GEOTHERMAL ELECTRIC POWER PRODUCTION IN THE UNITED STATES: A SURVEY AND UPDATE FOR 1990-1994

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ABSTRACT

This survey presents the geothermal power developments during the last five years in the United States. The role of geothermal energy is described relative to other forms of generation. A state-by-state review shows that California and Nevada are making significant use of geothermal energy, having 98 percent of all the U.S. installed geothermal power capacity. Even though growth continues, it is far slower than during the 1980's. By the year 2000, California and Nevada may realize increments of 242 and 205 MW, respectively. By then, the list of states with operating geothermal power plants could grow from the current California, Hawaii, Nevada and Utah to include Alaska, New Mexico and Oregon. By the end of the millennium, the United States installed capacity could reach nearly 3400 MW, if all the planned additions materialize. However, a more realistic assessment anticipates only 2237 MW of actual, operable geothermal capacity.

1. INTRODUCTION

The United States continues to lead the world in installed and operable geothermal power capacity as well as in electrical generation.

Geothermal energy is a small contributor to the electric power capacity and generation in the United States. For the period 1990-1994, geothermal plants constituted about 0.25 percent of the total operable power capacity. In 1990 those plants contributed 0.31 percent of the total generation but this has fallen steadily and for the first two months in 1994 it stands at 0.25 percent.

On a state and regional level, however, geothermal is a major player in California and Nevada, and has the potential to become significant in several localities of the northwest as well as on the Big Island of Hawaii.

The impressive geothermal growth in the decade of 1980's is over. From 1980-1989 the average annual growth in installed power capacity was about 18 percent; from 1990-1994 it was 0.3 percent. This recent period also saw the retirement of five units at The Geysers in California - the original four units representing a combined installed capacity of 78 MW and the 55 MW Bottle Rock plant.

Table 1 shows the historical development of geothermal capacity installed in the United States from 1960-1994 broken out by state.

2. TOTAL PRODUCTION OF ELECTRICITY: ALL SOURCES

Table 2 presents the actual ("operable"), as contrasted with installed, electric production capacity as well as the generation of electricity in the United States from all sources for 1990-1994. For 1994 only data for January and February were available at the time of writing. All data except those with footnote 5 were obtained from the National Energy Information Center (Freedman, 1994).

Geothermal production fell from 1990 to 1991 but recovered in 1992, only to slip significantly in 1993 (down 6.6 percent in generation). The 1994 data also show a continuing decline compared with the same two-month period in 1992 and 1993, down by 9.9 and 6.1 percent, respectively.

It must, however, be noted that the EIA data for geothermal energy appear to be much lower than the actual situation based on the data compiled for this paper. With reference to the data given in Table 1 and Tables 3-7 (given later in this paper), the operable geothermal capacity for, say, the year 1991 ought to be about 2.124 GW, some 410 MW higher than the EIA figure. The electricity generated from such a capacity should range from 14.8-16.7 TWh, allowing for an average capacity factor from 0.8-0.9; the EIA figure is only 8.087 TWh.

The values for geothermal capacity for 1993 and 1994 (footnote 5) were calculated using the data compiled for this paper; the value of C projected for the year 2000 is conservatively predicated on gaining 50 percent of the planned capacity additions and assumes a loss of 55 MW at The Geysers. Of course the totals (col. 10) for the years 1993, 1994 and 2000 include the geothermal capacities based on this study.

Table 1
U.S. GEOTHERMAL POWER GROWTH: 1960-1994

Year	CA	HI	NV	OR	UT	Total
	Cumulative installed megawatts, MW					
1960	11	0	0	0	0	11
63	24	0	0	0	0	24
67	51	0	0	0	0	51
68	78	0	0	0	0	78
1971	184	0	0	0	0	184
72	290	0	0	0	0	290
73	396	0	0	0	0	396
75	502	0	0	0	0	502
79	680.4	0	0	0	0	680.4
1980	931.4	0	0	0	0	931.4
82	1064.4	3	0	0	0	1067.4
83	1352	3	0	1	0	1356
84	1462	3	0.5	2.2	20	1487.7
85	1954	3	25.2	2.2	22	2006.4
86	2004	3	31.2	2.2	22	2062.4
87	2015	3	39.1	2.2	22	2081.3
88	2325.6	3	120.6	0	24	2473.2
89	2686	3	133.6	0	24	2846.6
1990	2610	0	133.6	0	31	2774.6
91	2610	0	146.6	0	31	2787.6
92	2532	0	195.7	0	31	2758.7
93	2565	25	195.7	0	31	2816.7
94	2565	25	195.7	0	31	2816.7
	91.1%	0.9%	6.9%	0%	1.1%	100%

Table 2
PRESENT AND PLANNED PRODUCTION OF ELECTRICITY]

Year	Geothermal C GW[3]	Geothermal E TWh[4]	Fossil fuels C GW	Fossil fuels E TWh	Hydro C GW	Hydro E TWh	Nuclear C GW	Nuclear E TWh	Totals[2] C GW	Totals[2] E TWh
1990	1.794	8.581	535.8	1940.7	87.2	279.9	108.0	576.9	735.1	2808.2
1991	1.715	8.087	538.8	1926.8	88.7	275.5	108.4	612.6	740.0	2825.0
1992	1.869	8.104	539.8	1928.7	89.7	239.6	107.9	618.8	741.7	2797.2
1993	2.021[5]	7.571	544.2[6]	1996.6	89.9[6]	265.1	108.3[6]	610.3	746.9[6]	2882.5
1994[7]	2.012[5]	1.205	548.7[6]	339.5	90.1[6]	39.0	108.7[6]	106.0	752.0[6]	486.1
2000	2.237[6]	---	565.1[6]	---	91.2[6]	---	110.96	---	772.3[6]	---

[1] Source (except as noted): Energy Information Administration/Monthly Energy Review, May 1994: EIA/Inventory of Power Plants in the United States, 1990, 1991, 1992:
[2] Totals include (besides sources shown): wood, waste, wind, photovoltaic and solar thermal energy plants connected to electric utility distribution systems.
[3] GW = 10^9W. [4] TWh = 10^9kWh. [5] This study. [6] Projected. [7] EIA data for Jan. and Feb. only.

