Appendix F – GPRA06 Geothermal Technologies Program Documentation

1. Introduction

The primary goal of the Geothermal Technologies Program is to reduce the cost of geothermal generation technologies, including both conventional and enhanced geothermal systems (EGS). EGS are defined as geothermal systems where the reservoir requires substantial engineering manipulation to make using the reservoir economically feasible.

Hydrothermal systems (flashed-steam power plants at the hotter reservoirs, and binary plants at moderate temperature reservoirs) are near-term commercial realities, based on known sites and indicated prospects largely discovered in the 1970s through 1990s. In flashed-steam power plants, steam from the reservoir passes directly through the power turbine. In binary plants, the geothermal fluid is used to heat a secondary working fluid, e.g., pentane; which, in turn, drives the power turbine.

EGS are expected to weigh in commercially in the longer term, based on resource assessments and exploration programs that are just beginning. While the program expects EGS to be applicable nationwide in the very long term, the first work on EGS will be concentrated west of the Rockies and it is modeled in that manner for GPRA.

Estimating the GPRA benefits involves projecting the market share for these technologies based on their economic and environmental characteristics. Separate estimates of geothermal energy physical resources and separate projections of technology improvements are used for hydrothermal (Flash and Binary) and EGS.

1.1 Target Markets

Geothermal power is expected to penetrate in three market segments: the least-cost power market, the state Renewable Portfolio Standards market, and the green power market. Only "centrally located" geothermal power plants were considered, although there is emerging industry interest in distributed applications. In fact, most geothermal known sites are located at some distance from the Western large urban markets, and the projects require substantial consideration of where the power will be sold and how it will be delivered. There is also an ongoing DOE program to measure the economics of small-scale modular geothermal plant technology development (<5 MW), but to date that has not been modeled in the GRPA processes.

- Least-Cost Power
  NEMS-GPRA06 and MARKAL-GPRA06 were run to estimate market penetration into the competitive bulk power marketplace for geothermal power technologies. The program goals for geothermal technology improvements are modeled directly by incorporating the capital and operation and maintenance (O&M) cost reductions. The models also take into account

site availability and maximum development per site per year for conventional and EGS geothermal capacity. The capital cost reductions for conventional geothermal were computed based on the program goals for surface systems and drilling cost improvements. The conventional geothermal O&M costs are from the EPRI/DOE *Renewable Energy Technology Characterizations* report [1]. The EGS characteristics were developed by Princeton Energy Resources International (PERI) in 2003 [2].

The DOE Geothermal Program has recently undertaken a large-scale restructuring of the means by which it sets its goals and bases them on detailed estimates of the specific R&D subprogram's (e.g., Exploration, Well Field Construction, Power Conversion, and Enhanced Geothermal Systems) likelihood of producing specific technology improvements at various levels of funding, and at various points in time. That restructuring will produce improved program goals for the FY-2007 GPRA work.

For the FY-2006 GPRA Baseline, the underlying estimates of cost reductions due to industry experience (a.k.a., "learning curve" effects) were modified from those in the AEO 2004 Reference Case. This was done because the DOE Energy Information Administration (EIA) appears to more or less have adopted the Geothermal Program estimates of technology improvements as its own estimates when they updated the learning functions for the AEO2004. The learning rate estimates in NEMS-GPRA-FY-2006 were set at one half the rates used in NEMS-AEO-2005. The resulting learning in the GPRA06 Baseline is very similar to that of the AEO2003 and the GPRA05 Baseline from last year.

- State Renewable Portfolio Standard (RPS) Markets
  While the Geothermal Program believes it has affected entry of geothermal power systems into the RPS markets, particularly in Nevada, the program gets no credit for this under GPRA assumptions. This is because announced plans for RPS projects are absorbed into the category of "Cumulative Planned Additions" in EIA's AEO tables, and not credited to the DOE Programs in the GPRA process. One effect of this is to systematically understate the impact of the DOE program's activities in very near term deployment of geothermal power projects.

