transfer coefficient for air-cooled condensers. This will involve a logical progression from small-scale development and theoretical modeling to working with a heat exchanger industry partner to working with a geothermal partner to validate the cost and performance advantages on a large scale. As appropriate, the vortex generator concept may be included within the tabs. The basic approach is to enhance the airside coefficient via boundary layer renewal while minimizing any associated increase in parasitic power requirement due to increased pressure drop.</li> <li>Promote commercialization of enhancement technology with industry partners in both the geothermal industry and the heat exchanger industry.</li> <li>Continue research activities with enhancements to further minimize airside pressure drops. Reducing pressure drops will allow fan power to be decreased or airflow rate to be increased, both of which will increase power output. This work will include development of improved fan blades and improved housings.</li> </ul>	A, B, E	5
<b>2.2</b>	<p><b>Support Industry to Develop Hybrid Cooling Systems</b></p> <ul style="list-style-type: none"> <li>Investigate indirect evaporative cooling to allow designers to approach the dew point temperature, as opposed to the wet bulb temperature, thereby allowing a 25% increase in plant power output of air-cooled plants in hot, dry climates.</li> <li>Investigate possible uses of heat pipes to reduce plant-pumping power.</li> <li>Complete an analytical assessment of the potential performance benefit of hybrid heat rejection systems – combined evaporative/sensible heat rejection schemes.</li> <li>Establish conditions for which these systems would be economically viable, and what technical barriers must be removed.</li> <li>Establish research plant to remove any technical barriers associated with the hybrid heat rejection systems.</li> </ul>	A, B, G	2
<b>2.3</b>	<p><b>Improve Non-Condensable Gas Removal Subsystems</b></p> <ul style="list-style-type: none"> <li>Validate in the field the use of membranes separation technology to</li> </ul>	A, G	1

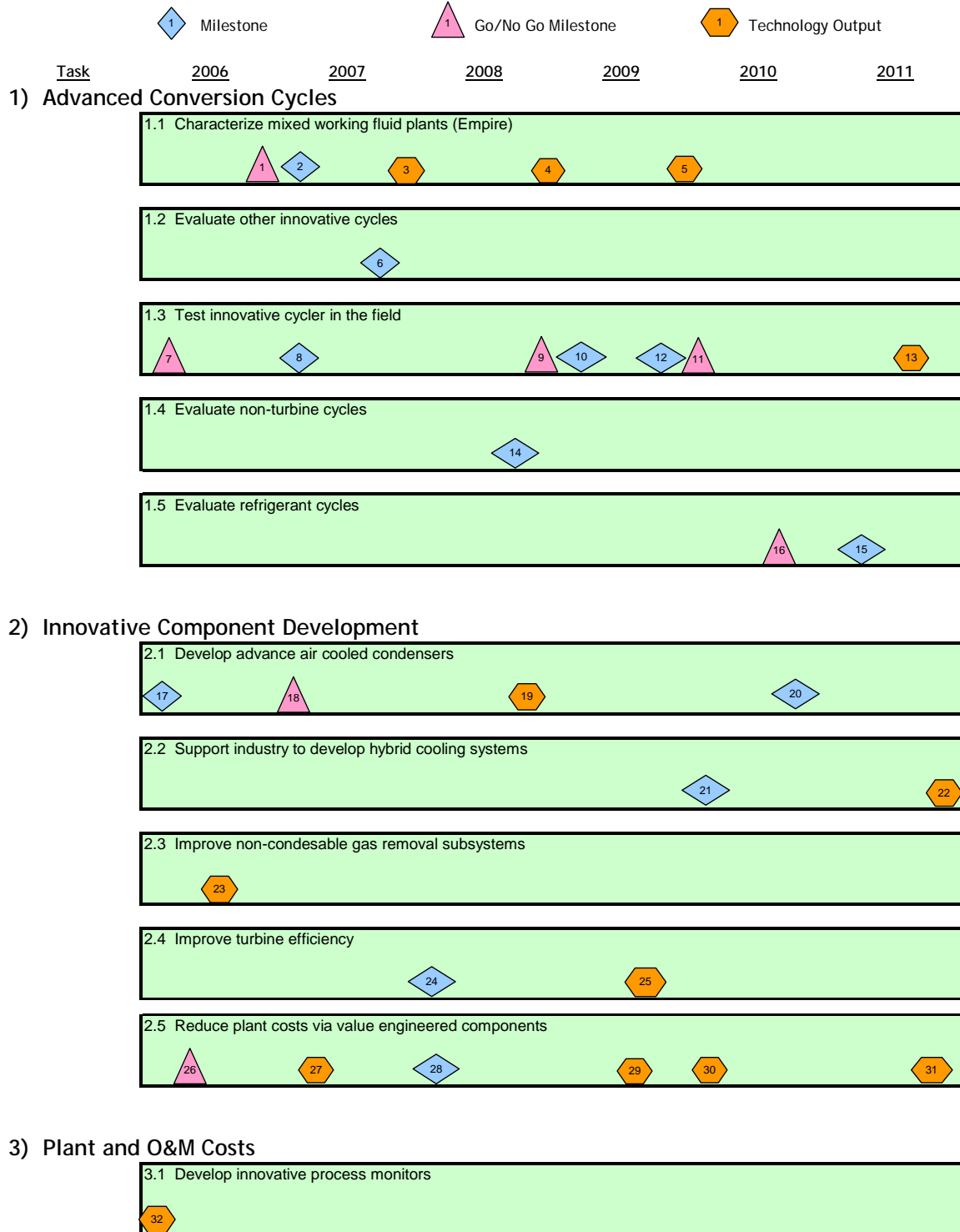
<b>Task</b>	<b>Description</b>	<b>Barriers</b>	<b>Duration in years</b>
	<p>continuously remove non-condensable gases from binary plant working fluid systems will be completed.</p> <ul style="list-style-type: none"> <li>Transfer the technology to a commercial or industry partner who will lead widespread commercialization and application.</li> </ul>		
<b>2.4</b>	<p><b>Increase Turbine Efficiency</b></p> <ul style="list-style-type: none"> <li>Improve binary turbine efficiency (currently high performance turbines achieve efficiencies of 85 to 87%). Technology improvements may be applicable to other rotating equipment (compressors, pumps and steam turbines) found in geothermal plants.</li> </ul>	A, E, K	2
<b>2.5</b>	<p><b>Reduce Plant Costs via Value-Engineered Components</b></p> <ul style="list-style-type: none"> <li>Define opportunities to improve existing components</li> <li>Issue subcontracts to industry to value-engineer the components to reduce costs and to enhance performance</li> <li>Field validate the value engineered components in actual geothermal power plant service</li> </ul>	E	5
<b>3.0</b>	<b>Plant and O&amp;M Costs</b>		
<b>3.1</b>	<p><b>Develop Innovative Process Monitors</b></p> <ul style="list-style-type: none"> <li>Work with industry to support commercial development and/or application of monitoring technologies that have been developed by the energy conversion program. These technologies include the steam quality monitor and the on-line microbial monitor.</li> <li>Complete field-testing to validate the technology used to monitor suspended solids in geothermal process streams. The specific application will depend on the location selected for the field test.</li> <li>Resolve the technical issues arising from the field-testing of the particulate monitor and pursue commercial development of the technology.</li> <li>Assess recent laser technology developments to determine whether these new lasers are suitable for the laser spectroscopy measurement of hydrogen sulfide emissions from geothermal plant cooling towers. If these lasers will provide the required detection sensitivity, they will be incorporated into the proposed system design.</li> <li>Conduct field-testing at an operating plant to validate the technology providing the continuous measurement of hydrogen sulfide emissions from a cooling tower. Successful validation of the technology will be followed up with efforts to pursue commercial application.</li> </ul>	A, D, F, G	1
<b>3.2</b>	<p><b>Understand Chemistry and Physics of Geothermal Brines</b></p> <ul style="list-style-type: none"> <li>Develop an improved understanding of the factors involved in the</li> </ul>	A, D, G	5

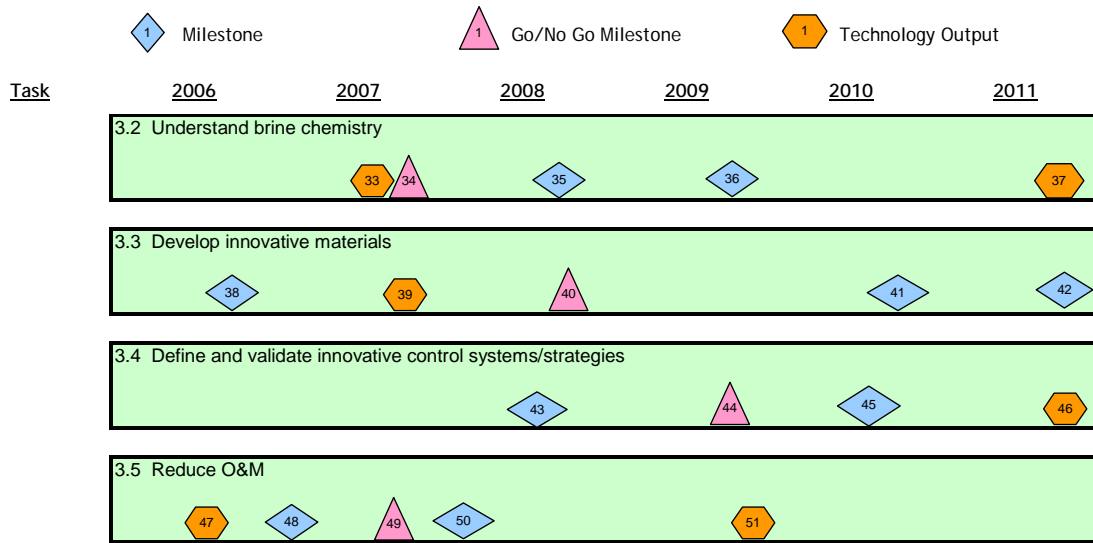
Task	Description	Barriers	Duration in years
	<p>precipitation of minerals from geothermal fluids, with specific interest on the precipitation of silica.</p> <ul style="list-style-type: none"> <li>Identify chemical processes or inhibitors that will mitigate or control the precipitation of silica. Identified inhibitors/processes will be field tested to determine their effectiveness.</li> <li>Perform field tests in partnership with industry to refine the selection process and/or to identify the required inhibitor or process.</li> </ul>		
<b>3.3</b>	<p><b>Develop Innovative Materials</b></p> <ul style="list-style-type: none"> <li>Focus material research on resources where corrosion has a significant adverse effect on capital and/or operating costs</li> <li>Develop cost effective alternative materials of construction for geothermal fluid piping systems and components.</li> <li>Conduct field-testing necessary to validate performance of the new materials in actual operating environments.</li> <li>Pursue commercial development of new materials</li> </ul>	E, G	5
<b>3.4</b>	<p><b>Define and Validate Innovative Control Systems/Strategies</b></p> <ul style="list-style-type: none"> <li>Define adaptive control techniques with potential to significantly reduce operating staff</li> <li>Subcontract with industry to supply an appropriate control system</li> <li>Field validate the control system to verify capability and to provide a basis for industry to confidently reduce operating staff and to employ remote control and monitoring of the plant</li> </ul>	G, J, K	7. 4
<b>4.0</b>	<p><b>Advanced Engineering Design and Construction Methods</b></p>		<b>8.</b>
<b>4.1</b>	<p><b>9. Utilizing Cost-Effective Plant Design and Construction Strategies</b></p> <ul style="list-style-type: none"> <li>Cycle technologies that minimize the effect of resource temperature decline will be identified and potential cost and performance benefits quantified.</li> <li>Standard design methods for binary plants will be emphasized to ensure that all designers have access to the latest databases and tools.</li> <li>Emphasis will be on standard process modules that with very little custom engineering can be combined in a “plug and play” mode to yield a near optimal plant. The custom engineering would be limited to site-specific aspects – this will significantly reduce design costs.</li> </ul>	H, I	10. 5

### 3.1.3.2.12. Milestones and Decision Points

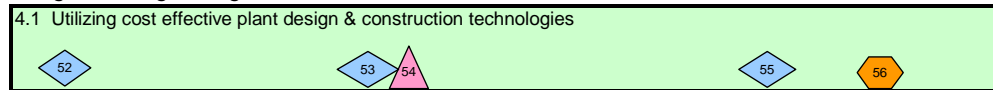
Table 3.18 shows the interrelationship of milestones, tasks, supporting input from other programs, and technology program outputs for the Energy Conversion program from FY06 through FY11.