3. GEOTHERMAL DEVELOPMENTS BY STATE

3.1 California

California accounts for over 90 percent of the installed geothermal power capacity in the country. The major areas of development are The Geysers, Coso, and the Imperial Valley including East Mesa, Heber and Salton Sea. Other areas with geothermal plants are Casa Diablo (Mono-Long Valley or Mammoth) and the Honey Lake Valley including Wendel and Amedee. Glass Mountain and Surprise Valley are scheduled for development. The locations of all of these areas are shown in Figure 1.

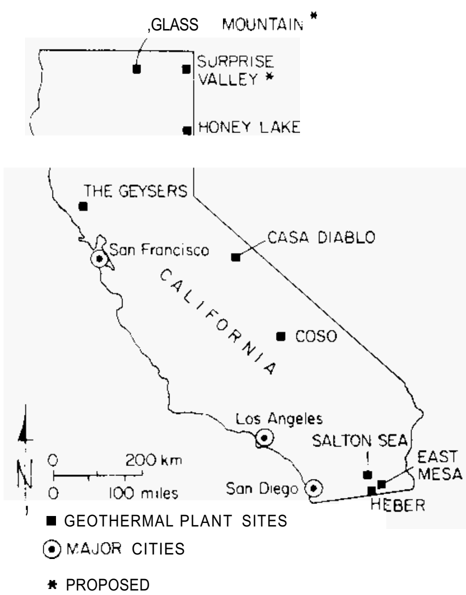

Figure 1
Geothemal Power plant Areas in California.

The Geysers

There have been no new plants installed at The Geysers dry steam field since 1989 when the 2x10 MW J.W. Aidlin plant came on-line. The four original PGLE units were officially retired in 1992: all surface equipment for Units 1 and 2 (11 and 13 MW) has been dismantled, and the removal of Units 3 and 4 (27 MW each) is in progress. The wells that are still serviceable will be reconnected to provide Steam to other units. Unit 1 had been designated a National Historic Mechanical Engineering Landmark in 1985 by the American Society of Mechanical Engineers. Two other plants are no longer in service: PG&E Unit 15 (59 MW, retired in 1989) and the OWR Bottle Rock plant (55 MW, closed in 1990).

Figure 2 shows the power plant locations at The Geysers. Table 3 gives data on the plants including the rating and the actual output for the years 1991, 1992 and 1993 (Hodgson, 1994). Owing to a shdrtfall of steam,.the difference between rated and actual power capacity is significant and is worsening, i.e., it was 663 MW in 1991, 768 MW in 1992 and 796 MW in 1993.

The price which PGLE. the largest geothermal operator, pays for its steam has iluctuated dramatically since 1960. Initially, PGLE paid its steam suppliers about $2/MWh, but the oil shocks of 1973 and 1979 caused large increases in the geothermal steam price which reached nearly $40/MWh in 1984-85. From 1987 until now, the price has ranged from $15-22/MWh, except for the CCPA contract which is in the range from $28-32/MWh (cooley, 1994).

Imperial valley

The intensive development of the Imperial Valley resources which took place during the 1985-1989 period slowed during 1990-1994. A new plant was added at Heber, another at the Salton Sea, and an expansion is in the engineering stage at the Salton Sea. Site maps and plant data for these two areas plus the East Mesa area are given in Figures 3-5 and Table 4.

- Heber area

A binary plant having a gross output of 40 MW and a net rating of 33 MW was installed iust north of the idle Heber Binary Demonstration plant. The plant consists of six modules, each of which has two generator Sets driven by a pair of turbines. This cascade-type energy conversion system is the latest evolutionary design of binary plant (DiPippo, 1994: Ram and Yahalom, 1988: Schochet, 1994). The new plant is owned by the Second Imperial Geothermal Company: the modules were supplied by Ormat.

- Salton Sea area

Salton sea Unit 2 (18 MW, net) came on line in 1990. It comprises three separate power units: a standard-pressure turbine (10 MW), a low-pressure turbine (5 MW) and a high-pressure turbo-expander (4 MW). The standard-pressure machine was previously used at the Brawley pilot plant, now dismantled (Crane, 1980; Rintoul, 1981). Most of the steam for Unit 2 comes from the adjacent Unit 1 which is not designed to use its high-pressure steam (Moss et al, 1982). Although Units 1 and 2 are interconnected, the former uses a crystallizer-clarifier system to control scaling caused by the high-temperature, hypersaline brines, whereas the latter uses an acid injection system (pH control) for the Same purpose (Signorotti and Hunter, 1992).

Casa Diablo

Two new binary plants were installed in 1990, each with a nominal rating of 10 MW and consisting of three modular units (Campbell and Harvey, 1991). The new plants, MP-II and PLES-I, are adjacent to each other and are located

