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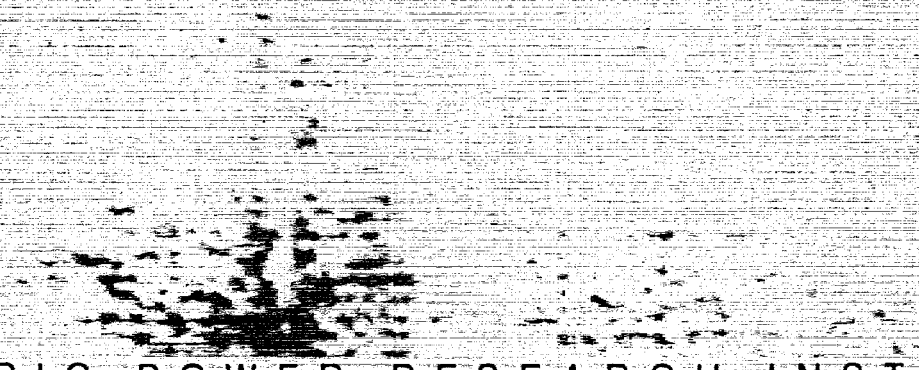

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WORLDWIDE GEOTHERMAL POWER PLANTS: STATUS AS OF JUNE 1980

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Introduction There are 100 geothermal power units now in operation throughout 12 countries, with a total installed capacity of just over 2110 MW. The average unit thus is rated at 21.1 MW. Newer units may be broadly classified as follows: (a) wellhead units of less than 5 MW; (b) small plants of about 10 MW; (c) medium plants of 30-35 MW; (d) large plants of about 55 MW; and (e) complexes typically consisting of several 55 MW units in a large geothermal field. There is a trend toward turbine units of the double-flow type with a 55 MW rating, used either alone or in a tandem-compound arrangement giving 110 MW in a single power house. This is particularly evident at The Geysers field in California. Double-flash units (separated-steam followed by a surface flash) are suited to high quality reservoirs having high temperature, high steam fractions at the wellhead, and low scaling potential. Single-flash units (separated steam) may be called for where scaling by the spent brine is a potential problem for the liquid disposal system. Binary plants are being used for some very low temperature reservoirs, particularly in the People's Republic of China, albeit in extremely small units. A large-scale pilot plant of the binary type is being planned for the Imperial Valley of California.

Summary Table 1 contains a summary of the geothermal power plants installed around the world by country.

Table 1. Summary of Installed Geothermal Power Plants

Country	No. of Units	Installed Capacity, MW
China	9	5.186
El Salvador	3	95
Iceland	2	32
Indonesia	1	0.25
Italy	37	420.6
Japan	7	166
Mexico	4	150
New Zealand	14	202.6
Philippines	6	224.2
Turkey	1	0.5
U.S.S.R.	1	5
United States	15	809.2
		2110.536 MW

It may be seen that the U.S. holds the lead in installed capacity. Futhermore, the average unit size in the U.S. is about 54 MW, whereas in Italy, which operates the most units, the average size is only 11 MW. It should also be pointed out that the actual capacities of the units in Italy and in New Zealand, the fourth largest geothermal power country, are well below the installed values owing to decline of the reservoirs. Italian gothermal plants have been operating since 1904 and those in New Zealand since 1958. The most rapid gains are taking place in the Philippines, now the third largest in installed capacity, where 220 MW have been brought on-line within the last 16 months.

Now we shall present more detailed tabular surveys of the geothermal plants in each country along with a few brief remarks in each case.

China (See Table 2) We have recently learned about the geothermal activities in the People's Republic of China. A more thorough study is contained in a companion paper in these Proceedings by this author.

Table 2. CHINA

Plant	Year	Type	Rating, MW
Fengshun			
Unit 1	1970	1-Flash	0.086
Unit 2	1971	Binary: i-C_4H_{10}	0.200
Unit 3	1979	n.a.	0.250
Huailai	1971	Binary: C_2H_5Cl; C_4H_{10}	0.200
Wentang	1971	Binary: C_2H_5Cl	0.050
Huitang	1975	1-Flash	0.300
Yingkou	1977	Binary: Freon; C_4H_{10}	0.100
Yangbajing			
Unit 1	1977	1-Flash	1.0
Unit 2	1979	1-Flash	3.0
		Total, installed	5.186 MW

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El Salvador (See Table 3) Ahuachapán is the site of one of the most successful flash-steam plants in the world. It is the subject of a companion paper in these Proceedings by this author.

