Potential Improvements to Existing Geothermal Facilities in California

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Keywords

Geothermal power plants, geothermal resources, plant capacity, capital costs, O&M costs, facility improvements

ABSTRACT

This paper summarizes the results of a recent study (the Facilities Improvement Report) performed with funding by the Public Interest Energy Research (PIER) program of the California Energy Commission (CEC). The Facilities Improvement Report describes potential improvements to 45 existing power plants in 7 currently producing geothermal fields in California. The improvements are of two general types: improvements in resource supply and improvements in surface facilities. To resolve inconsistencies in reported plant capacities, distinctions are made between original capacity, electro-mechanical capacity, 2005 capacity (which takes into account resource limitations), and actual annual average power. The total electro-mechanical capacity of the geothermal plants in California is about 2,650 MW-gross, and the 2005 capacity is about 1,850 MW-gross (1,600 MW-net).

The difference between the electro-mechanical capacity and the 2005 capacity (about 800 MW) represents the increase in power output that could be achieved if adequate resource supply were available. The difference between the most-likely resource capacity and the electro-mechanical capacity of existing plants shows the amount of incremental power output that could be achieved by a combination of plant improvements and construction of new plants in already producing fields. Most of the latter type of incremental potential (about 1,400 MW) is in the Salton Sea Field. Despite a surplus of electro-mechanical capacity in some areas of The Geysers, there is still potential for additional plant capacity in The Geysers (probably in the range of 100 to 150 MW).

As of 2005, the capital cost for new geothermal facilities in California is likely to be in the range of \$2,900 to \$3,500 per kW installed, including both drilling costs and plant construction. O&M costs are in the range of 1.8 to 2.5 ¢/kWh, excluding financing costs, depreciation, and any ongoing capital expenditures. Capital costs for the improvements described in the Facilities Improvement Report ranged from \$300 to \$3,000 per kW of increased output. O&M savings ranged from 0.02 to 1.0 ¢/kWh.

Introduction

This paper summarizes the results of a study of all geothermal power plants in California for the purpose of identifying potential improvements that could yield additional power to the California market. The study covered all Californian geo-

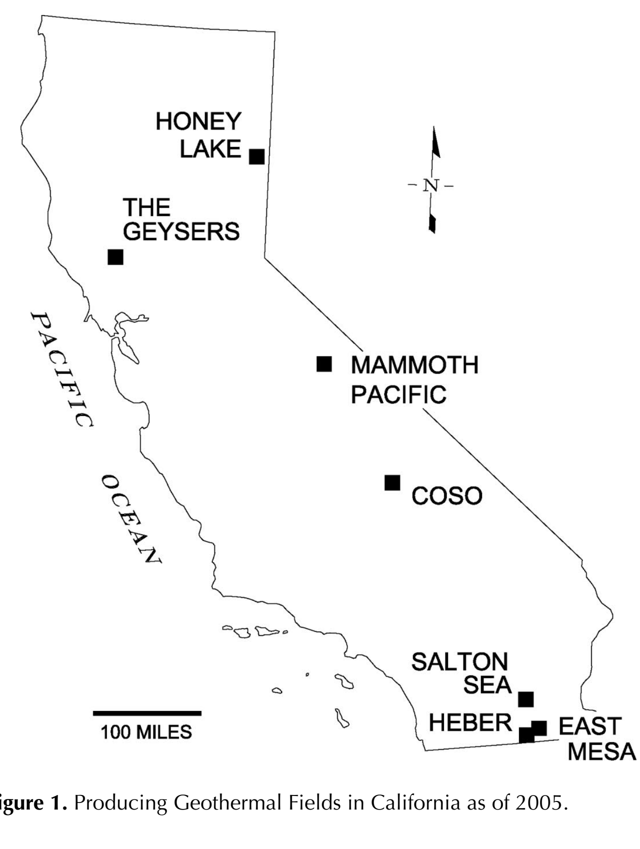

Figure 1. Producing Geothermal Fields in California as of 2005.

thermal plants that were active as of the start of 2005, including 45 power plants in 7 fields. Two general types of improvements were considered: improvements in resource supply (pertaining primarily to the wellfield and gathering system) and improvements in surface facilities (pertaining primarily to the plants). GeothermEx performed the study under a contract with the Hetch Hetchy Water and Power Division of the San Francisco Public Utilities Commission (Hetch Hetchy/SFPUC), with funding from the Public Interest Energy Research (PIER) program of the California Energy Commission (CEC). In conducting the study, we relied on published data and non-proprietary information in GeothermEx files, as well as site visits and interviews with operators of the facilities concerned. The full results of the study will be presented in a report (herein referred to as the Facilities Improvement Report) to be published by the CEC later this year (GeothermEx, in press).