**Figure 3.13 - Technology Development Paths for Energy Conversion**





#### 4) Advanced Engineering Design & Construction Methods



**Table 3.18 – Technical Task Milestones for Energy Conversion**

<b>Advanced Conversion Cycles</b>	
<b>Task 1.1 Characterize Mixed Working Plant Fluids</b>	
1.	Decide on Empire Project. (October 2006 Go/No Go Milestone)
2.	Complete Construction of Empire Plant. (September 2006 Milestone)
3.	Produce Monitoring Report. (September 2007 Technology Output)
4.	Produce Monitoring Report. (September 2008 Technology Output)
5.	Produce Monitoring Report. (September 2009 Technology Output)
<b>Task 1.2 Evaluate Other Innovative Cycles</b>	
6.	Analytically define cost reduction potential for best cycles. (August 2007 Milestone)
<b>Task 1.3 Field Test of Innovative Cycles</b>	
7.	Decide on phase 2 of DOE-GO field projects. (January 2006 Go/No Go Milestone)
8.	Complete construction of chosen power plant. (November 2007 Milestone)
9.	Produce Monitoring Report for field project. (September 2008 Technology Output)
10.	Select next field project. (October 2008 Milestone)
11.	Decide whether to proceed with construction. (October 2009 Go/No Go Milestone)
12.	Complete power plant construction. (September 2009 Milestone)
13.	Produce Monitoring report for field project. (July 2011 Technology Output)
<b>Task 1.4 Evaluate Non-Turbine Cycles</b>	
14.	Complete evaluation of non-turbine conversion technologies. (August 2008 Milestone)
<b>11. Task 1.5 Evaluate Alternative Non-Hydrocarbon Working Fluids</b>	
15.	Complete model development for refrigerant cycles. (November 2010 Milestone)
16.	Decide on future refrigerant cycle R&D. (August 2010 Go/No Go Milestone)

## **Innovative Component Development**

### **Task 2.1 Develop Advanced Air-Cooled Condensers**

17. Complete development of specification for tabbed circular fin. (November 2006 Milestone)
18. Decide on field testing. (October 2007 Go/No Go Milestone)
19. Produce Field Report on performance of ACC. (September 2008 Technology Output)
20. Complete field testing of ACC. (August 2010 Milestone)

### **Task 2.2 Support Industry to Develop Hybrid Cooling Systems**

21. Select partner and site for field test. (October 2010 Milestone)
22. Complete field tests and documentation. (September 2011 Milestone)

### **Task 2.3 Improve Non-Condensable Gas Removal Subsystems**

23. Complete testing and documentation. (July 2006 Technology Output)

### **Task 2.4 Increase Turbine Efficiency**

24. Select partner and turbine for improvement. (October 2008 Milestone)
25. Document improvements, commercialization by partner. (August 2009 Technology Output)

### **12. Task 2.5 Reduce Plant Costs Via Value-Engineered Components**

26. Decide on which components to value engineer. (March 2006 Go/No Go Milestone)
27. Formally review task by a selected panel. (January 2007 Technology Output)
28. Select second group of projects. (November 2007 Milestone)
29. Formally review task by a selected panel. (January 2009 Technology Output)
30. Field test selected value engineered component. (November 2009 Technology Output)
31. Report performance metrics for value engineered component. (July 2011 Technology Output)

## **Plant and O&M Costs**

### **Task 3.1 Develop Innovative Process Monitors**

32. Complete field tests of innovative monitors and document. (December 2005 Technology Output)

### **Task 3.2 Understand Chemistry and Physics of Geothermal Brines**

33. Document the studies from the CEC project, with recommendations. (March 2007 Technology Output)
34. Decide on a pilot facility. (September 2007 Go/No Go Milestone)
35. Select partner and site for the pilot facility. (July 2008 Milestone)
36. Industry review of project. (August 2009 Milestone)
37. Determine performance and economics of the recovery process. (July 2011 Technology Output)

### **Task 3.3 Task Develop Innovative Materials**

38. Determine performance of OMP coatings for sprayed condenser use. (August 2006 Milestone)
39. Compile performance data and applications data for PPS. (August 2007 Technology Output)
40. Decide on additional materials development. (July 2008 Go/No Go Milestone)
41. Complete field testing of advanced materials. (September 2010 Milestone)
42. Provide commercialization documentation for all advanced materials. (August 2011 Milestone)

### **Task 3.4 Define and Validate Innovative Control Systems/Strategies**

43. Determine characteristics of advanced control systems. (March 2008 Milestone)
44. Decide on a field project. (July 2009 Go/No Go Milestone)
45. Select site, partner and system. (December 2009 Milestone)
46. Complete the field project. (September 2011 Technology Output)

### **13. Task 3.5 Reduce O&M costs**

47. Document typical O&M costs and cost reduction opportunities. (April 2006 Technology Output)
48. Select and evaluate techniques for cost reduction. (November 2006 Milestone)
49. Decide on field projects. (May 2007 Go/No Go Milestone)
50. Select field projects. (October 2007 Milestone)
51. Complete evaluations of field projects. (September 2009 Technology Output)

#### **Innovative Design and Construction Techniques/Strategies**

##### **Task 4.1 Utilizing cost-effective plant design and construction strategies**

52. Define modular approach and characterize likely gains. (January 2006 Milestone)
53. Develop complete strategy for modularization. (October 2007 Milestone)
54. Decide on new plant project. (January 2008 Go/No Go Milestone)
55. Complete project design and construction. (July 2010 Milestone)
56. Develop standards for modularization. (January 2011 Technology Output)

## **3.2. Technology Application**

### **3.2.1. Technology Verification**

Technology Verification includes cost-shared resource verification and demonstration of near-term commercial products to move technologies from research and development to use and application by the U.S. geothermal industry and other stakeholders. All technologies from exploration, EGS, well field construction, and energy conversion are field tested at commercial scale to demonstrate performance improvements, in collaboration with cost-sharing industry partners considering adoption of the technology.

#### **3.2.1.1. Enhanced Geothermal Systems**

EGS technology development has conducted cost-shared field tests with industry in the past, and will continue with projects at one or more dedicated EGS experimentation and testing sites from FY 2006 through FY 2011. Verification activities beyond FY 2011 will occur at two or more additional sites in cooperation with cost-sharing industry partners.

Detailed EGS Field Verification information can be found in Section 3.1.1, Enhanced Geothermal Systems.

#### **3.2.1.2. Exploration**

The Exploration subprogram works with industry to verify improved or new technology. Although new technology is often transferred to industry through presentations at technical meetings, some technology is verified through cooperative field projects. The Exploration element anticipates that one or multi-technique field validation experiments will be conducted in the next five years.

Detailed Exploration Field Verification information can be found in Section 3.1.2, Exploration Assessment and Technology.

#### **3.2.1.3. Wellfield Construction**

Wellfield construction conducts field verification at industry sites. Field verification is done in cooperation with service companies, providing built-in technology transfer. Field verification, rather than being a research phase, is done in response to industry needs.

Detailed Wellfield Construction Field Verification information can be found in Section 3.1.3.1, Wellfield Construction.

#### **3.2.1.4. Energy Conversion**

Energy conversion field verification is required to persuade manufacturers to adopt new technologies.

Detailed Energy Conversion Field Verification information can be found in 3.1.3.2, Energy Conversion.

#### **3.2.1.5. Geothermal Resource Exploration and Definition (GRED)**

The Geothermal Resource Exploration and Definition (GRED) Program is a cooperative DOE/industry program to find, evaluate, and confirm geothermal resources throughout the western United States. The goal is to develop geographically diverse geothermal resources and increase domestic power generation. GRED enables industry to evaluate potential geothermal fields and resources, and links geothermal exploration and development projects with appropriate DOE-funded research and development capabilities.

Because hydrothermal resources are difficult to locate and characterize and have modest power output (< 200 MW), geothermal resource exploration and confirmation has proceeded slowly over the last decade. Several thousand megawatts of geothermal power are believed to be awaiting development, but the costs and risk in the exploration and testing of hydrothermal systems are a major roadblock.

Finding a hydrothermal system requires exploration techniques of the type discussed in Section 3.1.2, including remote sensing, geophysical techniques, geochemical techniques, and regional resource assessments. Remote sensing requires satellite or airborne data for identification of geothermal prospects. Geophysics research includes detection of thermal anomalies and associated fracture systems using advanced seismic imaging, electromagnetic imaging, and gravity surveys. Geochemistry research is focused on chemical signatures that imply the existence of a resource. Regional resource assessments involve surveying to assess a regional or area-wide resource base. All of these technologies are appropriately used in GRED projects.

Testing a geothermal resource requires access to the reservoir by drilling a slim-hole well and conducting logging and testing operations to assess temperature, flow potential, water chemistry, and other pertinent factors.

Finally, assessing the prospect requires data integration to determine whether the project site is capable of sustained geothermal production and warrants further development. At this stage, a GRED project ends.

##### **3.2.1.5.1. Technical Goals and Objectives**

Through GRED, the Program encourages the development of geothermal resources in the western United States by supporting exploration, well drilling, and resource definition. By providing this information publicly, the Program encourages geothermal exploration and drilling in new geothermal areas. The Program promotes the commercial use of geothermal energy, and GRED emphasizes previously unproven geothermal resources. Accomplishing this goal will enhance energy-supply diversity, reduce the emission of greenhouse gases in the United States, and create jobs and economic growth. This effort identifies new resource locations and adds to the knowledge base of geothermal resources.

By decreasing front-end risk and cost of exploration in geothermal projects, GRED supports the Program's goal of increasing geothermal power generation, and the GRED program connects industry with new technology developed by Program sponsored research to reduce the cost of geothermal energy production.

### 3.2.1.5.2. Technical Approach

GED projects have been developed through bi-annual solicitations in 2000 (GED I), 2002 (GED II) and 2004 (GED III). The GED program is being phased out in 2006. Awards have used Cooperative Agreements as the funding vehicle.

Projects for GED may be up to three phases with a nominal lifetime of three years:

1. Resource Evaluation selects a site for drilling a geothermal exploration well,
2. Drilling and Characterization accesses and characterizes the reservoir, and
3. Testing and Assessment defines the geothermal resource.

Projects were allowed to begin at any phase, but data and interpretations were required for all phases even if no funding was provided for the earlier phases, to assure that all information is in the public domain. Completion of a project phase was required before approval of funding for the successive phase.

DOE shared up to 80% of exploration, well drilling, and well testing costs in GED I and GED II, but GED III was based substantially on a risk criterion. For GED III, projects were broken up into three risk categories. High risk included projects where no wells penetrated into the projected resource. These high-risk projects could be funded at up to 80% DOE cost share. Medium-risk projects had wells penetrating the resource, but no production. Medium-risk projects could be funded at up to 50% DOE cost share. Low-risk projects were those already producing power from the resource. Low-risk projects were only considered if they were using new technology; the maximum DOE cost share was 20%.

### 3.2.1.5.3. Program Status

The GED program will be phased out during 2006 and 2007 by completion of all projects.

GED I fieldwork for seven funded projects was completed during 2004. One GED project is finalizing its assessment, but all others have been completed and the cooperative agreements closed.

GED II initially consisted of eight funded projects, but one was closed early when the principal company sold its geothermal properties and a second was never started due to legal and environmental difficulties. The remaining six projects achieved moderate-to-high success in accessing and testing new resources.

GED III resulted in eleven ongoing awards. These projects will be funded during the next two years and will close out normally.