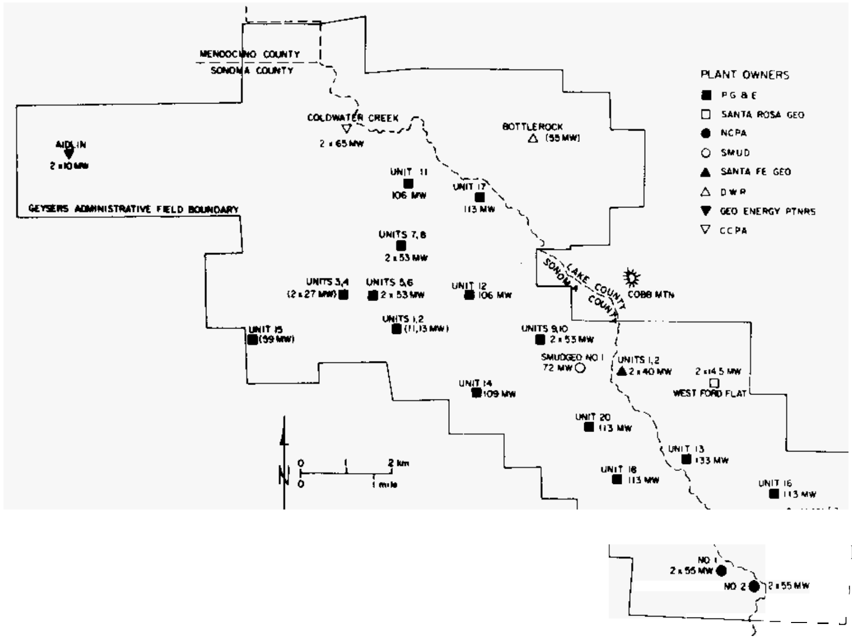

Figure 2
The Geysers Power Plants.

Table 3
TEE GEYSERS DRY STEAM POWER PLANTS

Owner	Unit	Year	Rating MW	Actual 1991	Output, MW 1992	1993
PG&E	1	1960	11	S	R	R
	2	1963	13	8	R	R
	3	1967	27	S	R	R
	4	1968	27	S	R	R
	5	1971	53	42	50	44
	6	1971	53	48	49	46
	7	1972	53	31	D	38
	8	1972	53	37	49	39
	9	1973	53	44	38	36
	10	1973	53	44	39	37
	11	1975	106	70	75	70
	12	1979	106	81	43	45
	13	1980	133	109	99	98
	14	1980	109	64	61	69
	15	1979	59	R	R	R
	16	1985	113	98	89	80
	17	1982	113	51	49	43
	18	1983	113	82	71	73
	20	1985	113	84	76	63
NCPA	1-1	1983	55			
	1-2	1983	55	75[1]	75[1]	71[1]
	2-3	1985	55			
	2-4	1986	55	751	75[1]	71[1]
SMUD	No.1	1983	72	78	78	62
SFG	1	1984	40	40	40	40
	2	1984	40	40	40	40
DWR	BR[2]	1985	55	R	R	R
CCPA	1	1988	65	55	55	56
	2	1988	65	S	S	S
SRGC	BC[3]	1988	2x11	22	22	22
	WFF[4]	1988	2x14.5	30	30	30
GEP/ CGP	JWA[5]	1989	2x10	18	18	20
	TOTALS:		1989	1326	**1221**	**1193**

[1] Both units; [2] Bottle Rock; [3] Bear Canvon; [4] West Ford Flat; [5] J.W. Aidlin.
S Standby: R Retired; D Down.
Source: Annual Report of the State Oil 6 Gas Supervisor, 1991 & 1992, CADOC, DOGGR.

Table 4
IMPERIAL VALLEY GEOTHERMAL POWER PLANTS

Owner	Plant	Type[1]	Year	No. of Units	Rating MW
● EAST MESA:					
GEO/ Mission	GEM 1	B	1979	1	13.4
	2	2F	1989	1	18.5
	3	2F	1989	1	18.5
OESI	ORMESA I	B	1987	26	24
	II	B	1988	20	16.5
	IE	B	1988	10	8
	IH	B	1989	12	6.5
	Sub-totals:			71	105.4
● HEBER:					
SDG&E	Binary Demo.	B	1985	1	R
Calpine/ ERC	Dual-Flash	2F	1985	1	47
SIGC	Second Imperial Project	B	1993	12	33
	Sub-totals:			14	80.0
● SALTON SEA:					
Magma	S.S. 1	1F	1982	1	10
	2	2F	1990	3	18
	3	2F	1989	1	47.5
	Vulcan	2F	1985	2	34.5
	A.W. Hoch (Del Ranch)	2F	1989	1	35.8
	J.J. Elmore	2F	1989	1	35.8
	J.M. Leathers	2F	1989	1	35.8
	Sub-totals:			10	217.4
	TOTALS:			**95**	402.8

[1] B Binary, 1F Single-flash, 2F Double-flash.
[2] A "Unit" has one turbine-generator set.

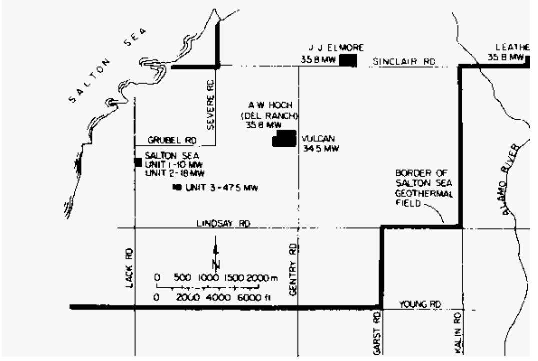

Figure 3
Salton Sea Geothermal Power Plante.

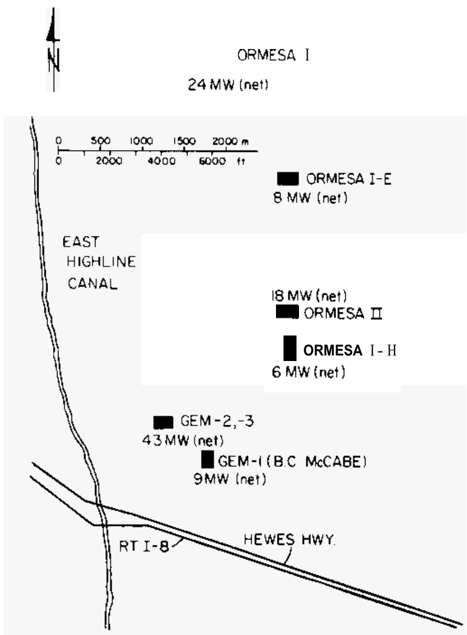

Figure 4
East Mesa Geothermal Power Plants.