Table 1. Geothermal Power Plants in California as of the Start of 2005.

No.	Plant Name	Other Name 1	Other Name 2	Field
1	Coso Units 1-3	Navy I Units 1-3	Navy 1 Units 1-3	Coso
2	Coso Units 4-6	Navy II Units 4-6	Navy 2 Units 4-6	Coso
3	Coso Units 7-9	BLM Units 7-9	BLM 1 Units 7-9	Coso
4	GEM 2	GEM II (Geo East Mesa II)	Unit 5	East Mesa
5	GEM 3	GEM III (Geo East Mesa III)	Unit 6	East Mesa
6	ORMESA I	OG I	Unit 1	East Mesa
7	ORMESA IE	OG IE	Unit 2	East Mesa
8	ORMESA IH	OG IH	Unit 4	East Mesa
9	ORMESA II	OG II	Unit 3	East Mesa
10	Heber 1	HGC (Heber Geothermal Company)	Dravo Dual-flash Plant	Heber
11	Heber 2	SIGC (Second Imperial Geothermal Company)		Heber
12	Amedee			Honey Lake (Amedee Area)
13	Wineagle			Honey Lake (Wendel Area)
14	Mammoth Pacific I	MP-I	G-1	Mammoth Pacific (Long Valley)
15	Mammoth Pacific II	MP-II	G-2	Mammoth Pacific (Long Valley)
16	PLES I	Pacific Lighting Energy Systems I	G-3	Mammoth Pacific (Long Valley)
17	Salton Sea Unit 1	S.S. 1	Unit I	Salton Sea
18	Salton Sea Unit 2	S.S. 2	Unit II	Salton Sea
19	Salton Sea Unit 3	S.S. 3	Unit III	Salton Sea
20	Salton Sea Unit 4	S.S. 4	Unit IV	Salton Sea
21	Salton Sea Unit 5	S.S. 5	Unit V	Salton Sea
22	CE Turbo	Vulcan/Hoch Turbo-expander		Salton Sea
23	Vulcan			Salton Sea
24	Hoch	Del Ranch		Salton Sea
25	Elmore			Salton Sea
26	Leathers			Salton Sea
27	Bottle Rock[a]	DWR (Department of Water Resources)		The Geysers
28	Calpine 1 - Aidlin	J. W. Aidlin		The Geysers
29	Calpine 2 - Bear Canyon	Bear Canyon		The Geysers
30	Calpine 3 - Sonoma	SMUDGEO No. 1	SMUD No. 1	The Geysers
31	Calpine 4 - West Ford Flat	West Ford Flat		The Geysers
32	Calpine 5 & 6 - McCabe	PG & E Units 5 & 6		The Geysers
33	Calpine 7 & 8 - Ridge Line	PG & E Units 7 & 8		The Geysers
34	Calpine 9 & 10 - Fumarole [a]	PG & E Units 9 & 10		The Geysers
35	Calpine 11 - Eagle Rock	PG & E Unit 11		The Geysers
36	Calpine 12 - Cobb Creek	PG & E Unit 12		The Geysers
37	Calpine 13 - Big Geysers	PG & E Unit 13		The Geysers
38	Calpine 14 - Sulphur Springs	PG & E Unit 14		The Geysers
39	Calpine 16 - Quick Silver	PG & E Unit 16		The Geysers
40	Calpine 17 - Lake View	PG & E Unit 17		The Geysers
41	Calpine 18 - Socrates	PG & E Unit 18		The Geysers
42	Calpine 19 - Calistoga	SFG (Santa Fe Geothermal)	SFG Units 1 & 2	The Geysers
43	Calpine 20 - Grant	PG & E Unit 20		The Geysers
44	NCPA 1 (Units 1 & 2)	NCPA 1-1 and NCPA 1-2	NCPA 1-2	The Geysers
45	NCPA 2 (Units 3 & 4)	NCPA 2-3 and NCPA 2-4	NCPA 3-4	The Geysers

Note a: Inactive plant

Description of Geothermal Facilities

One of the difficulties in assessing potential improvements in California geothermal facilities is simply keeping straight the name changes since the facilities were constructed. Table 1 lists the 45 geothermal power plants considered in this study, including other names that have historically been applied to the plants. Figure 1 shows the location of the 7 geothermal fields that contain these plants.