### 3.2.1.5.4. Current Activities and Technology Status

Completed field verification projects include:

*Rye Patch* - Pershing County, Nevada. A polyurethane treatment to cure a lost-circulation zone within a well was successfully applied, and the well was drilled, cased and cemented. Data suggest that the well is capable of sustained production of at least 1,118,000 lb/hr. As a result of this work, the power plant could supply 12.5 MW of new geothermal generating capacity.

*Steamboat Springs* - Reno, Nevada. This project assessed the potential for southward extension of the reservoir in an area that had never been tested. Well test data suggested that a large thermal zone with fluids at temperatures between 152° C and 161° C exists between about 400 and 1500 ft. This project helped identify approximately 42 MW of new capacity. The development of a new power plant was announced, but the property was sold prior to development.

*Blue Mountain* - northwest Nevada. This resource had no obvious surface expression and was discovered during exploration for minerals. Testing of a well was conducted in 2004 with poor results because of suboptimal wellbore conditions (damaged casing). The only high quality data from the well were the lithological and temperature results. However, Noramex announced that the findings were sufficient to begin planning for a 30 MW powerplant at the Blue Mountain site.

*Cove Fort / Sulphurdale* – Utah. The objective was to determine whether the existing geothermal resource could be extended westward, increasing plant capacity and/or developing new generation capacity. Temperature data suggested that the downhole temperatures in the test well were similar to those in the productive part of the field, indicating that the resource is extensive.

*Lightning Dock* - Animas Valley, New Mexico. The project consisted of geophysical work to assess the structural features and determine the optimum site for a well. Data analysis from drilling and two seismic traverses suggested that the initial hypotheses of the geologic model were not entirely correct.

*U-Boat* - Steamboat Hills, Nevada. The objective was to study the feasibility of adding another 30 MW of capacity at the Steamboat power plant by locating and tapping into the main reservoir and upflow zone. Discovery of these features required seismic, gravity and microseismic surveys and data analysis. This project provided considerable information on geologic structures.

Results of ongoing field verification projects are:

*Raft River* - southern Idaho. This project re-accessed available wellbores, assessed their condition, performed extensive testing to determine productive capacity, and performed a resource utilization assessment. The testing results were sufficient for U.S Geothermal to announce plans for a 10-15 MW power plant at the Raft River site as soon as power contracts could be negotiated. Final work includes an interference test (in 2005) and a final assessment.

*Lake City* - far northeastern California. The goal is to confirm the resource and plan development of the site for power generation. Wells were drilled in FY2005 with final results forthcoming.

*Truckhaven* - west flank of the Salton Trough in southern California. The work attempted to constrain an extensive shallow geothermal anomaly and provide information from which to select a test well(s) site. Preliminary results were integrated with remote sensing imagery and existing exploration data to provide a more complete model of the system. It is hoped that Phase II drilling can be conducted in FY2005.

*San Francisco Volcanic Field* - northern Arizona. This project has re-assessed the existing exploration data, geologically mapped the target area, obtained rock samples for age dating and mineral chemistry, performed gravity and magnetic surveys, and integrated these results to identify potential drilling targets and sites.

*Grass Valley* - north central Nevada. Geologic mapping, magnetic and gravity surveys, and a shallow temperature-gradient drilling program will be used to refine the model of the geothermal system, followed by drilling and assessment. This project is starting in FY05.

*Hot Sulfur Springs* - northern Nevada. Project work – primarily additional seismic surveying – will help delineate a target for the drilling of the well. This project is starting in FY05.

### **3.2.1.5.5. Technical Challenges**

The GRED program provides field testing of new DOE technology in exploration, drilling, logging, and testing to reduce costs and improve results, leveraging the Program's exploration and drilling work to improve each project's chance of success.

The GRED program fosters the use of new technology to:

- Improve the likelihood of success in identifying a prospect through exploration technology,
- Reduce the cost of drilling into the resource and testing the target zone,
- Maximize information obtained from drilling, coring, and logging, and
- Find deeper, hidden resources that are difficult to assess.

### 3.2.1.5.6. Technical Targets

Table 3.19 lists TIPs planned until subprogram closeout in 2008.

**Table 3.19 - TIPs for GRED**

Technology Improvement Potential	Metrics	2006	2011	2016
<b>GRED</b>				
Develop additional geothermal resources that are not currently productive.	Announcement of plans to develop a power plant at a GRED site	Identify eight sites with at least 10 MW each	Closed Out	Closed Out
Apply Program technology to GRED projects.	Application of exploration, drilling, logging, and/or testing technology	Use Program technology on at least eight projects	Closed Out	Closed Out

### 3.2.1.5.7. Barriers

GRED barriers include both technical and non-technical issues.

- A. For exploration, barriers include accurately locating faults or other enhanced fluid flow zones, identifying the high temperature source or outflow plume, and assessing the size and capacity of a resource.
- B. For well construction, issues include minimizing lost circulation problems, drilling faster, obtaining good cementing results, and providing a suitable well environment for logging and testing. These barriers are discussed in the appropriate technology sections.
- C. Non-technical barriers, typically the most difficult to resolve, include permitting, legal, and environmental issues that can delay or stop projects at attractive sites. The GRED program requires that all permitting must be completed and all environmental requirements must be met, but local opposition or other considerations often hinder performance.

### 3.2.1.5.8. Technical Task Descriptions

#### Metrics

The principal GRED program metric is the confirmation of new resources. It is measured by power plant development or planned and executed resource additions.

The GRED program monitors the results of each project, tabulates its contribution to new geothermal power generation, and assesses technical problems.

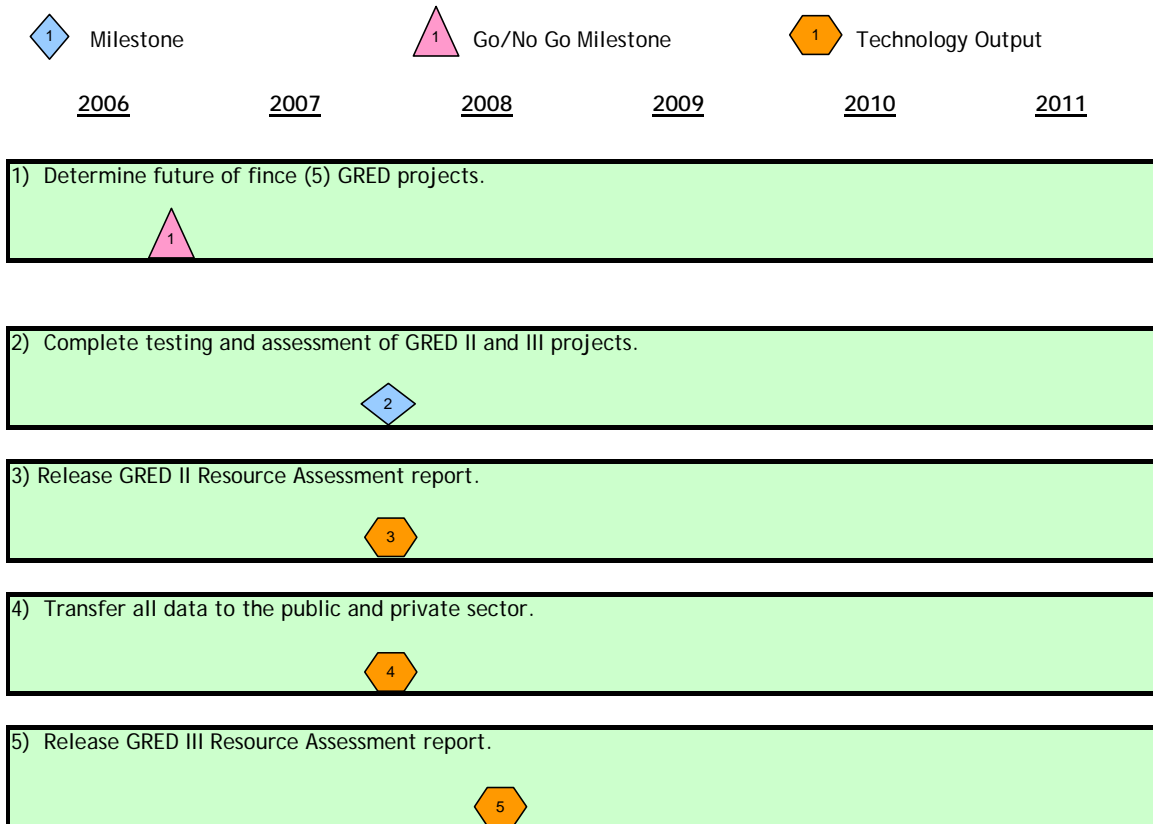
**Table 3.20 - Technical Task Descriptions for GRED**

<b>Task</b>	<b>Description</b>	<b>Barriers</b>	<b>Duration in Years</b>
<b>GRED I</b>			
<b>1</b>	<b>Seven Projects Funded (starting in FY00)</b> <ul style="list-style-type: none"> <li>• Six projects completed</li> <li>• Resources announced include:                             <ul style="list-style-type: none"> <li>12.5 MW at Rye Patch</li> <li>30 MW at Blue Mountain (with GRED II project)</li> <li>42 MW at Steamboat Springs</li> <li>49.5 MW at Fourmile Hill</li> </ul> </li> <li>• One project nearing completion                             <ul style="list-style-type: none"> <li>Preliminary Estimate at Lightning Dock (10-15 MW)</li> </ul> </li> </ul>	A, B, C	4
<b>GRED II</b>			
<b>2</b>	<b>Eight Projects Funded (starting in FY02)</b> <ul style="list-style-type: none"> <li>• Two projects completed</li> <li>• Four projects ongoing</li> <li>• Resources announced include:                             <ul style="list-style-type: none"> <li>30-90 MW at Raft River</li> <li>30 MW at Blue Mountain (with GRED I project)</li> </ul> </li> <li>• One project delayed</li> <li>• One project terminated early</li> </ul>	A, B, C	3
<b>GRED III</b>			
<b>3</b>	<b>Eleven Projects Funded (starting in FY04)</b> <ul style="list-style-type: none"> <li>• All projects starting in FY05</li> </ul>	A,B	3

**3.2.1.5.9. Milestones**

Table 3.21 shows the interrelationship of milestones and tasks for the GRED program element from FY05 through closeout in FY08.

**Figure 3.14 - Technology Development Paths for GRED**



**Table 3.21 - GRED Milestones**

<b><u>GRED II</u></b>
1) Determine future of five (5) GRED projects. (July 2006 Go/NO Go Milestone)
2) Complete testing and assessment of GRED II and III projects. (September 2007 Milestone)
3) Release GRED II Resource Assessment report. (September 2007 Technology Output)
4) Transfer all GRED data to the public and private sector. (September 2007 Technology Output)
5) Release GRED III Resource Assessment report. (April 2008 Technology Output)

### 3.2.2. Technology Acceptance

Technology Acceptance identifies and addresses market and institutional barriers by providing stakeholders with information on the economic, environmental and energy security benefits of developing the nation’s abundant geothermal resources. These activities encompass public-private partnership efforts on national, state and local levels across the western United States. The activity should significantly increase the development of geothermal energy by 2011. In the long term (five to 20 years), Technology Acceptance is expected to help expand geothermal energy use nationwide.

The GeoPowering the West (GPW) Initiative is the Program’s primary means of interaction with stakeholders other than the geothermal industry.