Iceland (See Table 4) Only two units are in operation, one at Krafla and one at the district heating plant at Svartsengi. The 30 MW unit at Krafla is a double-flash plant that has experienced considerable difficulty in maintaining an adequate and stable flow of geofluid. The active seismic nature of the field has contributed to the operational problems. The plant can produce only a fraction of its rated capacity. Two 1 MW steam turbines are incorporated into the Sudurns district heating plant at Svartsengi near Grindavik on the Reykjanes peninsula in southwestern Iceland. The turbines receive a portion of the steam flashed and separated from the hot geothermal wells, the bulk of the steam being supplied to a number of heat exchangers to raise the temperature of water from cold wells. The power is used on site to run pumps and other station auxiliaries.

Italy (See Table 5) All of Italy's geothermal electricity comes from dry steam reservoirs in three regions: Larderello, Travale, and Monte Amiata. Considerable exploration is underway to locate and define the liquid-dominated reservoirs that exist in the country. It is estimated that about 2000 MW may eventually come from liquid-dominated fields. The best areas lie on the southwestern side of the Italian peninsula and include the regions: Monti Volsini, Monti Cimini, Monti Sabatini, Colli Albani, Roccamonfina, Campania Ovest and Monte Vulture.

Japan (See Table 6) The first geothermal plant in Japan was the dry steam plant at Matsukawa. Since then several plants have been built on liquid-dominated reservoirs, most of these being of the flash-steam type. Two experimental binary plants were built, tested and dismantled. One of these, at the Otake field, was of the "steam-assist" type that used an advanced, multistage flash heater to generate saturated isobutane vapor for use in a radial-inflow turbine. The waste heat rejection system incorporated a dry cooling tower with a liquid assist. The other plant at Mori (Nigorikawa) on the northern island of Hokkaido employed refrigerant-114 as the working fluid, used an axial flow turbine, and more conventional shell-and-tube heat exchangers at both the hot and cold sides of the cycle. The newest plant in Japan is a small 1 MW unit to supply the needs of the Suginoi resort hotel at Beppu on the island of Kyushu. This is in a world famous hot springs area that was the

Table 3. EL SALVADOR

Plant	Year	Type	Rating, MW
Ahuachapán			
Unit 1	1975	1-Flash	30
Unit 2	1976	1-Flash	30
Unit 3	1980	2-Flash	35
Berlín	Future	Flash	100 (Est.)
Chinameca	Future	Flash	100 (Est.)
Chipilapa	Future	Flash	50 (Est.)
San Vicente	Future	Flash	100 (Est.)
		Total, Installed	95 MW

Table 4. ICELAND

Plant	Year	Type	Rating, MW
Námafjall	1969	1-Flash	3*
Krafla			
Unit 1	1978	2-Flash	30
Unit 2	Future	2-Flash	30
Svartsengi	1978	1-Flash	2
		Total, Installed	32 MW

*Dismantled after earthquake damage.

Table 5. ITALY

Plant*	Year	Rating, MW
Larderello		
Unit 2	c.1946	69.0
Unit 3	1969	120.0
Gabbro	1960	15.0
Castelnuovo	n.a.	50.0
Serrazzano	n.a.	47.0
Lago 2	n.a.	33.5
Sasso Pisano	n.a.	15.7
Monterotondo	n.a.	12.5
Travale	1973	15.0
Piancastagnaio	1969	15.0
Others (8 units)	-	27.9
	Total, Installed	420.6 MW

*All plants use dry steam; turbines are either condensing or noncondensing.

site of earliest Japanese attempts to harness geothermal energy in the 1920's. Geothermal plants in Japan must meet very tough environmental restrictions owing to their location in scenic national parks.

Mexico (See Table 7) Fifteen years after the beginning of the exploration of the Cerro Prieto field, the first power unit started producing electricity. Now there are four units generating 150 MW in a very reliable fashion, with a fifth unit of 30 MW under construction. This will complete the development of Cerro Prieto I. Additional development will necessitate the construction of a new plant complex in another part of the field. Some of the electricity from the plant is being sold to the U.S. for use in communities in southern California.