Definitions of Capacity

Another difficulty in assessing potential improvements in these facilities stems from a lack of consistency in published descriptions of plant capacities. This study has attempted to clarify this situation by distinguishing between several different definitions of plant capacity. For the purposes of this study:

- *Original capacity* is the amount of power a plant was originally designed to produce, at specified conditions of geofluid supply. It is equivalent to the turbine manufacturer's "nameplate" or "rated" capacity, expressed in gross megawatts (MW-gross), neglecting equipment modifications subsequent to initial construction.
- *Electro-mechanical capacity* is the amount of power (expressed in MW-gross) that a plant is capable of producing on a sustained basis without damage to the equipment, given a sufficient supply of geofluid. Because plant equipment is typically designed to accommodate a range of geofluid conditions (including conditions more favorable than the nominal design conditions), the electro-mechanical capacity is generally expected to be higher than the original

capacity. Exceptions would include plants that have been physically altered (for instance, by a turbine modification) so that the electro-mechanical capacity is now lower than when the plant was first constructed. In the current study, if there was no independent information on which to base a higher or lower estimate of the electro-mechanical capacity for a particular plant, the electro-mechanical capacity was assumed to be equal to the original capacity.

- *2005 Capacity* is the amount of power a plant could produce as of 2005, taking into account equipment modifications and limitations of geofluid supply, as acknowledged by the operator. It can be expressed in either MW-gross or MW-net, the difference between the two being the parasitic power needed to run the plant.
- *Actual annual average power* is the annual electrical energy generated in a representative recent year (minus the parasitic energy used to run the plant), divided by the number of hours in the year. The actual annual average power is expressed in MW-net.

Table 2 lists the power-output characteristics of the 45 geothermal plants, using the capacity definitions described above. The principal sources of information have included publications by plant operators (including web sites and filings with the U. S. Securities and Exchange Commission), information from turbine manufacturers, the Form EIA-906 Database of the U. S. Department of Energy (DOE), the web site of the Geothermal Energy Association (GEA), and previous summaries of geothermal plant capacity, such as EPRI (2001) and Lund et al. (2005). A full list of references is included in the Facility Improvement Report. In cases of discrepancies between sources, GeothermEx has used the power-output characteristics it believes to be most accurate, with primary guidance from information provided by the plant operators themselves. In some cases, plant capacity data are only publicly available in aggregated form. In these cases, data for several plants in a given field have been grouped in Table 2. The table shows that estimates of the combined capacity of geothermal power plants in California can range from 2,683 MW-gross to 1,501 MW-net, depending on the capacity definition applied. The total electro-mechanical capacity is less than the original installed capacity due to turbine modifications of several plants at The Geysers.

Table 2. Power-Output Characteristics of Geothermal Power Plants in California.

