Geothermal Scenarios Using NEMS

The operation of the Geothermal Model of the NEMS for AEO 2002 was described in a previous report in March 2002. Subsequently, the model was modified so that several scenarios could be run. These modifications involved changing the various components of capital and operating costs for each of the geothermal sites, changing the assumptions of how building constraints are implemented at each site, and changing the NEMS-based learning parameter. These cases were compared to each other and to a base run of the NEMS 2002 model.

Assumptions for the GeoBase Case

The GeoBase case had modifications to the assumptions on building constraints and to the capital and operating costs at each site.

Constraints on Builds. In the AEO 2002 base case, there are constraints at each site on the amount of builds on that site in each year. The constraints are that no more than 25 megawatts can be built on each site in one year, until 2015 when the amount changes to 50 megawatts. In the GeoBase case the assumptions were changed so that no more than 25 megawatts can be built on each site in one year, until the site has had builds in at least two years. After builds in two years (constrained to 25 megawatts in each of those years), the site is no longer constrained.

Adjustments to Capital and O & M Costs. In the AEO 2002 base case, each site is either a binary or a flash technology and has a base set of capital costs and operating and maintenance costs associated with it. These costs are constant over time and the capital costs are disaggregated into exploration, drilling, field, and plant costs, and the operating and maintenance costs are disaggregated into field and plant costs. In the GeoBase case, the costs were changed separately for binary and for flash sites and for capital and for O&M costs so that they were at the level shown in the *Technology Characteristics*[1] report. This was done by creating multiplicative adjustment factors for the costs that were then implemented in the code. The adjustment factors were calculated offline.

The cost adjustment factors were calculated separately for binary and flash sites and for capital and operating and maintenance costs. First, for each set of binary sites and flash sites the three sites with the lowest overall COE (annualized cost of electricity) were found. The COE was calculated for each site using the fixed charge factor for geothermal capital costs that is used in NEMS. Second, for each technology, the average capital costs and average operating and maintenance costs were found for those three lowest cost sites. Third, for each technology and each cost a multiplicative adjustment factor was created by dividing the cost (for year 1996 for binary and year 1997 for flash) from the *Technology Characteristics* report by the average cost calculated above. These adjustment factors were then used in the model code to adjust the initial costs for all sites and all cost categories.

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[1] *Renewable Energy Technology Characterizations*, Energy Efficiency and Renewable Energy, USDOE and Electric Power Research Institute, TR-109496, December 1997, Washington, DC.

Adjustments to NEMS Learning Factors. In the AEO 2002 base case, learning factors are calculated in the electricity model that are used to reduce capital costs over time as a function of the amount of builds ("learning by doing"). In the GeoBase case the learning factor function is not changed from the AEO 2002 base case (but is changed in some subsequent cases).

Case Results. The result of the GeoBase case is to increase the penetration of geothermal capacity. In the AEO 2002 base case (a modified version) the forecasted geothermal capacity in 2020 is 5.12 gigawatts. In the GeoBase case the forecasted geothermal capacity in 2020 increases to 6.32 gigawatts.

Assumptions for the GeoTC1 Case

The GeoTC1 case had modifications to the assumptions on building constraints, to the capital and operating costs at each site, and to the learning factors.

Constraints on Builds. In the GeoTC1 case the constraints on builds were the same as described for the GeoBase case.

Adjustments to Capital and O & M Costs. In the GeoTC1 case the adjustments to capital and operating and maintenance costs start with the same adjustment factors as described in the GeoBase case. However, in this case the costs also decrease over time at the same rate as in the *Technology Characteristics* report. Adjustments over time are made in the model code separately to capital and O & M costs and for each of two technologies, binary and flash.

Adjustments to NEMS Learning Factors. In the GeoTC1 case the NEMS learning factors for capital costs are turned off so that there is no additional learning beyond that represented in the capital costs already.

Case Results. The result of the GeoTC1 case is to significantly increase the penetration of geothermal capacity above the GeoBase case. In the GeoTC1 case the forecasted geothermal capacity in 2020 increases to 9.51 gigawatts.

Assumptions for the GeoTC2 Case

The GeoTC2 case had modifications to the assumptions on building constraints, and to the capital and operating costs at each site.

Constraints on Builds. In the GeoTC2 case the constraints on builds were the same as described for the GeoBase case.