- Green Power
  Flash, binary, and EGS technologies were all modeled as potential geothermal power plants that could be installed to meet the emerging green power market. Flash and binary technologies compete well within the green power market, with flash technology out-gaining binary due to its more attractive cost curve. EGS technologies have significant cost penalties that restrict capacity additions until after 2015, and even then only a very limited amount of EGS power is projected to be built to meet green power demand. Although geothermal plants were limited to the western portion of the United States, they were typically one of the least-expensive options, leading to significant penetration in those two regions. Projections for incremental green power geothermal installations were incorporated into the NEMS-GPRA06 and MARKAL-GPRA06 models as planned capacity additions.

1.2 Key Factors in Shaping Market Adoption of Geothermal Technologies

Most of the geothermal resources in the United States that are currently known lie in two western states, California and Nevada. Other potentially useful resources exist in Hawaii, Idaho, Oregon, and Utah. The other western states also have geothermal resources, but those are somewhat indeterminate with respect to near-term commercial quality. This means that relative few electric utilities and government regulators (federal, state, and local) are familiar with the promise and issues associated with geothermal energy as a source of electricity. This set of factors is being dealt with by the DOE Geothermal Program's "Geopowering the West" initiative [3], which has made substantial strides since 2001 in developing awareness and interest in twelve states. Some of the more significant issues are being addressed by the "Geothermal Collaborative"; for example, how geothermal power fits into the new state Renewable Portfolio Standards [4].

Note that commercial development of the Nation's primary scenic geothermal features, such as Yellowstone National Park, Wyoming, is simply off limits, under a number of Federal laws.

A second important factor is that, although a moderately large amount of geothermal hydrothermal resource capable of producing electricity appears to exist, much of that has either not been confirmed in detail or is too expensive to compete with conventional fuels. For example, costs are too high at some sites because the needed wells are too deep and expensive, or because the formation permeability is too low. The detailed estimates of site-specific costs are built into the NEMS Geothermal Electricity Submodule.

A third important factor is that the commercial work to discover and confirm a geothermal reservoir (a.k.a., "exploration") is risky and somewhat expensive. Because of that risk, the funding is entirely through equity capital, which is not always easy to procure. The Geothermal Program today works to ameliorate some of that risk through its Geothermal Resource Exploration and Definition Contracts, which encourage exploration by paying for the testing of new exploration methods and tools. That work is not explicitly modeled, but will eventually be, through the addition of new geothermal prospect sites to the NEMS-GRPA model, and perhaps to the EIA NEMS model. Other efforts to address the exploration issue lie in ongoing combined work of the Department of Energy and the Department of the Interior (e.g., Bureau of Land Management and the U.S. Geological Survey) to identify the most promising new sites for geothermal power development [5].

1.3 Methodology and Calculations

NEMS-GPRA06

The NEMS-GPRA06 electricity-sector module performs an economic analysis of alternative technologies in each of 13 regions. Within each region, new capacity is selected based on its relative capital and operating costs, its operating performance (i.e. availability), the regional load requirements, and existing capacity resources. Geothermal capacity is treated in a unique manner due to the specific geographic nature of the resources. The model characterizes 51 individual sites of known hydrothermal geothermal resources in only three western regions, each with a set of capital and O&M costs. For the Program Case, three EGS sites in each of the three regions were substituted for the most expensive hydrothermal sites in those regions.

Conventional Geothermal (Hydrothermal) Systems

The capital and O&M cost reduction goals of the program are applied to each of the 51 sites. **Figure 1** illustrates the resulting supply curve of the hydrothermal sites in the Northwest United States in 2006 and 2020 that can be developed in each of those years in NEMS-GPRA06. These curves reflect the GPRA cost reductions, as well as the financing assumptions from the *Annual Energy Outlook 2004* (*AEO04*) Reference Case, and the limit of developing only 100 MW at a site each year. The limit of 100 MW development per site per year is an increase from the *AEO03* assumption of only 25 MW or 50 MW (depending on year). The limit change is made to reflect the program's efforts to reduce the risk associated with new geothermal development. The lowest part of the curve is not depicted for 2020, because it represents a portion of the capacity already developed.