New Zealand (See Table 8) Although New Zealand was the first country to exploit successfully liquid-dominated reservoirs, it has not brought a new unit on-line since 1963 when the last unit started up at Wairakei. The installed capacity there is 192.6 MW, but it has never reached that value. Peak power was 173 MW in 1964-65; currently it produces about 145 MW and it is expected to generate about 125 MW indefinitely. A new plant named Ohaki at the Broadland-Ohaki field has been in the planning stage for a long time but various institutional impediments have caused delays in its implementation. The plan is to construct two 50 MW double-flash units at the site with an additional 50 MW possibly for the future. It appears that 1984 is the most optimistic date for inauguration of the first unit.

Philippines (See Table 9) Geothermal development is proceeding full tilt in the Philippines. Two sites, Makiling-Banahaw and Tiwi, both on the northern island of Luzon, are the locations of large power complexes. Already two units of 55 MW each are operating at both of these sites. [Personal communication, Dr. L. Rivero.] The installed capacity at each plant is expected to double by 1982. On the island of Leyte a 3 MW wellhead unit has been running since 1977 taking steam from one well in the Mahiao area. Three 37.5 MW are planned for this site. Although double-flash units will be specified, it is likely that initially they will be operated as single-flash units owing to uncertainties about the economics,and potential problems with silica deposition in the waste brine.

Table 6. JAPAN

Plant	Year	Type	Rating, MW
Matsukawa	1966	Dry Steam	20
Otake	1967	1-Flash	10
Onuma	1973	1-Flash	10
Onikobe	1975	1-Flash	25
Hatchobaru	1977	2-Flash	50
Kakkonda	1978	1-Flash	50
Otake Pilot*	1978	Binary: $i\text{-}C_4H_{10}$	1
Mori Pilot*	1978	Binary: R-114	1
Suginoi (Hotel)	1980	1-Flash	1
Nigorikawa	1981	1-Flash	50
Kuzeneda	Future	Flash	50 (Est.)
Kumamoto	Future	2-Flash	55 (Est.)
	Total, Installed		166 MW

*Tests Complete; Plants Dismantled.

Table 7. MEXICO

Plant	Year	Type	Rating, MW
Cerro Prieto I			
Unit 1	1973	1-Flash	37.5
Unit 2	1973	1-Flash	37.5
Unit 3	1979	1-Flash	37.5
Unit 4	1979	1-Flash	37.5
Unit 5	1982	2-Flash	30.0
Cerro Prieto II	Future	Flash	110 (Est.)
	Total, Installed		150 MW

Table 8. NEW ZEALAND

Plant	Year	Type	Rating, MW
Wairakei			
Station A	1958-1962	Multiflash	102.6
Station B	1962-1963	2-Flash	90.0
Kawerau	1961	1-Flash	10.0
Ohaki	1984	2-Flash	100.0
	Total,Installed		202.6 MW

Table 9. PHILIPPINES

Plant	Year	Type	Rating, MW
Tongonan			
Wellhead Unit	1977	1-Flash	3.0
Unit 1	1980	2-Flash	37.5
Unit 2	Future	2-Flash	37.5
Unit 3	Future	2-Flash	37.5
Makban (Makiling Banahaw)			
Wellhead Unit	1977	1-Flash	1.2
Unit 1	1979	2-Flash	55.0
Unit 2	1979	2-Flash	55.0
Unit 3	1981	2-Flash	55.0
Unit 4	1982	2-Flash	55.0
Tiwi			
Unit 1	1979	2-Flash	55.0
Unit 2	1979	2-Flash	55.0
Unit 3	1980	2-Flash	55.0
Unit 4	1980	2-Flash	55.0
Other Sites	Future	Flash	775
	Total, Installed		224.2 MW

United States (See Table 10) The largest geothermal power complex in the world is at The Geysers where three utilities are involved in several projects. The Pacific Gas and Electric Company now operates 14 units (Nos. 1-13 and 15), accounting for 798 MW. When unit 14 comes on-line later in 1980 the total will reach 908 MW. Before the end of 1984 it is planned to put an additional 660 MW on-line. The Northern California Power Agency plans to operate two units at The Geysers. Unit 2 will consist of two 55 MW turbines in a single power house and is expected in 1981. It will be followed in 1983 by a 66 MW unit. The Sacramento Municipal Utility District is moving ahead with SMUDGEO no. 1, a 55 MW unit scheduled for commercial start-up in December 1983. In addition the California Division of Water Resources has plans to build two plants, each of 55 MW, at Bottle Rock and South Geysers, with expected start-up dates in 1983. Stringent air pollution regulations make it necessary to install hydrogen sulfide abatement systems on all plants. Up-stream treatment will most likely be required to avoid air quality degradation during out-of-service periods when venting of steam takes place. Reinjection of condensate is standard practice.