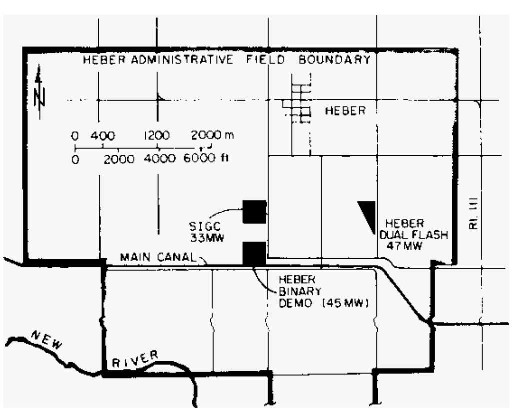

Figure 5
Heber Geothermal Power Plants.

about 600 m (1500 ft) east of the original plant, MP-I. The modular binary units were designed by The Ben Holt Company and the turbines were supplied by Rotoflow. See Figure *6* and Table 5 for more details.

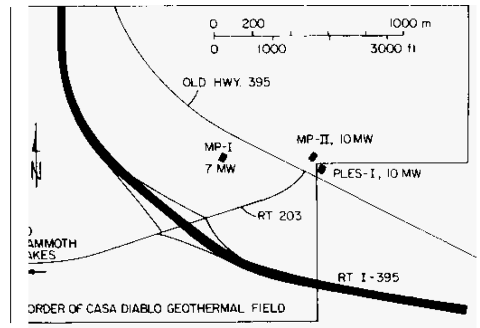

Figure 6
Casa Diablo Geothermal Power Plants.

Table 5
CASA DIABM (MAMMOTH) GEOTHERMAL POWER PLANTS

owner	Plant	Type	Year	No. of Units	Rating MW
Mammoth-Pacific	MP-I	B	1984	2	7
Pacific	MP-II	B	1990	3	10
Energy	PLES-I	B	1990	3	10
			TOTALS:	8	27

Honev Lake valley

There has been no new activity in this area since 1989 when the *30* MW hybrid geothermal-wood products plant went into operation (Habel, 1991). Geothermal hot water is used for its direct heat value to augment the efficiency of the wood-waste-fueled unit and contributes about *6* MW of the total plant output. See Figure *7* and Table *6* for more details.

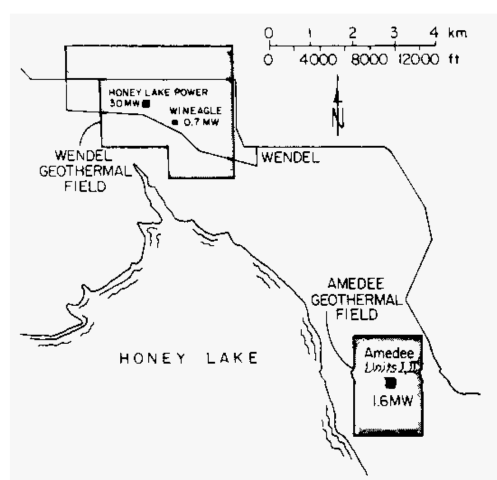

Figure 7
Honey Lake Valley Geothermal Power Plants.

Table 6
HONEY LAKE VALLEY GEOTHERMAL POWER PLANTS

Owner	Plant	Type	Year	No. of Units	Rating MW
Wineagle Devel.	Wineagle	B	1985	2	0.7
TPG/USEC	Amedee	B	1988	2	1.6
HL Power Company	Honey Lake	H[1]	1989	1	30[2]
			TOTALS:	5	32.3

1 H Hybrid: Wood waste/geothermal hot water.
2 Geothermal contribution is about 6 MW.

Coso

All power plants at Coso were installed in the 1987-1989 time period (Schoonmaker, 1989). See Figure 8 and Table 7 for more details.

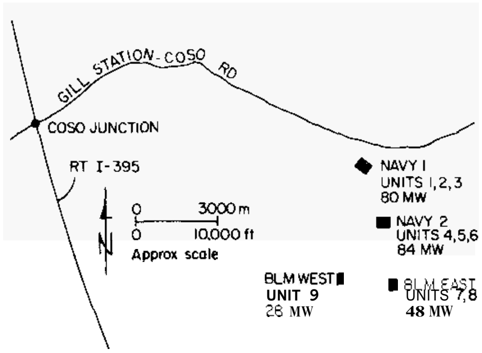

Figure 8
Coso Geothermal Power Plants.

Table 7
COSO GEOTHERMAL POWER PLANTS

Owner	Plant	Type	Year	No. of Units	Rating MW
CECI	Navy 1:				
	Unit 1	2F	1987	1	30
	2	2F	1988	1	25
	3	2F	1988	1	25
	Navy 2:				
	Unit 4	2F	1989	1	28
	5	2F	1989	1	28
	6	2F	1989	1	28
	BLM 1:				
	Unit 7	2F	1988	1	24
	8	2F	1988	1	24
	9	2F	1989	1	28
			TOTALS:	9	240

Planned additions

New plants or expansions are being planned for the following areas: Casa Diablo, Coso, Glass Mountain. Salton Sea and Surprise Valley. As is generally true throughout the geothermal industry, the feasibility of new plants is strongly conditioned by the availability of favorable power sales contracts and, of course, subject to approval by appropriate regulatory bodies.

The Salton Sea Unit 1 (Moss et al, 1982) will be expanded through the addition of a 20 MW unit to be built close to Unit 1; the new plant will be called "Unit 1 Expansion". The geo-fluid gathering system will incorporate the pH-control method to alleviate scaling, and is expected to be on-line in 1996 (Hildebrand, 1994).