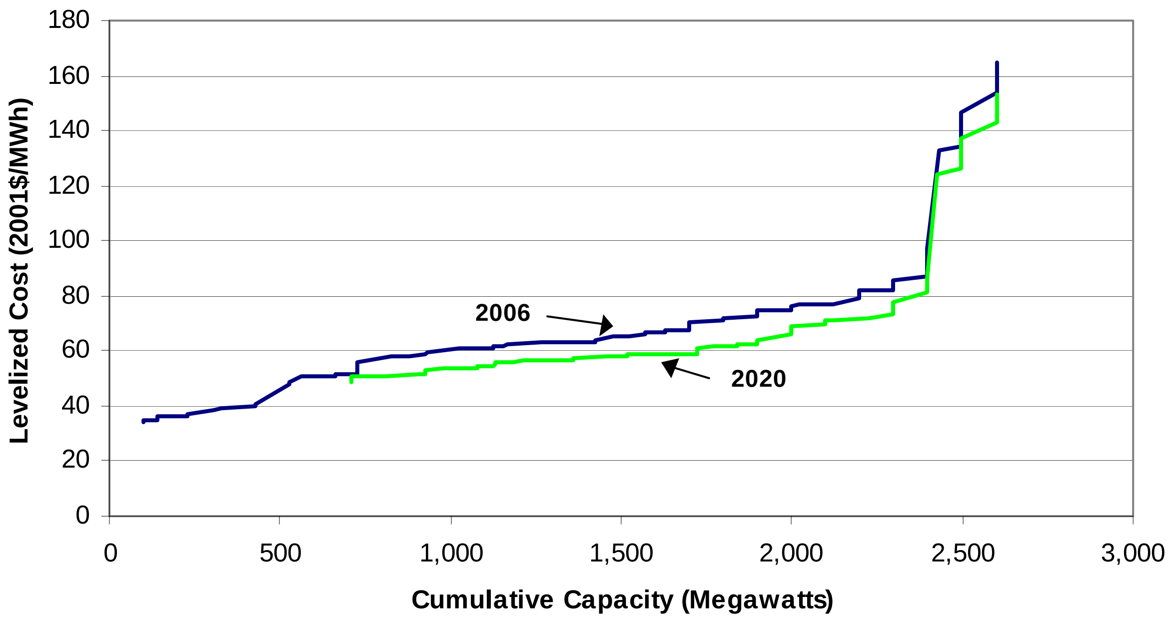

Figure 1. Geothermal Supply Curve – Northwest Region

Roughly 10 GW of hydrothermal resource in the Northwest and 23 GW in the lower 48 states is represented within NEMS-GPRA06. With the GPRA Base Case assumptions, much of this resource would be quite expensive to develop; today, an estimated 5 GW might be available at 6 cents per kWh.

Enhanced Geothermal Systems (EGS)

Characteristics for EGS systems were also provided. Nine new EGS sites, were substituted for the three most expensive hydrothermal sites in the western regions: Northwest Power Pool (NWP, Region 11), Rocky Mountain Power Area, Arizona, New Mexico, and Southern Nevada (RA, Region 12), and California (CA, Region 13). Each site represents a Type of EGS resource:

- Type I. A site where EGS would be used to improve an existing commercial hydrothermal reservoir.
- Type II. A site where EGS would work to develop economic power from identified sites with sub-commercial hydrothermal features.
- Type III. A site where EGS would be used as a longer-term strategy to develop power systems in volumes of rock that have not been identified as hydrothermal prospects.

Similar to the conventional sites, each geothermal site is further specified in four stages of increasing costs (**Table 1**).

Table 1. EGS Site Characterization for NEMS-GPRA06

		Potential Capacity 1 (MW)	Potential Capacity 2 (MW)	Potential Capacity 3 (MW)	Potential Capacity 4 (MW)	Capacity Factor
Region 11	EGS Type I	550	550	550	550	0.9
	EGS Type II	2500	2500	2500	2500	0.9
	EGS Type III	5000	5000	5000	5000	0.9
Region 12	EGS Type I	0	0	0	0	0.9
	EGS Type II	1250	1250	1250	1250	0.9
	EGS Type III	5000	5000	5000	5000	0.9
Region 13	EGS Type I	300	300	300	300	0.9
	EGS Type II	2500	2500	2500	2500	0.9
	EGS Type III	5000	5000	5000	5000	0.9

Capital and O&M costs were provided for the initial development at each site and were the same for all regions. The EGS and conventional costs are shown below in 2001 dollars (**Table 2**). Hydrothermal flash and binary system costs are shown here for comparison. The relatively high O&M costs in **Table 2** for the EGS systems is occasioned in part by the need to substantially replace much of the reservoir at about the 15 year point of the 30 year project life. Note also that, in the long run, it is reasonable that technology improvements for EGS could drive the capital costs of new EGS projects (potentially plentiful) below the cost of newly discovered binary systems (which are estimated to become increasingly scarce in the out-years of the simulations).