Table 10. UNITED STATES

Plant	Year	Type	Rating, MW
The Geysers			
PG&E 1-12,15	1960-1979	Dry Steam	663
PG&E 13,14	1980	Dry Steam	245
PG&E 16-21	1982-1984	Dry Steam	660
NCPA No. 1	1983	Dry Steam	66
NCPA No. 2	1981	Dry Steam	110
SMUDGEO 1	1983	Dry Steam	55
Bottle Rock	1983	Dry Steam	55
South Geysers	1983	Dry Steam	55
East Mesa - Magmamax	1980	Dual Binary: C_3H_8; i-C_4H_{10}	11.2
East Mesa - SDG&E	1980,82	1- and 2-Flash	48
Brawley - SCE	1980	1-Flash	10
Niland - SCE	1982	1-Flash	10
Niland - SDG&E	1982	Flash	50
Heber - SCE	1982	2-Flash	50
Heber - SDG&E	Future	Binary: mixt. i-C_5H_{12}; i-C_4H_{10}	50
Westmorland	Future	2-Flash	50
Raft River, Idaho	1980	Double Binary: i-C_4H_{10}	5
Puna, Hawaii	1980	1-Flash	5
Baca No. 1, New Mexico	1982	1-Flash	50
Roosevelt H.S., Utah	Future	Flash	55
Desert Peak, Nevada	Future	Flash	50
		Total, Installed	809.2 MW
		Total, Projected	2353.2 MW

Although the liquid-dominated portion of the field has yet to be defined or even characterized, it is expected that about 700 MW could be generated from that part of the field by 1990. In this regard it should be noted that it takes about 8 kg/h (18 lbm/h) of dry steam to generate 1 kW of electric power, about one-quarter of which ends up as condensate to be reinjected (assuming a shell-and-tube condenser is used). On the other hand a flash-steam plant requires about 45 kg/h (100 lbm/h) of geofluid per 1 kW of power, of which about 87% must be reinjected. Thus, to generate the same power, a flash plant must reinject almost 20 times more liquid than a dry steam plant.

From Table 10 it can be seen that a variety of projects are under way in the Imperial Valley of southern California, which according to some estimates holds the potential for about 9000 MW. Resources in at least five other states are expected to be exploited for power in the near future.

Other Countries (See Table 11) Of the countries listed only the Soviet Union has a plant of any size (5 MW) in operation. Indonesia is beginning to develop its gigantic geothermal potential by means of small wellhead units. Turkey has a tiny wellhead generator at Kızıldere, but severe scaling has prohibited any further development there. The Olkaria field in the Rift Valley of Kenya in east Africa seems to be a good prospect, and plans are moving ahead for the Kenya Electric Power Corporation to build a 15 MW plant. A "total energy" system is planned for the Portuguese island of São Miguel in the Azores. The geothermal energy with which the island abounds will be put to use to generate power (3 MW), provide heating and refrigeration, as well as for agricultural, horticultural and aquacultural uses.

Table 11. OTHER COUNTRIES

Country	Plant	Year	Rating, MW
Chile	El Tatio	Future	15
Costa Rica	Miravalles	Future	40 (Est.)
Guatemala	Amatitlán	Future	50 (Est.)
Honduras	Pavana	Future	50 (Est.)
Indonesia	Kamojang	1978	0.25
	Kamojang	Future	100 (Est.)
	Dieng	1980	2
Kenya	Olkaria	1982	15
	Olkaria	Future	30 (Est.)
Nicaragua	Momotombo	Future	30 (Est.)
Panama	Cerro Pando	Future	30 (Est.)
Portugal (Azores)	São Miguel	1980	3.0
Turkey	Kızıldere	Future	14 (Est.)
USSR	Pauzhetka	1967	5
	Other Sites	Future	78 (Est.)

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