See Table 8 for additional details for all planned plants.

Table 8
GEOTHERMAL PLANTS PLANNED FOR CALIFORNIA

Owner	Site	Plant	Type	Year	Rating MW
Magma	Salton Sea	S.S. 1 Expan.	2F	1996	20
LADWP	Coso	LADWP I	2F	1996	60
		II	2F	2000	90
CECI	Glass Mtn.	Glass Mtn. I	N/A	1996	30
Pacific Energy	Casa Diablo	MP-III	B	1996	12
TPG/CON	Surprise Valley	Lake City 1	N/A	N/A	30
				TOTAL:	242

3.2 Hawaii

A 25 MW hybrid single-flash/binary plant was commissioned in 1993 at Puna in the Kilauea East Rift zone on the Big Island of Hawaii (GRC, 1993a). The plant is located at the easternmost point of the island, about 5.6 km (3.5 mi) west of the Kapoho crater and the same distance southeast of the town of Pahoa. Another 30 MW plant is in the early planning stage at the same area. Within the next five years, an additional 25 MW plant may be built in the Rift zone. Table 9 gives more details.

Table 9
GEOTHERMAL PLANTS IN HAWAII:
EXISTING AND PLANNED

Owner	Site	Plant	Type	Year	Rating MW
● Existing:					
OESI	Puna, Big Island	PGV-I	H[1]	1993	25
			Sub-total:		25
● Planned:					
OESI	Puna, Big Island	PGV-II	H[1]	N/A	30
True/ MPGV	Puna, Big Island	Kilauea	1F	N/A	25
			Sub-total:		55
				TOTAL:	80

1 Hybrid: Single-flash/Binary.

3.3 Nevada

This summary is largely based on the update of geothermal usage in Nevada (Garside and Hess, 1994) and a review of projects in the Basin and Range Province (Benoit, 1994). As of 1994 there are power plants operating at ten different sites in Nevada with a total power capacity of 195.7 MW. Four plants came on line during 1990-1994: Soda Lake II (15 MW, 1990), Steamboat 2 (12 MW, 1992), Steamboat 3 (12 MW, 1992) and Brady Hot Springs (24 MW, 1992). The plants in Nevada include binary, single-flash, double-flash and total flow type energy conversion systems. Figure 9 and Table 10 give more details.

There are plans to develop power projects at the following new sites: Fallon Naval Air Station, Fish Lake Valley, Hot Sulfur springs, Rye Patch and San Emidio Desert. Also a second plant may be built at Dixie Valley and two more at Steamboat (Hildebrand, 1994: Meldav, 1994: Quinn, 1994). Many of these plans are not definite and, as mentioned earlier, depend strongly on securing favorable power sales agreements. In at least one case (Rye Patch), the resource has yet to be developed to the point of confidence to justify commercial development. If all plans come to fruition, more than 200 MW would be added, roughly doubling the current capacity. Table 11 gives more details.

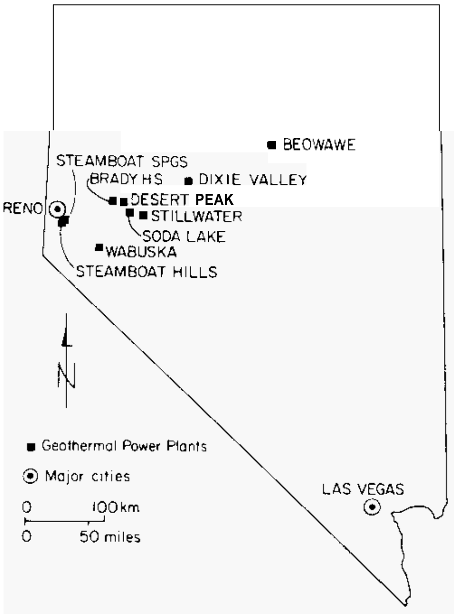

Figure 9
Geothermal Power Plant Areas in Nevada.

Table 11
GEOTKERMAL PLANTS PLANNED FOR NEVADA

Owner	Site	Plant	Type	Year	Rating MW
Caithness	**Dixie Valley**	**Caithness I**	**2F**	**1995**	**25**
San Emidio Resources	San Emidio Desert	San Emidio	B	1995	30
Magma	Fish Lake Valley	Fish Lake I	2F	1996	14
EPE&M	Hot Sulfur Springs	HSS	N/A	N/A	**9.9**
Far West	Steamboat	SB 4 SB 5	B K[1]	N/A N/A	24 12
OESI	Rye Patch	Rye Patch	B	N/A	N/A
N/A	Fallon Naval Facility	Fallon	N/A	**N/A**	90
				TOTAL:	**204.9**

[1] Kalina cycle.

one of the plants proposed for Steamboat is based on the Kalina cycle (Kalina and Leibowitz, 1989). A variation on the binary cycle, it achieves high efficiency through the use of an appropriate mixture (in this case, water and ammonia) as the cycle working fluid (which evaporates and condenses non-isothermally, improving the efficiency of the heat exchangers at both the hot and cold ends of the cycle) and by heat recuperation (which captures some of the energy that would otherwise be rejected). The cycle that is planned for use at Steamboat does not incorporate some of the more innovative features that are used in Kalina cycles in other applications. The DOE is scheduled to cost-share 20 percent of the plant cost (WE, 1993a).