### 3.2.2.1. External Assessment and Market Overview

The domestic power market is volatile, with rising natural gas prices driving increases in electricity rates. These market conditions present a substantial geothermal development opportunity, but other market factors thwart geothermal power technology deployment. Some of these factors are:

- A. Transactional Costs – Institutional barriers increase project transactional costs. Permitting, leasing approvals, and other bureaucratic requirements and delays add to costs, affect project timelines, and even prevent development.
- B. Technical Unfamiliarity – Many decision makers are not aware of geothermal benefits and resource locations. Targeted information products and state/utility stakeholder partnerships address this issue. Technical assistance eliminates unfamiliarity and uncertainties about new technologies.
- C. Power Market Processes – Most utilities, power marketers and regulators do not regard geothermal energy as a viable alternative today. Acceptance by utilities and power marketers depends on understanding constraints and opportunities and on the interest of public officials responsible for power sector regulation. Public Utility Commissions and consumer-utility boards are not well informed about economic and environmental benefits, and do not ask utilities and power companies to include geothermal energy in planning scenarios. Additionally, the erratic history of the production tax credit (PTC), with no similar market incentive for consumer-owned utilities, discourages investment in geothermal power. Failure to adopt ‘field-leveling’ policies results in high thresholds for geothermal market maturity, and presents a critical barrier.
- D. Leasing, Permitting, and Public Policies – In some cases, land use plans, federal and state agency requirements, and policies constrain the development of geothermal projects.
- E. Environmental, Tribal, and Public perception – Geothermal energy is identified with environmental problems such as air and water emissions, both real and imagined. This affects development on historic, non-reservation, tribal lands. Outreach addresses this barrier.

### 3.2.2.2. Internal Assessment and Program History

GPW, established in 2000, identifies barriers to geothermal power development at the regional, state, and local levels and seeks to eliminate them. The GPW team has developed technical assistance and outreach activities aimed at key user communities – state government officials, power developers and utilities, industry, Native Americans, economic development agencies, and other stakeholders.

The GPW team includes partners from DOE, the Regional Offices, national laboratories, other federal agencies, industry partners, regional associations, tribes, and states. The Geothermal Resources Council, Geothermal Energy Association, Geothermal Education Office, Geo-Heat Center, Bob Lawrence and Associates, National Conference of State Legislators, Western Area Power Administration, and Washington State University have supported GPW activities.

In 2004, GPW achieved the highest rating among EERE outreach efforts by providing a customer-friendly approach, relevant information, and by interactively working with the geothermal industry and state stakeholders.

In 2004, GPW held a Peer Review evaluating its activities, using objective criteria and independent peer reviewers to judge GPW’s merits, results, and effectiveness, and provide recommendations for improving the effectiveness of GPW activities. The reviewers noted that the geothermal industry is facing greater opportunities due to Renewable Portfolio Standards

in several western states. The GPW message about geothermal potential and benefits has contributed to the current market status and the future potential for expansion.

### 3.2.2.3. Federal Role

GPW addresses institutional barriers to development, technology transfer, communications, and outreach. The initiative serves as a catalyst to bring geothermal technologies to wider market acceptance through the public's realization of geothermal energy potential. The Federal government's role is essential to this knowledge/technology transfer because the research and development experts at the various universities and national laboratories, experience with industry needs and issues, and close associations with stakeholders make the Program a trusted neutral party in providing information.

Success in this program area contributes to the EERE mission by enhancing energy productivity; bringing clean, reliable, and affordable energy technologies to the marketplace; making a difference for Americans by enhancing energy choices, and contributing to the nation's energy security, environmental, and economic development initiatives.

### 3.2.2.4. Approach

GPW identifies and develops processes to resolve market-related issues inhibiting geothermal resource use. Directly addressing these issues through stakeholder interaction brings those who can benefit from increased geothermal generation into the process.

The approach involves:

- Prioritizing states with undeveloped high-quality geothermal resources,
- Leveraging and building institutional partnerships,
- Developing innovative pilot applications,
- Replicating successes,
- Using and coordinating existing national, regional, and local expertise,
- Coordinating with established institutions,
- Working with industry developers, and
- Working with the R&D elements of the Program.

GPW builds state-level support for promoting geothermal energy development. A state-focused strategy acknowledges the critical state role in policymaking, incentive adoption, R&D involvement, and demonstrations. This state-based strategy is complemented by high-level national and regional efforts to align policies, remove barriers, and disseminate information.

GPW task activity is organized by:

- **State-Based Activities:** GPW helps establish State Working Groups (SWGs) which serve as the key organizers for state efforts. The SWGs form the network of energy professionals and geothermal stakeholders needed to facilitate communication, activities, and outcomes. A geothermal SWG can identify and address needs and translate them into actions.
- **Geologic Assessments:** The initiative facilitates work between states and the USGS to determine how much geothermal resource exists and how much of that energy can be economically used.
- **Interagency Facilitation:** Interagency Facilitation works with government agencies and institutions to alter, reduce, or mitigate policies and procedures that inhibit development.
- **Utility Sector Support:** GPW seeks to gain increased utility sector acceptance for geothermal power production as clean, safe, secure, and reliable, and seeks to ensure it is considered in the utility evaluation and planning process.

- **RDD&D Technology Transfer:** The Research, Development, Deployment, and Demonstration (RDD&D) approach matches technologies with stakeholder needs and obtains essential feedback from the industry and marketplace to guide further research and development.

### 3.2.2.5. Performance Goals

The ultimate measure of success is market acceptance. The Geothermal Technologies Program and the geothermal industry share a common goal: sustained growth of an economic geothermal energy supply, which is a clean energy option for heating and powering the Nation’s homes and businesses.

Performance goals are listed by GPW task area.

#### **State Based Activities**

*State Working Groups* – Full establishment of a state-working group meeting the criteria:

- SWG formed with state agency lead, other state engineers, economists, developers and champions identified;
- Geothermal industry, targeted utilities, businesses, university researchers, and other stakeholders identified;
- Kick-off meeting publicized and held;
- SWG strategic plan (such as education, policy, energy and water laws, resources, financial, utilization, sustainability) completed with issues, impediments, and barriers identified;
- Policy needs identified (e.g., renewable portfolio standards (RPSs));
- Three development power projects identified;



**Figure 3.15 - An example of a geothermal direct use application in horticulture in Idaho.**

- Three development direct use projects identified;
- Vision of EGS communicated;
- Requests for GPW technical assistance (including RDD&D needs), and
- Distribution of press releases highlighting above activities and notable findings.

*Tribal Geothermal* – Engagement with tribes to predict and mitigate opposition to power projects based on understanding of tribes’ issues. This work focuses on early discovery of problems that hindered past geothermal development. Nevada, California and New Mexico are the states that have accomplished the most in this area.

- Identification of tribes with geothermal resources,
- Documentation of those resources,
- Field investigations for interested tribes,
- Project engineering support for prospective installations, understanding of cultural issues, and addressing tribal opposition to projects on historic, off-reservation tribal lands.

### **Geologic Assessments**

*State Based Geothermal Assessment* – State geoscientists are compiling geothermal and geologic information that will be provided to the USGS for a new, comprehensive geothermal resource assessment. The Program is providing staff to assist with this activity. The assessment staff will characterize state geothermal resources in a formal report to the USGS.

- *USGS Resource Assessment* – The USGS will obtain data from the states and provide a western states resource assessment that characterizes and maps geothermal resources. The USGS will update Circular 790 including methodologies and analyses for geothermal resources.

### **Interagency Facilitation**

*Interagency Focus and the National Geothermal Collaborative (NGC)* – The NGC will facilitate resolution of high level policy barriers with agencies and stakeholders. Workshop education and consensus documents provided by NGC will be discontinued. NGC will focus on ‘Expedited Permitting and Leasing’ of geothermal resource along with utility and financing issues relating to development of geothermal resources. State policies will be addressed at both the local and state levels. A Programmatic EIS will be scoped and a go/no go decision will be made.

*Agricultural Extension Service* – The Department of Agriculture (USDA) implements services at the local level, where many geothermal resources are best used. The USDA will implement geothermal site analysis as an included extension service. This technical assistance includes supporting geothermal projects technically and financially, installing geothermal systems, and developing USDA Farm Bill template for proposals and continuing submittals.

### **Power Sector Support**

GPW spearheads a consistent, coordinated, high-quality communication effort with the power sector. The Western Area Power Administration (WAPA), SWGs and the Utility Geothermal Working Group (UGWG) assist with the plan. The plan identifies the target audience, informational topics of greatest importance, and the appropriate delivery vehicle for the message. The plan’s targeted audiences are retail utility customers, resource planning managers, transmission managers, and PUC boards.

*Utility Geothermal Working Group* – The UGWG provides a forum for discussion of geothermal technology and analysis of barriers that impact power applications, and serves as a source of credible information on geothermal technologies and deployment status. The group holds technical geothermal forums and coordinates membership efforts and actions. The UGWG collaborates with GPW program partners. Membership is open to all power companies and utilities in the United States, Canada, and Europe, including investor-owned, public power, and rural electric cooperative utilities, as well as associate member corporate, government, and academic organizations. The UGWG’s goals are:

1. Identify and target likely geothermal energy-buying utilities or other potential utility sector geothermal stakeholders and introduce them to the UGWG.

2. Assess geothermal performance with utilities or stakeholders currently buying geothermal energy, obtain testimonials, and identify ‘champions.’
3. Develop Portfolio Prerequisites and Needs Assessments. The utility sector needs supporting information to consider geothermal inclusion in the state portfolio, such as industry and resource identification, possible supply curves, inputs to utility integrated resource planning, portfolio analyses, actual geothermal power purchase agreements (PPAs), system models, Renewable Portfolio Standards or other incentives, resolution of asset/liability of independent power purchases, and general utility training about geothermal characteristics. Achievement of this goal is measured by geothermal utility sector planning such as Renewable Portfolio Standards, requests for proposal, integrated resource plans, or other utility commission involvement.
4. Share utility lessons learned. The UGWG and GPW document their experiences including resource identification, purchase power agreements and experience with the public. Power generation case studies will be written and distributed to all UGWG members and SWG. The number of installations and selected case studies will be a measure of progress.
5. Pilot-test *the Guidebook to Expanding the Role of Renewables in a Power Supply Portfolio* with two consumer-owned utilities. With the aid of this guidebook, the utilities will define geothermal generation objectives, and analyze and model geothermal energy costs and risks.
6. Conduct regular meetings of the UGWG, including identifying annual operating plans and activities for FYs 2006-2011.

*Geothermal Power Partnership Strategy* – GPW collaboration with the National Rural Electric Cooperative Association (NRECA) and the American Public Power Association (APPA) provides access to more than 3,000 consumer-owned utilities across the United States. This collaboration enables GPW to contact many otherwise inaccessible utilities and educate these groups about geothermal energy technologies and their benefits.

Grants are provided to NRECA and APPA annually. These grants result in:

- Publication of articles in NRECA and APPA periodicals,
- Development of interns who often pursue careers in the energy industry, and
- Workshops, web casts, and technical studies.

### **RDD&D Technology Transfer**

R&D activities provide research results and technologies which meet the needs of industry and stakeholders. The Program is proactive in presenting these results to industry and others who will benefit from this information.

#### **3.2.2.6. Strategic Goals**

GPW’s strategic goals are to:

1. Reduce the transactional costs of geothermal power and direct use development by removal, reduction, or mitigation of institutional barriers, and
2. Characterize geothermal energy as clean, safe and reliable so that it is appropriately valued in the utility sector.

Interagency and state working groups will address federal and regional institutional barriers to reduce transactional costs. Technology unfamiliarity will be addressed through educational outreach and assistance. The GPW initiative aids geothermal development in the utility sector through technology transfer.

Geothermal technology transfer and educational outreach focus on organized state activities, with the goal of advancing market maturity in individual states. Barrier reduction, technology transfer,

and educational outreach are necessary (though not alone sufficient) for capitalization of geothermal projects and sustained, orderly development of geothermal resources across the western states.

### **3.2.2.7. Market Challenges and Barriers**

Market challenges are covered in the technical discussions in Section 3.

### **3.2.2.8. Technical Challenges and Barriers**

The primary GPW challenge is developing and strengthening relationships with relevant policy and decision-makers at all levels of government and within the power industry to bring about greater use of geothermal resources. Section 3.2.2.4 provides details about how this non-market challenge is being addressed.

### **3.2.2.9. Strategies for Overcoming Barriers and Challenges**

Sections 3.2.2.4 and 3.2.2.10 discuss how GPW seeks to overcome barriers and challenges.