Table 2. Geothermal Cost Characteristics for NEMS-GPRA06

	2005	2010	2015	2020	2025
Capital Cost (2001$/kW)					
Flash	1,882	1,784	1,728	1,703	1,681
Binary	2,807	2,661	2,577	2,539	2,507
EGS I	2,400	2,132	1,864	1,596	1,328
EGS II	2,760	2,452	2,144	1,835	1,527
EGS III	3,120	2,772	2,423	2,075	1,726
Total O&M Costs (2001$/kW-yr)					
Flash	80.3	71.2	66.6	62.5	60.7
Binary	84.3	71.7	63.9	56.3	55.3
EGS I	150.0	132.0	114.0	96.0	78.0
EGS II	172.5	151.8	131.1	110.4	89.7
EGS III	195.0	171.6	148.2	124.8	101.4

Note: Flash and binary costs vary by site. These costs shown here are based on the lowest cost-available site in 2005 with technology improvements applied over time.

While the estimated technology improvements in **Table 2** may appear to be somewhat aggressive, they are supported by recent detailed research into the historical costs of geothermal hydrothermal power systems, between 1980 and 2000 [6]. The 1980s saw extensive development of hydrothermal power systems in the United States, and the early 1990s saw that extended by American geothermal firms in the Philippines and Indonesia, so there was a useful test bed of historical deployment for analyzing costs. The research found that over the 20-year period, the real (inflation adjusted) total capital costs of both flash and binary hydrothermal systems had decreased by about 45%. The Geothermal Program believes that substantial opportunity for technology improvement remains.

MARKAL-GPRA06

The geothermal technologies represented in MARKAL-GPRA06 reflect the Geothermal Program goals (defined for FY-05, as described above) for both conventional systems and EGS. For conventional geothermal systems, the capital and operating and maintenance costs were changed to reflect program goals. However, EGS represents a new geothermal resource not previously represented in the MARKAL-GPRA06 model. The program identified three separate types of potential geothermal reservoirs, as discussed above.

Due to program activities, the capital and O&M costs of EGS systems are projected to decline over time. **Table 3** shows the estimated capital and O&M costs for the three types of EGS systems for 2000 and 2050.

Table 3: EGS Generation Assumptions for MARKAL-GPRA06

EGS Type	Projected Resource MWe	2000 Cost Capital Cost 01$/kW	2000 Cost O&M 01$/kW/yr	2050 Cost Capital Cost 01$/kW	2050 Cost O&M 01$/kW/yr
I	**3,400**	2,448	153	934	50
II	**25,000**	2,815	176	1,074	58
III	**60,000**	3,182	199	1,214	66

The EGS sites projected under the program are grouped into a set of supply steps and the discount rate of these technologies is set at 8% (instead of 10% for the industrial average) to reflect the accelerated depreciation schedule permitted by the IRS for renewable generation technologies. The EGS systems are modeled as centralized base-load generation.

Geothermal plants compete directly with fossil fuel-based plants for both electricity generation and meeting peak power requirements. In MARKAL-GPRA06, EGS becomes more competitive as its higher capital cost is offset by increased fossil fuel costs, which increase as demand increases.

GREEN POWER MARKET MODEL

PERI used the Green Power Market model to project regional green power additions [7]. These capacity additions are used by NEMS-GPRA06 and MARKAL-GPRA06 as planned new capacity or minimum capacity additions.

As shown elsewhere in this report, the only two technologies that penetrate the Green Power Market, as modeled in the EERE GPRA-2006 exercise, are photovoltaics and wind. The Geothermal Program analysts and management are surprised by this, since geothermal contributed substantially to the Green Power markets in California when they were first set up in the late 1990s [8]. However, the incremental green power projections used for GPRA only include additional capacity stimulated by cost reductions through R&D.

1.4 Sources

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8. Anon., “Calpine Receives 2004 Green Power Leadership Award from DOE and EPA,” Calpine Corporation News Release, Nov. 9, 2004.