Table 10
GEOTHERMAL POWER PLANTS IN NEVADA

Owner	Plant	Type	Year	No. of Units	Rating MW
CECI/CVG	Beowawe	2F	1985	1	16.0
BPP	Brady Hot springs	2F	1992	3	21.1
CECI	Desert Peak	2F	1985	2[1]	8.7
Oxbow	Dixie Valley	2F	**1988**	1	66.0
Empire Geothermal	Empire	B	1987	4	3.6
OESI	Soda Lake 1 2	B B	1987 1991	3 6	3.6 13.0
Far West	Steamboat I IA 2 3	B B B B	1986 1988 1992 1992	7 2 2 2	6.0 1.1 14.0 14.0
OESI/CON	SW[2] I	B	1989	14	13.0
Tad's	Wabuska I II	B B	1984 1987	1 1	0.5 0.7
Caithness/ Sequa	**SBH[3]**	**1F**	1988	1	14.4
		TOTALS:		**50**	**195.7**

A Biphase Total-Flow expander is installed along with a dual-pressure steam turbine.
Stillwater.
Steamboat Hills -Yankee/Caithness.

3.4 Utah

In 1990 the Bud L. Bonnett power plant came on line at the Sulphurdale/Cove Fort geothermal field (GRC, 1990a). The unit is rated at 7 MW and is the latest addition to the power complex at that site. There are also a 2 MW backpressure steam turbine and four binary units (with a total rating of 2 MW) which are located downstream of the steam turbine. Figure 10 and Table 12 give more details.

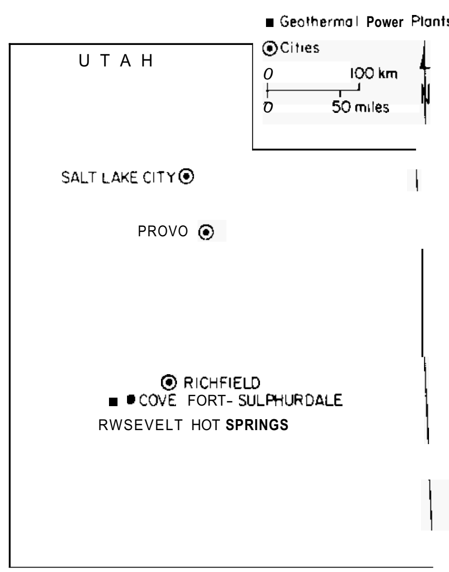

Figure 10
Geothermal Power Plant Areas in Utah.

Table 12
GEOTHERMAL POWER PLANTS IN UTAH

Owner	Plant	Type	Year	No. of Units	Rating MW
UPD	Blundell I	1F	1984	1	20
City	CF[1] No.1	B	1985	4	2
of	CF Steam	DS[2]	1988	1	2
Provo	Bonnett	DS	1990	1	7
			TOTALS:	**7**	**31**

[1] **Cove Fort.** [2] **Dry steam.**

3.5 Other Plants Planned for the United States

The plants that are planned for California. Hawaii and Nevada were-mentioned earlier. Now we will describe those that are planned for states which currently do not have any plants.

Alaska

OESI and the Alaska Energy Authority are exploring the possibility of installing a 15 MW unit at Unalaska Island by 1996 (Schochet. 19941. The project was initiated in 1991.

New Mexico

The long-idle binary units at Hammersly Canyon near Lakeview in Oregon (DiPippo, 1983: GRC, 1984) were bought in 1993 by Burgett Geothermal Greenhouses of Cotton City, New Mexico (GRC, 1993b). Dale Burgett intends to install the three 0.3 MW units to power the greenhouse operations. The facility is very close to the Lightning Dock KGRA in the southwestern part of the state. The geofluid is obtained from shallow well pumps and will be used to heat irrigation water after it leaves the heat exchangers of the power units. Ultimately the geofluid itself will be used for irrigating Burgett's fields. The facility should be in full operation in 1995 (Burgett, 1994).

Oregon

There are plans to develop two new geothermal prospects in Oregon: Newberry Crater (GRC, 1993c) and Vale (GRC, 1993d). If the initial projebt at Newberry is succeisful, the ultimate capacity of the field could reach 100 MW. Both plants. like the Glass Mountain (CA) proposed plant '(see Table 8), are demonstration plants in conjunction with the BPA.

See Table 13 for more details on these planned plants.

Table 13
GEOTHERMAL PLANTS PLANNED FOR ALASKA, NEW MEXICO AND OREGON

Owner	Site	Plant	Type	Year	Rating MW
OESI	**Unalaska Isle., AK**	**Unalaska**	**N/A**	**1996**	**15**
Burgett	**Cotton City,NM**	**Burgett Geoth. Greenhouses**	**B**	**1995**	**0.5**
CECI	Newberry Crater,OR	Newberry 1 BPA Demo	N/A	1998	*30*
TPG	Vale,OR	vale BPA Demo	N/A	1998	30
			TOTAL:		**75.5**

4. GEOTHERMAL WELL DRILLING

The drilling of wells to support geothermal power generation has tapered off since the **1980's.**

4.1 California

The vast majority of geothermal power wells in the United States are in California. For the period 1990-1993 (for which complete data exist), the number of exploration, production, injection and observation wells drilled fell from **38** in 1990 to 26 in 1991 and 1992, but rose to 32 in 1993 (Hodgson, 1994: Thomas, 1994). Heber (13 wells) and The Geysers (10 wells) are currently the most actively drilled areas in the state. Table 14 gives more information on geothermal wells drilled in California.

The total number of production and injection wells in service increased by 9.5 percent from a total of 685 in 1990 to 750 in 1993. See Table 15 for more details. Since the total power capacity actually fell over this period, the increase in wells in service reflects the decline in well performance. The drop-off in average productivity (as measured by megawatts **per** oroduction well) can be seen in Table 16. **The** 'two sets of figures correspond to values based on installed and actual power, the latter being more indicative of the true average power capacity of the wells in operation. Both steam and hot water wells are included in the calculations.