### **3.2.2.10. Tasks**

#### **State-Based Activities**

As recommended by the Peer Review, efforts in the states are the main focus of GPW. State geothermal working groups (SWGs) are the basis for technology transfer and outreach to local communities and developers. SWGs raise awareness in a community, state, or region of the economic benefits of geothermal energy development. By identifying and publicizing barriers to development, the working groups help political, economic, and industry leaders address institutional issues and create a more favorable regulatory and economic environment for geothermal development. Institutional issues include permitting, land access, renewable portfolio standards, tax credits, environmental justice, resource assessment, financing, utility planning, green tags, and green pricing programs.

GPW supports the SWGs through:

- State-level geothermal workshops,
- State geothermal resource mapping,
- Awareness and technology transfer workshops on geothermal energy,
- Efforts to increase use of geothermal energy development on public lands,
- Efforts to increase federal use of geothermal energy,
- Outreach to public power and rural cooperatives for use of geothermal energy, and
- Outreach to Native Americans with geothermal resources on tribal lands.

GPW carries out some or all of the following activities to advance geothermal market maturity in a state:

- Perform state reconnaissance to find key stakeholders.
- Determine geothermal industry or business interests.
- Determine applicable energy policies.
- Conduct a “kick-off” public meeting designed to gain attention.
- Conduct follow-up activities to form a state strategy (such as education, policy, resources, financial, utilization, sustainability).
- Identify geothermal “champion(s)”.
- Identify and characterize the geothermal resource (i.e., maps).
- Identify potential projects and beneficiaries.
- Identify issues, impediments, and barriers.
- Advance state strategies (e.g., for economic development).

- Involve utilities in power projects.
- Award State Energy Project (SEP) funds.
- Provide technical assistance and nationally based information.
- Broad promotion and publicity of efforts.
- Outreach to electric utilities through workshops, utility events, and various information dissemination vehicles.
- Offer a vehicle for integration of Program R&D with state opportunities.

### **Geologic Assessments**

Geothermal development depends on resource availability and understanding of the resource. The approach to geologic assessment is simple - determine how much geothermal resource is available and how much of that energy can be economically developed.

First, all available state information is collected, including areas drilled and depths, temperature profiles, data on permeability, fluid flow rates, and thermal gradients, so that this information can be analyzed. This requires identification of state geologists who can collect and compile this information. Second, the state geologists prepare the data using a US Geologic Survey (USGS) accepted format. Third, the USGS will analyze the data for the update of the geothermal resource estimates previously performed in the 1978 assessment, published as USGS Circular 790. Both an interim and final report will be published in 2008 and 2010. The Program is providing support to the USGS for these analysis and reporting activities.

### **Interagency Facilitation**

Interagency Facilitation addresses policies and procedures that inhibit development and works with government agencies and institutions to remove, reduce, or mitigate these barriers. Tasks include:

- Cataloging and assessing key impediments and institutional issues
- Supporting current projects under development
- Engaging other agencies such as the BLM, USFS, and USDA
- Engaging high level utility, industry and tribal organizations
- Supporting or developing transmission analyses
- Developing and communicating agency-specific resource
- Creating a plan for R&D market integration and other analysis tasks
- Facilitating interactions and communicating results among stakeholders

### **Utility Sector Support**

Energy developers and the utility sector, including the regulators and policy makers of state government, are essential to realizing the promise and potential of geothermal technologies. GPW coordinates with western utility efforts to prevent overlap or duplication of effort.

As recommended by the Peer Review, the GPW element for energy developers and suppliers produces hard information, application notes, and case studies. GPW activities include:

- Identifying likely geothermal energy-purchasing utilities or other potential utility sector geothermal stakeholders.
- Conducting state-based utility geothermal workshops.
- Creating and communicating information that utilities require for resource evaluation and access (i.e., cost, location, operations characteristics, etc.).
- Assessing geothermal performance with utilities that are current geothermal energy purchasers or stakeholders, obtaining testimonials, and identifying 'champions'.

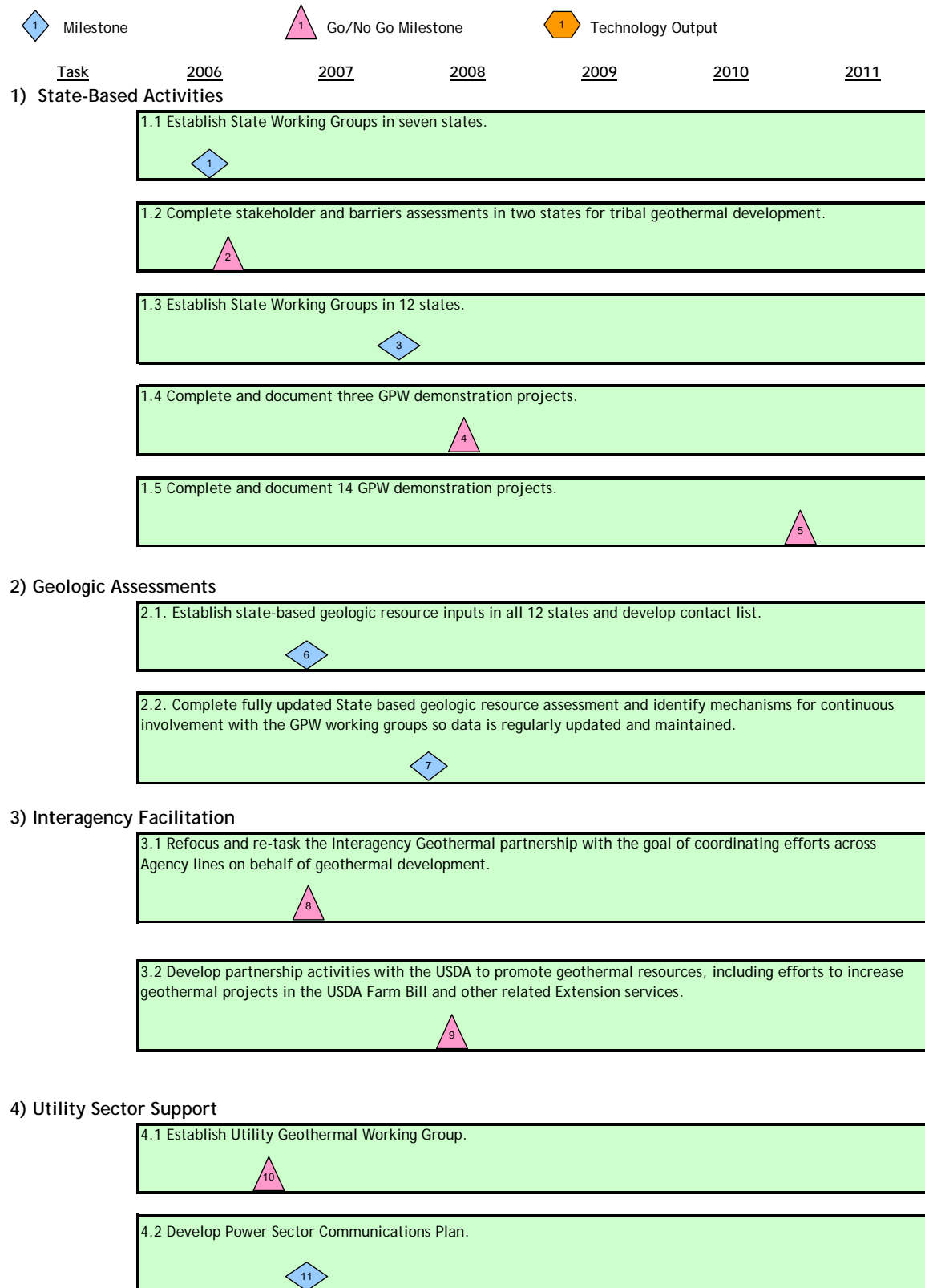
- Preparing analyses and reports in the model of the recent Public Interest Energy Research report on geothermal and transmission prepared for the California Energy Commission.

#### **RDD&D Technology Transfer**


GPW, as the main outreach and deployment task area of the Program, provides a crucial channel to match R&D efforts with industry needs. Where the program has demonstration needs, industry is recruited to implement new technology. Where developers have technical issues, the GPW team identifies the technology solutions available within the Program. GPW acts as an interface between industry needs (market pull) and Program products and services (technology push).


#### **3.2.2.11. Milestones and Decision Points**

**Figure 3.16 – GPW Operations Paths**




 Milestone

 Go/No Go Milestone


 Technology Output

Task                      2006                      2007                      2008                      2009                      2010                      2011


4.3 Identify, package and distribute information to four target groups, including: retail utility customers, resource planning managers, transmission managers, and PUC / utility boards.




4.4 Establish Utility Geothermal Working Group.




4.5 Disseminate portfolio prerequisites and needs assessments for utilities in 3 states.








4.6 Disseminate portfolio prerequisites and needs assessments for utilities in 3 more states.








4.7 Disseminate utility lessons learned report to 12 states.



4.8 Maintain a Geothermal Power Partnership Strategy with NRECA and APPA.


                        

4.9 Develop annual operating plan.


                        

### 5) RDD&D Technology Transfer


5.1 Identify and match needs through state survey of projects.



5.2 Create an inventory of available Program products and services.



5.3 Document technology transfer for 3 projects.



5.4 Document technology transfer for 10 projects.



**Table 3.22 - GPW Milestones and Decision Points**

**1. State Based Activities**

1. Establish State Working Groups in seven states. (March 2006 Milestone)
2. Complete stakeholder and barriers assessments in two states for tribal geothermal development. (May 2006 Go/No Go Milestone)
3. Establish State Working Groups in 12 states. (September 2007 Milestone)
4. Complete and document three GPW demonstration projects. (March 2008 Go/No Go Milestone)
5. Complete and document 14 GPW demonstration projects. (September 2010 Go/No Go Milestone)

**2. Geologic Assessments**

6. Establish State based geologic resource inputs in all 12 states and develop contact list. (December 2006 Milestone)
7. Complete fully updated State based geologic resource assessment and identify mechanisms for continuous involvement with the GPW working groups so data is regularly updated and maintained. (December 2007 Milestone)

**3. Interagency Facilitation**

8. Refocus and re-task the Interagency Geothermal partnership with the goal of coordinating efforts across Agency lines on behalf of geothermal development. (December 2006 Go/No Go Milestone)
9. Develop partnership activities with the USDA to promote geothermal resources, including efforts to increase geothermal projects in the USDA Farm Bill and other related Extension services. (December 2007 Go/No Go Milestone)

**4. Utility Sector Support**

10. Establish Utility Geothermal Working Group. (September, 2006 Go/No Go Milestone)
11. Develop Power Sector Communications Plan. (December 2006 Milestone)
12. Identify, package and distribute information to four target groups, including: retail utility customers, resource planning managers, transmission managers, and PUC / utility boards. (March 2007 Milestone)
13. Establish Utility Geothermal Working Group. (March 2006 Go/No Go Milestone)
14. Disseminate portfolio prerequisites and needs assessments for utilities in 3 states. (March 2006 Milestone)
15. Disseminate portfolio prerequisites and needs assessments for utilities in 3 more states. (March 2007 Milestone)
16. Disseminate utility lessons-learned report to 12 states. (March 2009 Milestone)
17. Maintain Geothermal Power Partnership Strategy with NRECA and APPA. (December 2006-2010 Milestones)
18. Develop annual operating plan. (December 2006-2010 Milestone)