<table>
<tr><th>Plant Name</th><th>Year</th><th>Original Capacity (MW-Gross)</th><th>Electro-mechanical Capacity (MW-Gross)</th><th>2005 Capacity (MW-Gross)</th><th>2005 Capacity (MW-Net)</th><th>Actual Annual Average Power (MW-Net)</th></tr>
<tr><td>Coso Units 1-3</td><td>1987</td><td>92.2</td><td>100</td><td>90</td><td>85</td><td>81.3</td></tr>
<tr><td>Coso Units 4-6</td><td>1990</td><td>90</td><td>100</td><td>90</td><td>85</td><td>85.2</td></tr>
<tr><td>Coso Units 7-9</td><td>1989</td><td>90</td><td>100</td><td>90</td><td>85</td><td>69.4</td></tr>
<tr><td>GEM 2</td><td>1989</td><td>20</td><td>20</td><td>17</td><td rowspan="6">47</td><td>9.3</td></tr>
<tr><td>GEM 3</td><td>1989</td><td>20</td><td>20</td><td>17</td><td>8.8</td></tr>
<tr><td>ORMESA I</td><td>1987</td><td>30</td><td>30</td><td>20</td><td>15.2</td></tr>
<tr><td>ORMESA IE</td><td>1989</td><td>10</td><td>10</td><td>10</td><td>6.9</td></tr>
<tr><td>ORMESA IH</td><td>1989</td><td>13.2</td><td>13.2</td><td>12</td><td>5.8</td></tr>
<tr><td>ORMESA II</td><td>1988</td><td>20</td><td>20</td><td>19</td><td>14.2</td></tr>
<tr><td>Heber 1</td><td>1985</td><td>52</td><td>52</td><td>52</td><td>38</td><td>37</td></tr>
<tr><td>Heber 2</td><td>1993</td><td>48</td><td>48</td><td>48</td><td>34</td><td>34</td></tr>
<tr><td>Amedee</td><td>1988</td><td>1.6</td><td>1.6</td><td>1.6</td><td>1.2</td><td>No data</td></tr>
<tr><td>Wineagle</td><td>1985</td><td>0.7</td><td>0.7</td><td>0.7</td><td>0.5</td><td>No data</td></tr>
<tr><td>Mammoth Pacific I</td><td>1984</td><td>10</td><td rowspan="3">40</td><td rowspan="3">35</td><td rowspan="3">25</td><td>4.9</td></tr>
<tr><td>Mammoth Pacific II</td><td>1990</td><td>15</td><td>8.8</td></tr>
<tr><td>PLES I</td><td>1990</td><td>15</td><td>11.4</td></tr>
<tr><td>Salton Sea Unit 1</td><td>1982</td><td rowspan="10">350</td><td rowspan="10">350</td><td rowspan="10">350</td><td>10</td><td>8.8</td></tr>
<tr><td>Salton Sea Unit 2</td><td>1990</td><td>20</td><td>13.5</td></tr>
<tr><td>Salton Sea Unit 3</td><td>1989</td><td>49.8</td><td>44.1</td></tr>
<tr><td>Salton Sea Unit 4</td><td>1997</td><td>39.6</td><td>39.2</td></tr>
<tr><td>Salton Sea Unit 5</td><td>2000</td><td>49</td><td>27.3</td></tr>
<tr><td>CE Turbo</td><td>2000</td><td>10</td><td>6.3</td></tr>
<tr><td>Vulcan</td><td>1985</td><td>34</td><td>34.6</td></tr>
<tr><td>Hoch</td><td>1988</td><td>38</td><td>36.8</td></tr>
<tr><td>Elmore</td><td>1990</td><td>38</td><td>37.6</td></tr>
<tr><td>Leathers</td><td>1989</td><td>38</td><td>37.6</td></tr>
<tr><td>Bottle Rock</td><td>1985</td><td>55</td><td>55</td><td>Inactive</td><td>Inactive</td><td>Inactive</td></tr>
<tr><td>Calpine 1 - Aidlin</td><td>1989</td><td>25</td><td>25</td><td>17</td><td>16</td><td>14.1</td></tr>
<tr><td>Calpine 2 - Bear Canyon</td><td>1988</td><td>22</td><td>22</td><td>18</td><td>16</td><td>15.9</td></tr>
<tr><td>Calpine 3 - Sonoma</td><td>1983</td><td>71</td><td>78</td><td>38</td><td>35</td><td>34.8</td></tr>
<tr><td>Calpine 4 - West Ford Flat</td><td>1988</td><td>29</td><td>29</td><td>29</td><td>26</td><td>24.5</td></tr>
<tr><td>Calpine 5 & 6 - McCabe</td><td>1971</td><td>110</td><td>110</td><td>82</td><td>75</td><td rowspan="11">545</td></tr>
<tr><td>Calpine 7 & 8 - Ridge Line</td><td>1972</td><td>110</td><td>110</td><td>76</td><td>72</td></tr>
<tr><td>Calpine 9 & 10 - Fumarole</td><td>1973</td><td>110</td><td>110</td><td>Inactive</td><td>Inactive</td></tr>
<tr><td>Calpine 11 - Eagle Rock</td><td>1975</td><td>110</td><td>74 [a]</td><td>65</td><td>60</td></tr>
<tr><td>Calpine 12 - Cobb Creek</td><td>1979</td><td>110</td><td>110</td><td>58</td><td>53</td></tr>
<tr><td>Calpine 13 - Big Geysers</td><td>1980</td><td>138</td><td>102 [a]</td><td>80</td><td>70</td></tr>
<tr><td>Calpine 14 - Sulphur Springs</td><td>1980</td><td>114</td><td>74 [a]</td><td>63</td><td>55</td></tr>
<tr><td>Calpine 16 - Quick Silver</td><td>1985</td><td>124</td><td>124</td><td>72</td><td>61</td></tr>
<tr><td>Calpine 17 - Lake View</td><td>1982</td><td>124</td><td>124</td><td>58</td><td>50</td></tr>
<tr><td>Calpine 18 - Socrates</td><td>1983</td><td>124</td><td>124</td><td>60</td><td>51</td></tr>
<tr><td>Calpine 20 - Grant</td><td>1985</td><td>124</td><td>124</td><td>47</td><td>40</td></tr>
<tr><td>Calpine 19 - Calistoga</td><td>1984</td><td>85</td><td>85</td><td>80</td><td>70</td><td>67.9</td></tr>
<tr><td>NCPA 1 (Units 1 & 2)</td><td>1983</td><td>110</td><td>128</td><td>69</td><td>65</td><td>60.7</td></tr>
<tr><td>NCPA 2 (Units 3 & 4)</td><td>1985</td><td>110</td><td>128</td><td>68</td><td>63</td><td>59.6</td></tr>
<tr><td>TOTAL</td><td></td><td>2,683</td><td>2,642</td><td>1,832</td><td>1,605</td><td>1,501</td></tr>
</table>