Table **14**
GEOTHERMAL WELLS DRILLED **FOR** EXPLORATION, PRODUCTION, INJECTION AND OBSERVATION AT CALIFORNIA PLANT SITES: 1990-1993

Plant site	1990	1991	1992	1993
Amedee	0	0	0	0
Casa Diablo	14	4	1	0
Coso	2	**8**	12	5
East Mesa	**4**	1	**3**	2
The Geysers	10	11	6	10
Heber	0	0	1	13
Salton Sea	8	2	3	2
Wendel	0	0	0	*0*
TOTALS:	**38**	**26**	26	32

Table **15**
AVERAGE NO. OF PRODUCTION AND INJECTION WELLS IN OPERATION AT CALIFORNIA PLANT SITES:
1990-1993

Plant site	Prod. wells '90	'91	'92	'93	Inject. wells '90	'91	'92	'93
Amedee	2	2	2	2	0	0	0	0
Casa Diablo	**4**	io	io	io	3	5	4	4
Coso	47	57	63	68	13	13	15	17
East Mesa	39	42	42	43	33	36	39	40
The Geysers	442	436	444	451	25	26	29	29
Heber	10	10	10	12	9	**9**	9	12
Salton Sea	32	33	35	34	23	23	22	25
Wendel	2	2	2	2	1	1	1	1
TOTALS:	**578**	**592**	**608**	**622**	**107**	**113**	**119**	**128**

Table 16
AVERAGE PRODUCTIVITY OF GEOTHERMAL WELLS IN OPERATION AT CALIFORNIA PLANT SITES: 1990-1993

Year	MW/Production well MW-installed	MW-actual
1990	**4.5**	**3.7**
1991	**4.4**	**3.3**
1992	**4.2**	**2.9**
1993	**4.1**	**2.8**

4.2 Nevada

Geothermal well drilling in Nevada peaked in 1991 when 31 wells of all types were completed. Over the period 1990-1993 a total of 35 production and 17 injection wells were drilled. Table 17 (whiting, 1994) gives more details.

Table 17
GEOTHERMAL WELLS DRILLED FOR PRODUCTION, INJECTION, GRADIENT AND OBSERVATION IN NEVADA: 1990-1994[1]

Well type	1990	1991	1992	1993	1994
Production	5	10	10	10	1
Injection	6	6	2	3	0
Gradient/ observation	5	15	11	2	5
TOTALS:	16	31	23	15	6

[1] As of this writing.

4.3 Hawaii

The primary drilling activity in Hawaii from 1990-1994 has been in support of the 25 MW Puna Geothermal Venture power plant. All drilling has been confined to the active Kilauea East Rift Zone where very high temperatures have been encountered. Unfortunately, permeability in the high temperature part of the reservoir has been unpredictable and not always sufficient to yield commercial productivity. A recent slim-hole drilling program was conducted with EPRI funding (UHawaii, 1993) to better define the Kilauea prospect. Table 18 gives a listing of wells drilled on Hawaii for geothermal purposes (GRC, 1990b; UHawaii, 1983).

Table 18
GEOTHERMAL WELLS DRILLED IN HAWAII: 1961-1993

Year	No. wells	Well designation
1961	4	Hawaii Thermal Power wells
1973	1	NSF-Kilauea research well
1976	1	HGP-A
1979	2	Hualalai volcano
1980	1	Ashida-1
1981	5	Kapoho State, KS-1, -lA: Lanipuna-1, -1(ST)[1], -6
1982	1	KS-2
1990	3	True/MPGV; SOH-4. -1
1991	4	KS-3, -7, -8; SOH-2
1993	2	KS-9, -10
TOTAL:	24	

[1] Side-track.

4.4 Other states

There were few wells drilled in the other states which might have high-grade geothermal prospects.

Alaska

The only site under serious consideration is Unalaska Island in the Aleutians, but there was no drilling from 1990-1994. There are plans to drill five wells to support the proposed 15 MW power plant - three for production and two for injection, but the earliest that this can happen is 1995 (Liss, 1994: Schochet, 1994).

Idaho

The field at Raft River has been idle since the 5 MW pilot binary plant was shut down in 1982 (Bliem and Walrath, 1983). No drilling took place from 1990-1994 (Carlson, 1994).

New Mexico

No drilling was done from 1990-1994 at either the Valles Caldera or the Fenton Hill site. Both areas had been actively developed starting in the mid-1970's: the former area was abandoned due to low well productivity (poor permeability), and the latter area was used as a test facility for Hot Dry Rock technology. Flow tests were carried out at the HDR site from 1990-1993 (Brown, 1993).

A new area of interest in New Mexico is Rincon, located about 48 km (30 mi) north-northwest of Las Cruces (Witcher, 1991). In 1993, a 365 m (1200 ft) slim hole was drilled at Rincon, and a redrill/deepening is scheduled for 1995. There are' indications that a resource may exist with a temperature as high as 150 C (300 F) that could support binary power generation and agricultural development (Witcher, 1994)

Oregon

A total of five deep wells were drilled during 1990-94 (Olmstead, 1994). See Table 19. The two wells drilled in 1990 (CECI) lie east of the Three Sisters volcanos and west of Bend. The two drilled in 1993 (Anadarko) are in the Pueblo Valley at the southern end of the Alvord KGRA. The most recently drilled well (TPG) is in the Vale area. Permits have been issued to TPG to drill more than a dozen additional deep wells in the Vale area.

Table 19
GEOTHERMAL WELLS DRILLED IN OREGON: 1990-1994[1]

Year	No. wells	Well designation
1990	2	CE-BH-4, -7
1991	0	
1992	0	
1993	2	Pueblo Valley 52-22A, 66-22A
1994	1	ESI-A-S Alt
TOTAL:	5	

[1] As of this writing.

Utah

Only one well was drilled from 1990-1994, a production well at the Sulphurdale/Cove Fort area by Mother Earth Industries in 1992 (Tempest, 1994).

5. GEOTHERMAL LOCALITIES

The U.S. Geological Survey published an extensive compendium of the geothermal resources in the United States in 1978 (Muffler, 1978). This document, U.S.G.S. Circular 790, remains the accepted reference work on this subject.