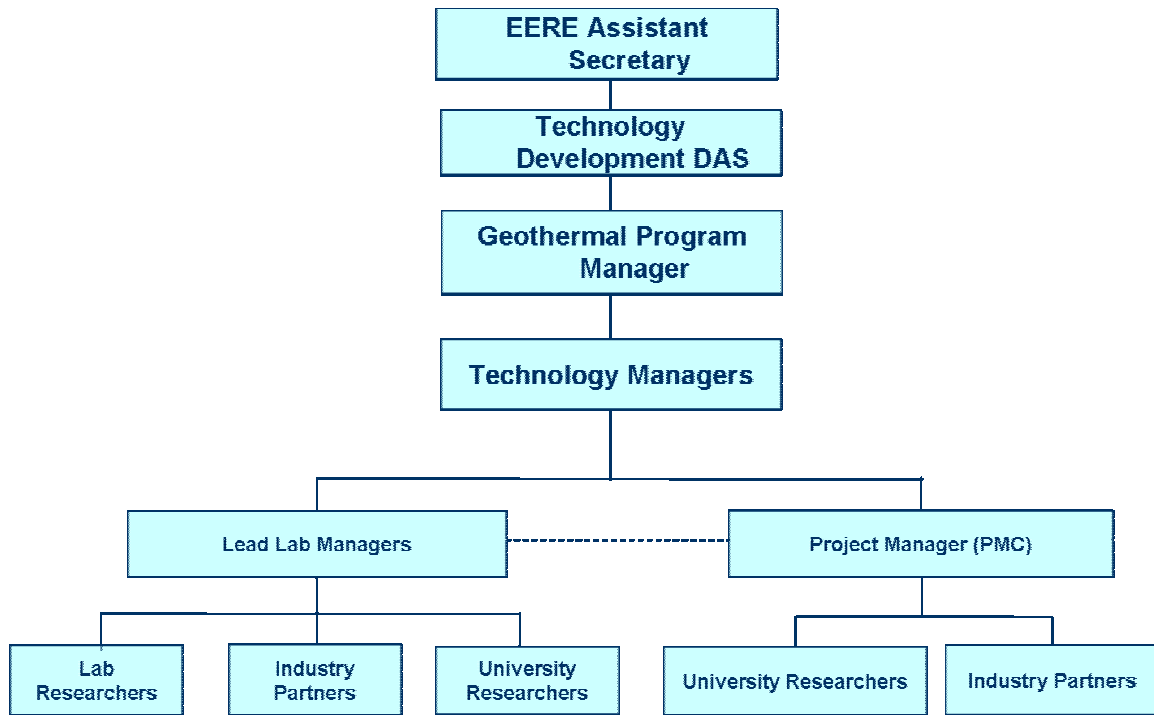
**5. RDD&D Technology Transfer**

19. Identify and match needs through state survey of projects. (March 2007 Milestone)
20. Create an inventory of available Program products and services. (December 2007 Milestone)
21. Document technology transfer for 3 projects. (March 2008 Go/No Go Milestone)
22. Document technology transfer for 10 projects. (July 2010 Milestone)

## 4. Program Administration

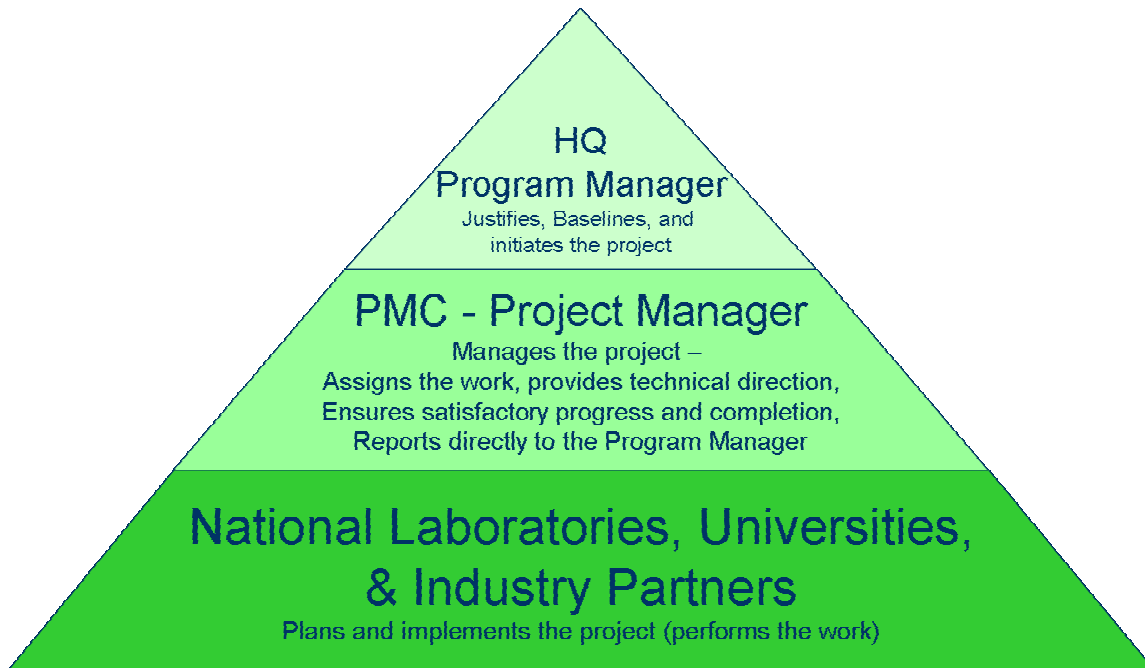
### 4.1. Organizational Structure

In 2001, the Administration released the President's Management Agenda, which called for an increased emphasis on results throughout the federal government. The Program's organizational structure is designed to run a results-oriented process that will achieve the strategic goals with maximum efficiency.



The Headquarters Program Manager justifies the Program, develops baseline performance metrics, and transfers funds to the Project Management Center (PMC) and the national laboratories. HQ Technology Managers carry out the Program Manager's directives, administer changes to planned activities, track achievement of milestones, monitor progress, and prepare program guidance letters. The PMC manages the financial assistance projects, assigns the work, provides technical direction, ensures satisfactory progress and completion of projects, and reports to the Technology Managers.

National Laboratory leads manage and integrate research and deployment activities, and collaborate with industry and universities to identify future research needs. Lead Lab Managers interface directly with the Technology Managers and the Program Manager.



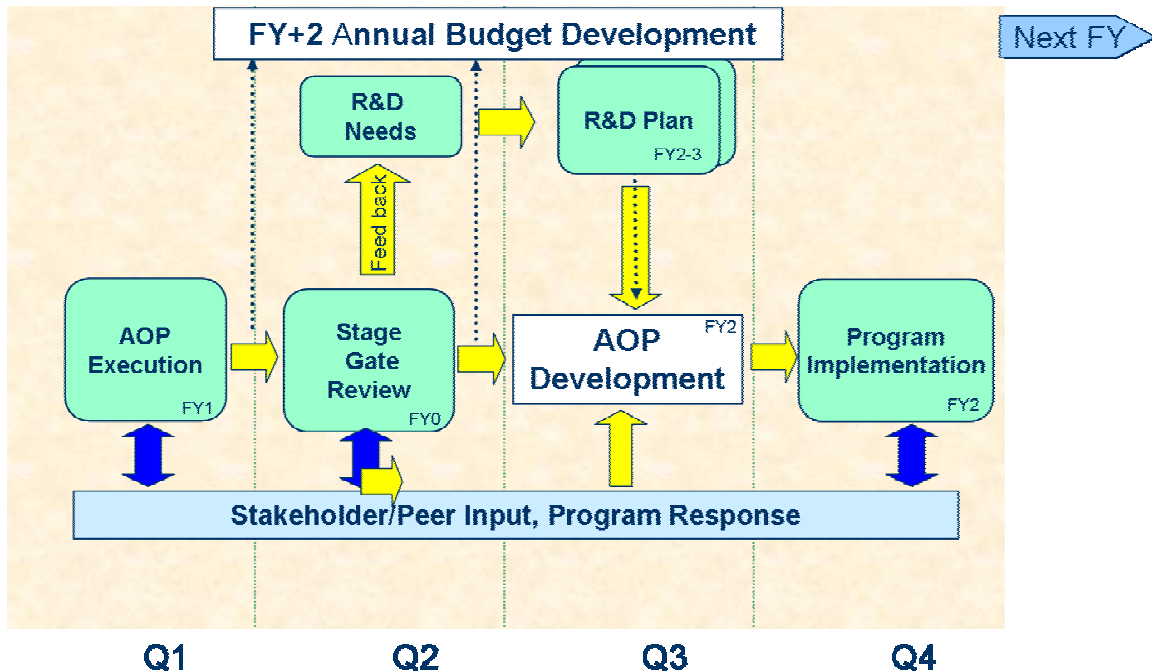
Research is carried out through the National Laboratories, industry partners, and universities. Research projects at the National Laboratories are funded through DOE based on their core competencies. The universities and industry partners respond to cost-shared solicitations jointly developed by the HQ Technology Manager and the PMC. The PMC conducts technical merit reviews of proposals, executes the budget and monitors the project through completion. The PMC provides a full suite of procurement and project management capabilities, and ensures that project management practices are consistent with those employed throughout EERE.

#### 4.2. Program Funding Mechanisms

Program priorities and goals are presented in the Geothermal Technologies Program Strategic Plan. Funding needs for any given fiscal year are determined based on the suite of projects conducted at the laboratories, universities and industries. Based on program priorities and the Peer Review of ongoing projects, the technology managers develop the funding distribution. The HQ Technology Manager and the PMC develop solicitations for research and development work for universities and industry partners. The content of the solicitations is determined by:

- 1) Peer review recommendations on research that:
  - a) meets the goals of the program,
  - b) is not being addressed, or
  - c) requires a greater level of effort;
- 2) Annual meetings with industry representatives to identify industry priorities (industry priorities typically shift relatively slowly, over a three- to five-year period); and
- 3) Annual plans from the National Laboratories, where laboratory managers develop research plans based on input from scientists and industry partners.

The solicitations require that applicants cost share 20% of research and development projects and 50% of demonstration projects. The Technology Managers determine laboratory funding based on the laboratories' Annual Operating Plan submissions, peer review results, and program priority.



The management of solicitations and the merit review process is performed by the PMC. A Selection Official (SO) appoints a panel of expert reviewers bound by non-disclosure and conflict-of-interest agreements to assess proposals. PMC conducts the merit review process in accordance with the Federal Register Notice dated December 20, 2001 and 10 CFR 600.13. The reviewers score the projects based on Solicitation criteria. The aggregated scores are used to rank the projects and a selection range is established. The SO applies the Program Policy Factors to projects in the selection range and makes a final selection, following which the PMC Contracting Officer makes the awards.

#### 4.3. Cost Management and Monitoring

EERE tracks costs and uncosted balances using multiple systems at Headquarters and through the PMC. At the PMC, the National Energy Technology Laboratory uses the Project Management Information System (ProMIS), and the Golden Field Office uses the Project Management Database. The PMC uses these systems to transmit data to EERE through the DOE Standard Accounting and Reporting System (STARS). STARS data is accessed by EERE through the I-MANAGE Data Warehouse (IDW). Data from the IDW is pulled into a reporting and analysis application called COGNOS. Once in COGNOS, data on costs and uncosted balances are reviewed by EERE Technology Program staff.

Data on costs and uncosted balances are regularly monitored and evaluated against current performance and the program's priorities. The evaluation uses data from the EERE Corporate Planning System on performance and program priorities along with DOE financial data from the COGNOS reporting application. EERE staff consult with field project managers at the PMC and National Laboratories to track costs and uncosteds against project milestones and Program goals.

#### 4.4. Environmental Safety and Health

EERE is committed to successfully integrating ES&H into its activities and objectives. In its *Safety Management System Policy*, the Department has adopted an approach which requires the integration of environment, safety, and health (ES&H) into the planning, execution, and measurement of all work performed at its sites and facilities. The EERE ES&H staff advises the ASEE on ES&H policy; performance and resources; adherence to statutory, regulatory, and DOE

requirements; the National Environmental Policy Act (NEPA); occupational safety and health; and emergency management activities. The team assists senior management in establishing EERE-wide policy, guidance, and performance expectations. It monitors EERE Headquarters and Field ES&H performance to apprise the ASEE of organizational performance and participates in the development of EERE-wide ES&H strategic and management plans. It manages the safety and wellness and Federal Employee Occupational Safety and Health (FEOSH) programs for Headquarters Federal employees. It also serves as lead for specific ES&H functions, provides EERE-wide technical guidance and assistance as requested (e.g., preparing of ES&H/NEPA documents, implementing new ES&H requirements), and participates in Departmental committees as the EERE representative.