Note a: Electro-mechanical capacity reduced by turbine modification.

Potential Improvements

GeothermEx has previously estimated the resource capacities of California geothermal fields as part of an earlier study for Hetch Hetchy/SFPUC, as described in the PIER Geothermal Database (GeothermEx, 2004). According to that estimate, the 7 currently producing geothermal fields in California have a combined resource capacity with a minimum

Table 3. Resource Capacities of Active California Geothermal Fields.

Field	Minimum Resource Capacity (MW-gross) (1)	Most-Likely Resource Capacity (MW-gross) (1)	Electro-mechanical Capacity of Existing Plants (MW-gross)	2005 Capacity of Existing Plants (MW-gross)	Difference Between Electro-mechanical Capacity and 2005 Capacity (MW-gross)	Difference Between Most-Likely Resource Capacity and Electro-mechanical Capacity (MW-gross)
Coso	246	356	300	270	30	55
East Mesa	119	148	113.2	95	18	35
Heber	109	142	100	100	0	42
Honey Lake	6	8	2.3	2	0	6
Mammoth Pacific	70	111	40	35	5	71
Salton Sea	1,350	1,750	350	350	0	1,400
The Geysers	1,200	1,400	1,736	980	756	-336
Total	3,100	3,914	2,642	1,832	810	1,272

Note (1) Source: GeothermEx (2004), PIER Geothermal Database. Assumes 30-year life.

value of 3,100 MW-gross and a most likely value of about 3,900 MW-gross. Table 3 lists the resource capacity estimates for these fields and compares them to the electro-mechanical capacities and the 2005 capacities of existing plants.

The difference between the electro-mechanical capacity and the 2005 capacity (approximately 800 MW-gross) derives primarily from resource conditions that have failed to meet the original performance specifications of the plants. In other words, this is the approximate magnitude of the potential improvement in power output that could be achieved if adequate resource supply (steam and/or hot water) could be made available, with no changes to the existing plants. The vast majority of the gap between the electro-mechanical capacity and the 2005 capacity (over 750 MW) is attributable to The Geysers.

The difference between the most-likely resource capacity and the electro-mechanical capacity of existing plants provides an idea of the amount of the incremental power output that could be achieved by improving existing plants or by constructing new plants (and drilling new wells to support them) in currently producing fields. The largest block of this incremental potential (about 1,400 MW-gross) is in the Salton Sea field. Considering just the electro-mechanical capacity of existing plants, The Geysers has a surplus of about 300 MW over the most-likely resource capacity. However, because the surplus in electro-mechanical capacity is concentrated in certain areas of The Geysers while other areas remain relatively under-developed, there is probably still potential for economical new plant capacity at The Geysers, i.e., new capacity that would not interfere excessively with existing plants operating at their 2005 capacity. Calpine has estimated this potential for new plant capacity at The Geysers to be in the range of 150 to 300 MW (Tom Box, personal communication, 18 October 2005).