The state of Nevada has recently revised and reclassified its geothermal prospects (DOE, 1993b; Hoops, 1994). The following four areas have been newly designated as KGRA's for the purpose of competitive bidding for leases on Federal lands:

Fish Lake Valley (Esmeralda County)
New York Canyon- (Pershing County)
Round Mountain (Nye County)
Salt Wells (Churchill County).

The following four areas have been reclassified as individual KGRA's; the upper pair were originally grouped together as were the lower pair:

Brady	Hazen
Soda Lake	Stillwater.

The following six areas remain as KGRA's:

Beowawe	Rye Patch
Dixie Valley	San Emidio Desert
Gerlach	steamboat springs.

The following 15 areas have been declassified and will not be considered as KGRA's for Federal bidding purposes:

Baltazor	Leach Hot Springs
Colado	Moana Springs
Double Hot springs	Pinto Hot Springs
Elko Hot Springs	Ruby Valley
Fly Ranch	Soldier Meadow
Hot Springs Point	Trego
Kyle Hot Springs	Warm Springs
	Wilson Hot Springs.

Although Circular 790 lists additional areas in Nevada not mentioned above, those areas have failed to attract any interest and may be considered unattractive for development at this tine.

6. PROFESSIONAL GEOTHERMAL PERSONNEL

There are certainly many more individuals working on geothermal projects than those who belong to the GRC, but we can use the GRC membership as a conservative measure of those engaged in geothermal work of all kinds. This would include scientists, engineers, technicians, drillers, managers, analysts, etc.

Data'on GRC membership for the last ten years is given in Table 20 (Mata, 1994). The membership varies cyclically, with peaks correlated with the quinquennial international meetings. The average U.S. membership is 966, the average non-U.S. membership is 151, and the average total is 1116. The fall-off in membership in the years following an international meeting does not necessarily indicate a loss of jobs in the geothermal industry, but more likely is caused by the natural tendency of people to lose touch with their professional societies absent a compelling reason to maintain their affiliation. If this hypothesis is correct, one would expect another surge in membership associated with the 1995 World Geothermal Congress.

Assuming that there could be as many as two or three people working on geothermal projects for each one who belongs to the GRC, then there could be as many as 3000-4000 people in the U.S. doing work related to geothermal energy.

Table 20
GEOTHERMAL RESOURCES COUNCIL MEMBERSHIP

Year	United States	Non-U.S.	Total
1985	837	75	912
1986	1089	159	1248
1987	1032	155	1187
1988	940	136	1076
1989	830	110	940
1990	1031	147	1178
1991	1048	190	1238
1992	1026	191	1217
1993	997	166	1163
1994	826	178	1004

7. OUTWOK AND CONCLUSIONS

If all the planned new capacity comes on line during the next five years, the installed geothermal electric power capacity would increase by 578 MW and reach a total of 3395 MW. This would represent an average annual growth rate of about 3.8 percent. Most of the growth will be in the states of California and Nevada. For more details, see Table 21 (values have been rounded to the nearest megawatt).

A more realistic assessment, based on the current actual capacity and assuming that only half of the planned additions appear over the next five years, would lead to the prediction of about 2237 MW of operable geothermal capacity in the year 2000.

Table 21
OUTLOOK FOR U.S. GEOTHERMAL POWER DEVELOPMENT
(Installed megawatts, by state)

Year	AK	CA	HI	NM	NV	OR	UT	Total
1994	0	2565	25	0	196	0	31	2817
incr.	15	242	55	1	205	60	0	578
2000	15	2807	80	1	401	60	31	3395

It will be interesting to see how the industry will fare when some of the power sales agreements that were negotiated in times of relatively high avoided costs go out of existence. Several of these apply to plants in the Imperial Valley and are scheduled to change during the next five years. The Drice paid for the energy will become the thin-current avoided cost, a much lower value than that paid during the early stage of the contract.

When the present excess capacity in the western states begins to disappear and when the present low price of fossil fuel, particularly natural gas, begins to increase, geothermal energy will resume its once strong growth.

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IN MEMORIAM

In loving memory of my father
Rinaldo DiPippo
master patternmaker and wood craftsman
who plied his trade till the day he died:
January 5, 1914 - October 10, 1994.

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KEY TO ABBREVIATIONS

BLM	U.S. Bureau of Land Management
BPA	Bonneville Power Administration
BPP	Brady Power Partners
C	Capacity (Table 2)
CADOC	California Dept. of Conservation
CCPA	Central California Power Agency
CECI	California Energy Company, Inc.
CGP	Cloverdale Geothermal Partners
CON	Constellation
CVG	Crescent Valley Geothermal
DOE	U.S. Department of Energy
DOGGR	California Div. of Oil, Gas and Geothermal Resources
DWR	California Dept. of Water Resources
E	Electrical generation (Table 2)
EPE&M	Earth Power Energy & Minerals
EPRI	Electric Power Research Institute
GEP	Geothermal Energy Partners
GRC	Geothermal Resources Council
KGRA	Known Geothermal Resource Area
LADWP	Los Angeles Dept. of Water and Power
MPGV	Mid-Pacific Geothermal Venture
N/A	Not available
NCPA	Northern California Power Agency
NSF	National Science Foundation
OESI	Ormat Energy Systems, Inc.
PG&E	Pacific Gas & Electric Company
PLES	Pacific Lighting Energy Systems
SDG&E	San Diego Gas & Electric Company
SFG	Santa Fe Geothermal
SIGC	Second Imperial Geothermal Company
SMUD	Sacramento Municipal Utility District
SRGC	Santa Rosa Geothermal Company
TPG	Trans-Pacific Geothermal, Inc.
TRUE	True Geothermal Energy
UPD	Utah Power Division of PacificCorp
USEC	U.S. Energy Corporation