Each EERE program is responsible for ES&H of its workplace and workers, as well as for ensuring that ES&H is fully considered and implemented in program planning, R&D, budgeting and contracting. Each program, when executing projects and acquiring items over which EERE has acquisition/procurement responsibility, addresses ES&H commensurate with the severity of the associated hazards and the potential for injury or illness, loss or damage, or environmental mishaps to private or Government resources, consistent with mission requirements and economical considerations. The scope, complexity, and level of documentation of each ES&H effort is tailored to the size, mission, hazards, and complexity of each project. The approval of specific requirements to be included in contracts is delegated to an EERE Contracting Officer, and the programs review the requirements prior to their approval & implementation.

#### 4.5. Communication and Outreach

Information dissemination, communications, and outreach activities in EERE are carried out by the Office of Communication and Outreach (OCO). OCO communicates the EERE mission, program plans, accomplishments, and technology capabilities to a variety of stakeholder audiences including Congress, the public, educational institutions, industry, and other government and non-government organizations. In addition, OCO prepares speeches and presentations by the Assistant Secretary and others when requested; manages the EERE public website and EERE's centralized public information clearinghouse; manages official correspondence; and coordinates reviews of EERE-related statements by other DOE offices and Federal agencies.

OCO coordinates outreach and information activities across EERE, integrating communications efforts from all programs to provide a unified approach to audiences. Consumers learn about all relevant EERE technologies, rather than receiving information on only one aspect of energy efficiency or renewable energy. This coordination is designed to remove barriers to technology acceptance and implementation; provide accurate information on EERE technologies; and target opportunities where rising prices or energy supply constraints may spur acceptance of new technologies.

The Geothermal Technologies Program has shared its Outreach and Technical Assistance Plan with various EERE Communications and Outreach Office staff as an initial step in coordinating activities.

**The primary objective of the Program's Communications and Outreach activities is sharing geothermal information effectively with stakeholders.** Technology and application-specific communications products advance the technical and market acceptance of geothermal technology.

**The strategy of Geothermal's Communications and Outreach activities is to build state-level support for increased geothermal power production.** Through GeoPowering the West (GPW), the Program provides state-based technical information transfer and assistance focused on 19 Western states. Technology advances may eventually support geothermal communication and

outreach activities in all states. In 2005, GPW was recognized as the highest rated outreach program within EERE. The GPW initiative is discussed in Section 3.2.2.

The Geothermal Technologies Program's Communication Goals are:

- To create and foster a preference for proven and appropriate geothermal technologies.
- To build awareness and support for continued investment in geothermal R&D to improve performance, lower cost, and increase efficiency.
- To foster an understanding that geothermal energy is a clean and renewable resource.
- To provide credible, current, and accurate information about geothermal technologies.

The Program's Outreach and Education Goals are

- To develop and produce information that conveys the realistic potential and promise of geothermal energy use, and associated benefits and impacts.
- To help ensure that accurate, specific, and current information is available to decision makers and policymakers, researchers, and consumers.
- To promote and publicize noteworthy Program accomplishments and contributions, such as the six R&D 100 Awards in the last five years.
- To make this information easily accessible to target audiences, especially high-priority audiences, through a variety of media and mechanisms, and to proactively reach target audiences.
- To ensure that educators and students of varying levels can easily obtain general and technical information helpful in raising understanding and awareness about geothermal principles and technologies.
- To interpret geothermal research, and develop (when appropriate) educational products or databases to support school outreach.

### **Target Audiences**

The Program identifies appropriate target audiences, becomes acquainted with their attitudes and preferences, and produces suitable information products. These products are delivered to target audiences cost-effectively using the best available channels. Currently, 300 DOE-funded geothermal communications products are in circulation.

#### Target Audiences:

- DOE and EERE Management
- Congressional Membership and Staff
- Decision Makers:
  - Federal (e.g., USDA, BLM, USFS, FEMP, FERC, and DoD)
  - State (e.g., state energy offices, PUCs, legislators, geologists, NASEO, NARUC)
  - Local (e.g., municipal utilities, building and environmental depts.)
- Geothermal Industry and Stakeholders
- Geothermal State Working Groups
- Utilities and Power Producers/Industry
- Environmental Organizations
- Teachers, Students, and University Researchers
- Native Americans
- Consumers
- Economic Development Commissions and Agencies (local, state, and regional)
- Builders and Developers
- Investment Community

Interactions with target audiences can occur through special meetings (e.g., state working groups and trade missions), conferences (e.g., geothermal, energy, policy, and environmental), exhibitions (e.g., power generation and clean energy equipment), and media (e.g., program website and the GRC Bulletin). The Program distributes communication products through organizations such as GEA, GEO, WAPA/PRP, NASEO, and NARUC.

Networking with specific audiences, such as state legislators and staff, is achieved through collaborative partnerships with organizations like the National Conference of State Legislators. Additional networking efforts are made through organizations such as the Western Governors' Association, Western Interstate Energy Board, Western Electricity Coordinating Council, and the Western Renewable Energy Generation Information System.

Reaching all education levels (K-12, university, and research staff) ensures that geothermal energy is included in environmental and renewable energy education programs. Students represent a fertile opportunity for teaching the promise and potential of geothermal energy, and their knowledge and familiarity will yield benefits as they become decision makers in the future. Teachers are reached through continuing education and local or regional conferences and meetings related to energy and the environment. Participation in such activities establishes and fosters contacts, and helps the Program obtain constructive feedback on developing appropriate educational materials and tools.

A representative cross-section of the 700 Communication Products and Program Outreach Activities includes:

**1. *Geothermal Today*** – A high profile, visually appealing, wide-distribution publication produced every two years that conveys Program R&D and outreach highlights to target audiences and stakeholders.

**2. *Program Website*** – The DOE geothermal website is a communications, technology transfer, and outreach channel easily accessible to increasing numbers of stakeholders and the Program's target audiences. The web site is an important method of sharing information, such as state resource maps, in a timely and inexpensive way.

**3. *Technical Assistance to States*** – This GPW activity entails working with emerging, new, and existing state working groups. In some cases, states need a catalyst to initiate state-level kick-off meetings and follow-up activity.

**4. *State Fact Sheets and Case Studies*** – State fact sheets, produced with the participation of state contacts and working groups, are a tool to inform state-level decision makers and policymakers about their states' geothermal energy and potential.

**5. *Transactions*** – This publication, produced by the Geothermal Resources Council (GRC), is a reference book on advances in resource characterization, exploration, development, and associated technologies. It is published in conjunction with the annual GRC technical meeting, and is a standard reference for geothermal experts worldwide.

**6. *DOE Geothermal Technologies Newsletter*** – This newsletter is printed four times yearly and is inserted in the GRC magazine, *Geothermal Bulletin*. The insert summarizes federal R&D efforts and other department news, including solicitations and awards. The newsletter helps raise awareness about DOE geothermal development activities among professionals, stakeholders, and the public.

**7. *Exhibits and Conference Support*** – Participating as an exhibitor at geothermal, energy, and utility shows and conferences increases awareness of geothermal energy potential and benefits. New contacts are made at these meetings and conferences, and the message of geothermal energy's potential and benefits is reinforced.

**8. Information Center and Hotline** – The Washington State University Energy Office provides consumer-related information product dissemination services for the various EERE programs. This organization broadens the reach of the Program’s information products.

**9. Electronic Newsletter** – Geothermal-biz.com, the Program’s electronic newsletter, helps geothermal entrepreneurs – companies, small businesses, Native American tribes, homeowners, and individuals – develop geothermal direct-use and small power generation projects. This newsletter reaches as many as 1,700 individuals and companies.

**10. GRC Technical Sessions Meeting** – This annual, DOE-sponsored meeting is an ideal place to make contacts, exchange R&D results and ideas, develop partnerships or collaboration opportunities, discuss policy developments and needs, network, and maintain relationships.

#### **Stakeholder Feedback – GPW Peer Review in 2004**

The GPW initiative held its first peer review in June 2004. The review process used objective criteria and qualified independent peer reviewers to judge the merits, results, and effectiveness of the GPW program and its components. The Program’s stakeholders made several recommendations regarding communications, outreach, and information products:

- Hold annual coordination meetings of all GPW broad-based partners to ensure coordination and understanding of the program.
- Designate the National Renewable Energy Laboratory (NREL) as the lead organization for a coordinated GPW website.
- Link all GPW-funded websites from the NREL GPW site.
- Designate NREL as coordinator and clearinghouse for all GPW publications.
- Require that all publications funded with GPW money be distributed electronically at no cost via the Internet.

## Appendix 1: MYPP Drivers

Numerous legislative, Administration, and Department policies and procedures dictate both the need for, and the process and content of Multi-year program planning over and above program manager's planning needs. These include:

- Government Performance and Results Act (GPRA)
  - Linkage of budget request to outputs and outcomes and to the Strategic Plan
- President's Management Agenda and OMB Program Assessment and Rating Tool (PART)
  - Provide program justification
  - Set performance goals
  - Link dollars to planned activities
  - Establish targets/milestones
  - Measure progress and resulting benefits
  - Include decision points and end points
- CFO
  - Report quarterly and annual milestones linked to DOE Strategic Goals
  - Management and Evaluation (ME-20) Program Plans
- Congress (House Rpt.108-554 - Energy and Water Development Appropriations Bill, 2005)
  - Beginning with submission of the fiscal year 2007 budget request...submit to Congress detailed five-year budget plans for all major program offices and a consolidated five-year budget plan for the entire Department.
  - Preparation of these five-year program plans and the comprehensive five-year DOE plan to be a Federal function

A Program may consult with its contractors in developing its five-year plans, but the actual preparation of these plans is not to be contracted out; this work is to be done by Federal employees of the Department of Energy.

## Appendix 2: Glossary

**Activities.** All the action steps necessary to produce program outputs.

**Activity, Key.** The third level of the work breakdown structure, below “program” and “subprogram” and above “project”.

**Auditable.** Justifiable/empirical evidence is available and readily accessible to verify stated results. The documentation should directly confirm the reported result in a clear and consolidated manner. Identifying supporting documentation should not be an afterthought in formulating a performance measure. All submitted performance should include specific documentation that could serve as evidence for the reported result.

**Annual Milestone.** (see “Milestone”)

**Baseline.** The starting point from which gains are measured and targets are set. The baseline year shows actual program performance or prior condition for the given measure in a specified prior year.

**Beneficiary.** (see “Customer”)

**Benefits.** (see “Outcome”)

**Critical Events.** A critical path milestone or external factor that affects the achievement of a program outcome.

**Critical Path Milestone.** (see “Milestone”)

**Customer.** The beneficiaries of the program’s products or services, e.g., citizens, business, governments, and internal Federal operations.

**Decision Point.** A clearly defined point during the performance of an activity where a decision can be made to go on to the next phase, to stop, change direction, or re-focus the activity. Decision points include the identification of circumstances under which the program should end (see “End Point”). A decision point can also be a termination point if the decision is made to prematurely end the activity because milestones have not been reached, or cannot be reached with knowledge that is available or reasonably anticipated (see “Termination Point”). (*Related Concepts:* Off-ramp; Exit strategy; go/no-go decision point; critical path milestone).

**Efficiency Measure:** A description of the level at which programs are executed or activities are implemented to achieve results, while avoiding wasting resources, effort, time, and/or money. Program efficiency can be defined simply as the ratio of the outcome or output to the input of any program.

**End Point.** (*Synonyms and Related Concepts.* “Completion Milestone”). The *planned* conclusion of an R&D or deployment activity program that reflects the intended successful achievement of a desired goal.

**Evaluation, Program.** Systematic studies conducted periodically or on an ad hoc basis to assess how well a program is working. They help managers determine if timely adjustments are needed in program design to improve the rate, or quality, of achievement relative to the committed resources.