Costs of Improvements

An important part of the objective of the Facilities Improvement Report has been to quantify the costs and benefits of potential improvements. To provide a basis for comparison, GeothermEx has endeavored to ascertain current estimates of capital costs for new geothermal facilities, as well as O&M costs for existing facilities. The following estimates are based on GeothermEx's familiarity with a number of geothermal projects currently operating or under development, as well as comments by operators interviewed for this study on cost ranges they consider realistic.

As of 2005, capital costs for new geothermal facilities in California are likely to be in the range of $2,900 to $3,500 per kilowatt (kW) installed. This would include both the cost of the power plant and the wellfield (wells and gathering system). It would also include the cost of several miles of new transmission line, though not a major grid upgrade. The range in capital costs stems from differences both in resource characteristics (such as depth, temperature, and salinity) and in plant technology. A recent knowledgeable estimate for new binary geothermal projects in California is $3,000 per kW installed. A new project with a dry-steam plant at The Geysers is estimated to cost $3,200 per kW (Tom Box, personal communication, 25 July 2005). In the Salton Sea field, a large flash plant (about 200 MW) has been estimated to cost $3,500 per kW (Jonathan Weisgall, personal communication, 11 April 2005). The latter estimate is toward the high end of the spectrum, because the geothermal brines of the Salton Sea require specialized plant equipment and well completions (including titanium casing in production wells). In general, the range of values cited above is in reasonable agreement with the average value of $2,950 per kW (in 2003 dollars) estimated for new geothermal facilities in California in the PIER Geothermal Database (GeothermEx, 2004).

O&M costs for geothermal facilities in California are currently in the range of 1.8 to 2.5 cents per kilowatt-hour (¢/kWh), excluding financing costs, depreciation, and any ongoing capital expenditures. As used in this study, O&M would include the following components:

- Labor and benefits
- Services and supplies
- Property taxes
- Royalties and lease payments
- Insurance
- Workovers
- Administrative expenses

Given this definition, the O&M cost for binary facilities in California can be estimated at 2.0 to 2.5 ¢/kWh (Dan Schochet, personal communication, 1 July 2005). The same range (2.0 to 2.5 ¢/kWh) would be typical for dry-steam facilities at The Geysers, though particular projects could be outside this range depending on royalties and other factors (Tom Box, personal communication, 29 June 2005). For the double-flash facilities at Coso, O&M costs in 2004 averaged 2.8 ¢/kWh, based on information in a 10-K filing with the U.S. Securities and Exchange Commission (Caithness Coso Funding Corporation, 2005). The Coso O&M costs include revenue-sharing payments to the U.S. Navy that are higher than typical royalty rates. If royalties at Coso were calculated at 4% of operating revenues, then 2004 O&M costs (the sum of plant operating expenses and the hypothetical royalty) would have been in the range of 1.5 to 2.6 ¢/kWh, with an average value of 2.0 ¢/kWh. This adjusted value is more in line with O&M rates observed at other geothermal facilities. O&M values for the flash plants utilizing the hypersaline resource at the Salton Sea are not publicly available.

Financing costs typically add several ¢/kWh to the effective cost of operating geothermal facilities. For example, a facility costing $2,900/kW, of which 70% is borrowed at an interest rate of 10% for a term of 15 years, would incur a levelized financing cost of 3.4¢/kWh (assuming a 90% capacity factor). Moreover, most geothermal facilities have periodic capital expenditures after initial start-up that can cost on the order of several million dollars (such as make-up wells and plant modifications). Financing costs and ongoing capital expenditures need to be considered together with O&M costs to determine the price at which a geothermal operator can afford to sell power.

The Facilities Improvement Report describes numerous options for improving resource supply and plant technology. Some improvements can be characterized in terms of capital cost per increment of net power output ($/kW). Others are harder to associate with a specific increase in power output, but may be characterized in terms of their potential savings in O&M costs (¢/kWh). Capital costs for the improvements described in the Facilities Improvement Report ranged from $300 to $3,000 per kW of increased output. O&M savings ranged from 0.02 to 1.0 ¢/kWh. In general, if the capital cost of an improvement is significantly less than $2,900 (the low end of the capital cost per kW for a new plant), then the improvement may be worth considering. Similarly, even a fraction of a cent improvement in O&M costs may be significant as a proportion of total O&M costs in the range of 1.8 to 2.5 ¢/kWh.