Adjustments to Capital and O & M Costs. In the GeoTC2 case the adjustments to capital and operating and maintenance costs start with the same adjustment factors as described in the GeoTC1 case, where the costs decrease over time at the same rate as in the *Technology Characteristics* report.

Adjustments to NEMS Learning Factors. In the GeoTC2 case the NEMS learning factor function for capital costs is turned back on (unlike the GeoTC1 case).

Case Results. The result of the GeoTC2 case is to significantly increase the penetration of geothermal capacity above the GeoBase case to a level higher than the GeoTC1 case. In the GeoTC2 case the forecasted geothermal capacity in 2020 increases to 11.04 gigawatts.

Assumptions for the GeoTC3 Case

The GeoTC3 case had modifications to the assumptions on building constraints, and to the capital and operating costs at each site.

Constraints on Builds. In the GeoTC3 case the constraints on builds were the same as described for the GeoBase case.

Adjustments to Capital and O & M Costs. In the GeoTC3 case the adjustments to capital and operating and maintenance costs start with the same adjustment factors as described in the GeoBase case. However, in this case some costs decrease over time based upon direction from the NREL Technical Monitor. First, exploration and drilling capital costs for both binary and flash sites decrease to a level that is 0.50 of their initial level by 2008. They continue at that level to 2020. Second, plant capital costs for binary sites only decrease to a level that is 0.80 of their initial level by 2010. They continue at that level to 2020.

Adjustments to NEMS Learning Factors. In the GeoTC3 case the NEMS learning factor function for capital costs is not changed from the AEO 2002 base case.

Case Results. The result of the GeoTC3 case is to increase the penetration of geothermal capacity above the GeoBase case, but to a level less than the GeoTC1 and GeoTC2 cases. In the GeoTC3 case the forecasted geothermal capacity in 2020 increases to 8.11 gigawatts. (The differences are discussed in more detail below.)

Additional Side Cases for Testing

Some additional side cases were run for debugging or for testing. In particular, a GeoTC4 case was run in which experiments were made to the method in which the initial costs were adjusted.

Discussion of Results

The results for the various runs are shown in Table 1 and in the graph. The results are the same for all scenarios in 2000 and in 2005. In 2000 the forecast has not yet begun, and in 2005 the model does not yet have an impact because it takes three years from the time decisions are made about capacity until the plant is actually built and running. The GeoBase case has relaxed building constraints and decreased initial costs that are constant over time (other than learning) and shows a modest increase in geothermal capacity over the AEO Base case. The GeoTC1 case has relaxed building constraints and decreased initial costs, but includes significantly declining costs over time (although it does not include the endogenous learning). The GeoTC1 case consequently shows a significant increase in geothermal capacity over the GeoBase case. The GeoTC2 case is the same as the GeoTC1 case except that it also includes the endogenous learning which decreases costs even further. The result is that the GeoTC2 case

shows an increase in geothermal capacity over the GeoTC1 case. The GeoTC3 case is somewhat different in the way that it is constructed. Some categories of costs are decreased to significantly lower levels by 2008 and 2010. This causes the GeoTC3 case to have the highest geothermal capacity by 2010. However, it levels off and increases at a much slower rate, to a lower level in 2020, than the GeoTC1 and GeoTC2 cases. One cost category that is decreased, exploration and drilling capital cost, is typically a small part of the overall capital cost so has a lesser impact. The other cost category that is decreased, plant costs in binary plants, is typically a much larger part of the overall capital cost, but binary plants have generally higher costs and are typically less competitive.

One notable feature, seen primarily in the graph, is that the trajectories show the geothermal cases taking off quickly at some point, then returning to a lower rate of increase. This is a function of the way that the building constraints are implemented. The constraints are fairly strong until there have been builds at the site for two years, then they are unconstrained. In a typical scenario, in the early part of the forecast several sites are constrained, but then they simultaneously have the constraints lifted and there is a rapid build (in some sense, the pent-up demand is released).

Table 1. Geothermal Run Results to 2020 for Various Scenarios (Gigawatts)

	2000	2005	2010	2015	2020
AEO Base*	2.85	3.05	3.51	4.41	5.12
GeoBase	2.85	3.05	4.56	5.80	6.32
GeoTC1	2.85	3.05	4.54	8.38	9.51
GeoTC2	2.85	3.05	4.65	8.82	11.04
GeoTC3	2.85	3.05	4.90	6.37	8.11

* - A slightly modified AEO Base case.