**External Factor.** A factor that may enhance or nullify underlying program assumptions and thus the likelihood of goal achievement. Goal achievement may also be predicated on certain conditions (events) not happening. They are introduced by external forces or parties, and are not of the agency's own making. The factors may be economic, demographic, social, or environmental, and they may remain stable, change within predicted rates, or vary to an unexpected degree.

**Go/No-go Milestone.** (See “Decision point”)

**Graduation Criteria:** Clearly defined (and almost always quantitative) thresholds of key performance indicators that, when reached, would allow further development and commercialization to be turned over to the private sector under expected future market and policy conditions.

**Input.** Resources required to produce outputs and outcomes.

**Logic Model.** A tool to describe the linkages among program resources, activities, outputs, customers reached, and short, intermediate and longer term outcomes.

Specific logic model terms are:

- Resources or Inputs include human and financial resources as well as other inputs required to support the program such as partnerships. Information on customer needs is an essential resource to the program.
- Activities include all those action steps necessary to produce program outputs.
- Outputs are the products, goods and services provided to the program’s direct customers or program participants.
- Customers receive the program outputs and react in ways that lead to outcomes.
- Outcomes are changes or benefits resulting from activities and outputs. Programs typically have multiple, sequential outcomes, sometimes called the program’s outcome structure. First, there are “short term outcomes”, those changes or benefits that are most closely associated with or “caused” by the program’s outputs. Second, there are “intermediate outcomes,” those changes that result from an application of the short term outcomes. “Longer term outcomes” or program impacts, follow from the benefits accrued through the intermediate outcomes.
- “Outcomes” are typically multiple and sequential (sometimes called the program’s outcome structure). There are “short-term outcomes” representing changes or benefits directly associated with, or “caused,” by the program’s outputs. There are “intermediate outcomes” that are changes resulting from the short-term outcomes, and “ultimate” outcomes that occur in the more distant future. In some discussions of logic models, intermediate outcomes are referred to as “mid-term” outcomes, and ultimate outcomes are called “long-term outcomes.”
- Key contextual factors are external to the program and not under its control that could influence its success either positively or negatively. Antecedent variables are those the program starts out with, such as client characteristics. Mediating factors are those influences that emerge as the program unfolds, such as new competing programs.

**Long term.** (see “Short” and “Intermediate” term)

<b>Short term</b>	3 years or less
<b>Intermediate term</b>	4-10 years
<b>Long term</b>	10 years or more

**Market Failures or Barriers.** Deficiencies that obstruct or impede the development of or entry of technologies or practices into the market or prevent efficient operation of the market.

**Market Barriers and Description and Examples**

## Failures

- o Deficiencies in information / awareness Lack of consistent, accurate, unbiased information on the performance, benefits, and costs of different energy technologies and services. End users and decision-makers have limited awareness of efficiency/ renewable options and benefits and costs. Current tax provisions or other subsidies favor other technologies or practices. Principal/Agent issues (information asymmetry) may arise when knowledge of all of the costs and benefits is not fully shared between facilitators or delegated managers and the ultimate customer/decision-maker (e.g., relationship between builders and buyers).
- o Policy, regulation Potentially incompatible policies, regulations, or codes & standards
- o Cost and Financing Limited access to capital (e.g., low-income households, small businesses). Purchasers are more concerned with low first-cost than with life-cycle cost. Financing instruments available do not provide credit for the savings that the buyer will realize.
- o Technical capacity and knowledge Limited knowledge and capacity of service providers, project developers, users, and decision-makers – For example, insufficient skills or experience with ‘systems (optimization)’ and how to specify, design whole systems or applications for end-users. Limited experience with transactions and processes necessary to successfully procure and implement a technology or service.
- o Risk Aversion Some potential buyers or users of improved technology and practices may give greater weight in their decision-making to the "downside risk" of a technology failure than they give to the upside benefits of a technology success.
- o Market fragmentation and undeveloped market structures Market fragmentation arises when market agents and investors make decisions in one market segment without adequately interacting with others from the other market segments. (e.g., the fragmentation that characterizes the U.S. building industry where developers, designers, builders, utilities, engineers, and occupants pursue objectives which often are at cross-purposes.) Undeveloped market structures include lack of infrastructure to support technology use as has been the case for alternative fueled vehicles which require significant fueling infrastructure).
- o Misplaced or Displaced Incentives The person or organization who would make the decision about adopting a particular technology or practice is different from the one who would derive economic benefits. A classic example is a landlord who makes building investments and a tenant who pays all of his own utilities.
- o Externalities Price signals don't reflect costs – e.g., don't account for many environmental costs, or are not time-differentiated.
- o Public Goods The social benefits cannot be appropriated by any one company to a sufficient degree to justify the required investment.
- o Market Power When firms have market power they tend to cut back production in order to drive up prices and increase profits – e.g., product supply decisions made by a few powerful equipment manufacturers.

**Meaningful.** A performance measure is “meaningful” if it measures the outputs the program is intended to achieve. Performance measures should be relevant to the program, and therefore capture the most important aspects of a program’s mission and priorities. Meaningful measures will be useful for the program partners, stakeholders, and citizens. Although it is tempting to design measures around existing data, those are not always the most meaningful.

**Metric.** Unit of measurement used to assess an input, milestone, output or outcome measure. Metrics may be quantitative such “dollars per gallon” or qualitative such as “completed/not completed.”

**Milestone.** A measurable, discrete event or accomplishment marking identifiable and measurable progress toward a desired result. Milestones are further characterized as annual performance, critical path, or completion milestones.

- **Annual milestone.** A performance milestone that marks progress toward an outcome on a fiscal-year basis.
- **Critical path milestone.** A performance milestone that must be completed on schedule for an output to be produced on schedule
- **Completion milestone.** The final performance milestone marking a completion decision-point or the achievement of a final output.

**Mission Statement.** The charter of the program and provides the basis for all subsequent planning activity. Program performance goals flow up into the program’s mission

**Objective.** (Synonym is “goal.” See “Goals and performance measures”)

**Off-ramp.** (See “Decision Point”)

**Outcomes:** Results that are *external* to the program but that are of direct importance to the intended beneficiary and that contribute to the achievement of the program’s vision. Outcomes are also useful trend indicators for the program to determine whether or not it is on course to reach its vision endstate. Programs are expected to monitor outcomes, even though they are not ultimately responsible for their accomplishment.

**Outputs:** Anticipated measurable results from *internal* program activities for which the program may be held accountable. Programs are expected to measure outputs on a regular basis.

**Partners.** Other agencies and intermediaries responsible for carrying out different aspects of the program including “including grantees, sub-grantees, contractors, cost-sharing partners, and other government partners.”

**Peer Review.** A rigorous, formal, and documented evaluation process using objective criteria and qualified and independent reviewers to make a judgment of the technical/ scientific/business merit, the actual or anticipated results, and the productivity and management effectiveness of programs and/or projects.

**Performance Goal.** A tangible, measurable target against which actual achievement can be measured, such as a quantitative amount, value or rate. A performance goal must contain a date. Performance goals are output-oriented while program strategic goals are outcome-oriented.

**Performance Measure.** A general term for any indicator, statistic or metric used to gauge program performance.

**Program** – a centrally managed set of activities directed toward a common purpose or goal in support of an assigned mission area. Generally, a program is the highest level of work breakdown structure within a specific mission area.

**Program assessment:** A determination, through objective measurement and systematic analysis, of the manner and extent to which Federal programs achieve intended objectives.

**Project** – The lowest level of the work breakdown structure. It is an executable element of a program, normally with a discrete start and end point, as well as a scope, schedule and budget. A single project has a program lead, may have multiple phases that cover more than one year, has a project manager and may include multiple awards in support of its objective. For monitoring and assuring progress, interim and final milestones are instituted as an integral part of the project management process.

**Relevance.** Attribute of performance measures that are of consequence to the program’s mission, vision and goals.

**Resources.** (See “input”)

**Roadmap.**

Short-term. (See “long-term”)

**Stakeholder.** Persons or groups who are affected by and/or have an interest in the existence and performance of the program. Beneficiaries and customers are subsets of stakeholders.

**Strategic Goal.** Program goals that aim to achieve the program’s vision. Strategic goals are outcome oriented and broader than performance goals and contain elements that are beyond the program’s control. They may contribute significantly toward achieving the endstate described in the vision, and are the accumulated program outcomes. As opposed to performance goals, which are output-oriented and more near-term, strategic goals are outcome-oriented and can be longer-term. These measures should be monitored by the program, but not necessarily measured. Program outcome goals should relate to and in the aggregate be sufficient to influence the strategic goals or objectives

**Sub-Program.** Has the same characteristics of a program (but represents one additional level of division). It is the second level of the work breakdown structure.

**Target.** Quantifiable or otherwise measurable characteristic that tells how well a program must accomplish a performance measure. Targets must be *ambitious* (i.e., set at a level that promotes continued improvement) and *achievable* given program characteristics.

**Termination Point.** The *unplanned* conclusion of an R&D or deployment activity program that results from a decision point. An termination point may result from a program successfully meeting its goals ahead of time or from failure to meet performance or other conditions for termination. Industry-relevant programs should identify any “off ramps” in their program plans – whether, when, and how aspects of the program may be shifted to the private sector.

**Trendable.** A milestone, preferable quantitative, that marks project or program progress using a consistent metric applied on a periodic basis.

**Vision Statement.** A vision statement describes the desired future state of the market and society that the program intends to help achieve.

## Appendix X: Resource Allocation Plan

Program Element	2006	2007	2008	2009	2010	2011	PRIORITY
	<b>Dollars in Thousands*/Annual FTEs</b>						
HQ Management FTE	6	6	6	6	6	6	
Support Service Contractor	1	1	1	1	1	1	
PMC FTE	2	2	2	2	2	2	
Support Service Contractor	2	2	2	2	2	2	
<b>Technology Development</b>							
<b>Enhanced Geothermal Systems</b>	\$7,898	\$9,000	\$10,500	\$11,500	\$11,800	\$11,800	<b>High</b>
University/Industry FTE	21	24	28	31	31	31	
National Laboratory FTE	9	10	12	13	13	13	
<b>Resource Development</b>	\$3,655	\$2,553	\$2,000	\$2,000	\$2,000	\$2,000	<b>Low</b>
University/Industry FTE	10	7	5	5	5	5	
National Laboratory FTE	4	3	2	2	2	2	
<b>System Development</b>	\$8,246	\$8,246	\$7,299	\$6,299	\$6,299	\$6,299	
<b>Wellfield Construction</b>	\$4,246	\$4,246	\$3,799	\$3,299	\$3,299	\$3,299	<b>Medium</b>
University/Industry FTE	11	11	10	9	9	9	
National Laboratory FTE	5	5	4	4	4	4	
<b>Energy Conversion Technology</b>	\$4,000	\$4,000	\$3,500	\$3,000	\$3,000	\$3,000	<b>Medium</b>
University/Industry FTE	11	11	9	8	8	8	
National Laboratory FTE	4	4	4	3	3	3	
SubTotal (Technology Development)	\$19,799	\$19,799	\$19,799	\$19,799	\$20,099	\$20,099	
<b>Technology Applications</b>							
<b>Verification</b>	\$2,000	\$2,000	\$2,000	\$2,000	\$1,700	\$1,700	<b>Low</b>
University/Industry FTE	5	5	5	5	5	5	
National Laboratory FTE	2	2	2	2	2	2	
<b>Deployment</b>	\$1,500	\$1,500	\$1,500	\$1,500	\$1,500	\$1,500	<b>Low</b>
University/Industry FTE	4	4	4	4	4	4	
National Laboratory FTE	2	2	2	2	2	2	
SubTotal (Technology Applications)	\$3,500	\$3,500	\$3,500	\$3,500	\$3,200	\$3,200	
<b>Total</b>	<b>\$23,299</b>	<b>\$23,299</b>	<b>\$23,299</b>	<b>\$23,299</b>	<b>\$23,299</b>	<b>\$23,299</b>	