Categories of Improvements

The Facilities Improvement Report provides detailed descriptions of a number of options for improving existing geothermal facilities in California. For the purposes of this summary paper, the following lists provide an overview of the categories of improvements considered.

Possible approaches to improving resource supply include:

- Reducing steam-separation pressure and/or flowing wellhead pressure for plants using flash or dry-steam technology
- Drilling make-up wells
- Performing workovers or stimulations of existing wells
- Drilling larger-diameter, multi-leg, or highly deviated wells
- Controlling scaling or corrosion problems
- Modifying pipelines in gathering systems and injection systems
- Increasing the setting depth of downhole production pumps
- Optimizing the injection of reservoir-derived water
- Injecting water from sources outside the reservoir

Possible approaches to improving surface facilities include:

- Modifications to steam turbines
  - o Modifications to accommodate lower turbine-inlet pressure
  - o Turbine-nozzle cooling
  - o Bowed nozzles and blades with three-dimensional design
  - o Longer last-stage blades
  - o Partial-arc steam admission
- Modifications to heat-rejection systems
  - o Increasing the size of heat-rejection systems for dry-steam and flash plants
  - o Using advanced direct-contact condensers for dry-steam and flash plants
  - o Changing from air cooling to wet cooling for binary plants
  - o Augmenting air cooling with water spray for binary plants
- Modifications to process configuration
  - o Addition of topping or bottoming cycles
  - o Use of modular power units
  - o Use of internal interstage reheating in flash-steam plants
  - o Use of hybrid configurations (flash-steam/binary or fossil-fuel/geothermal)
- Modifications to non-condensable gas (NCG) removal systems
- Modifications to hydrogen sulfide (H_2S) abatement systems
- Improvements in plant operation and maintenance (O&M) procedures
  - o Better mitigation of scaling and corrosion
  - o Reduction of parasitic power consumption
  - o Better monitoring and control systems
  - o By-product recovery

The applicability of these possible improvements to specific geothermal projects clearly needs to be evaluated on a case-by-case basis. The Facilities Improvement Report lays the groundwork for such evaluations by presenting matrices of geothermal projects and the potential improvements that may apply for each.

Acknowledgements

The authors would like to acknowledge the support of the CEC in providing funding for the Facilities Improvement Report. Constructive comments from the CEC staff, from the PIER Technical Review Team, from Ray Dracker at the Center for Resource Solutions, and from members of the Renewable Program Advisory Committee (RPAC) were very helpful. Ronald DiPippo made valuable contributions to the Facilities Improvement Report, including illustrations from his recent book on geothermal power plants (DiPippo, 2005). The authors have greatly appreciated the willingness of the operators of California geothermal plants to provide information about their projects.

References

Caithness Coso Funding Corporation (2005). Form 10-K filing for the U. S. Securities and Exchange Commission for fiscal year ended 31 December 2004. (http://www.getfilings.com/o0001088866-05-000002.html) (accessed 10 July 2005).

Department of Energy (2005). Form EIA-906 database, Monthly Utility Power Plant Database: (http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html).

DiPippo, R. (2005). Geothermal power plants: principles, applications and case studies. Elsevier Advanced Technology, Oxford, England.

EPRI (2001). California renewable energy market and benefits assessment. California Energy Commission, PIER.

Geothermal Energy Association website: (http://www.geo-energy.org/Facilities/CA/CA.htm).

GeothermEx, Inc. (2004). New geothermal site identification and qualification. Consultant report for California Energy Commission, Publication No. P500-04-051, April 2004. Report and accompanying PIER Geothermal Database available on the web: (http://www.energy.ca.gov/pier/final_project_reports/500-04-051.html).

GeothermEx, Inc. (in press). Existing Geothermal Facility Improvements. Consultant report for California Energy Commission, draft submitted 15 February 2006.

Lund, J. W., R. G. Bloomquist, T. L. Boyd, and J. Renner (2005). The United States of America country update. World Geothermal Congress Proceedings, Antalya, Turkey, 24-29 April 2005.