SMALL GEOTHERMAL POWER PROJECT EXAMPLES

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WHAT ARE SMALL GEOTHERMAL POWER PROJECTS?

According to Vimmerstedt (1998 - and this Bulletin), small geothermal power projects are less than 5 MWe. Others (Entingh, et al., 1994a and b, and Pritchett 1998a) refer to a range of 100 to 1000 kWe as "small." In this article, we will use the 5 MWe definition as small.

Small power projects, often called "village power" and sometimes as "off-grid power," can serve rural people in developing countries; since, this market may be best served by many small generating units, rather than fewer larger ones. For examples, at 50 watts per household for lighting, 1 MWe could serve 20,000 households (Cabraal, et al., 1996). Entingh, et al., (1994a) estimates that the demand for electric capacity per person at off-gird sites will range from 0.2 kW in less-developed areas to 1.0 kW or higher in developed areas. Thus, a 100-kWe plant could serve 100 to 500 people, and a 1,000-kWe plant would serve 1,000 to 5,000 people. However, one of the main problems with small geothermal power projects is that they are unlikely to obtain financing due to high cost per installed kW and low rate of return; thus, these remote projects often must be subsidized by the government to encourage local economic development.

Alternative power at remote locations, which is usually provided by diesel generations, can be much more expensive per kWh than geothermal, as the fuel transportation costs are high. For example at Fang, Thailand, a 300-kWe geothermal binary plant supplies power from 6.3 to 8.6 cents/kWh, compared to the alternative of diesel generators at 22 to 25 cents/kWh (Schochet, 1998).

Small geothermal power units are already common, though not always in remote applications. They are sometimes used within larger geothermal developments, either because they are cost effective, because they fit with incremental development plans, or because they were installed early in a site's development.

According to Vimmerstedt (1998):

> "Small geothermal units are used in larger developments for several reasons. First, a modular approach can be less expensive overall because of shipping and handling costs. Second, small modules increase reliability and improve flexibility when adapting to changing well and system performance. Third, a small, remote well is sometimes located so far from other wells that a power plant sized to the remote well costs less than transmission pipes for the fluid [to a larger centralized plant]. Well spacing must take reservoir characteristics into consideration, and so can not be optimized for power plant size alone."
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> "Small units are also found at larger sites where they were used during early phases of site development. Placing a small plant at the site of a larger anticipated development supplies electricity during development of the field [and can provide a return on investment sooner. Also, if the initial electricity demand at the site is low, then the small-scale plant can be fully utilized until a larger one is justified. When there is a problem in resource development, a smaller plant can utilize resource confirmation holes, or shallow, less expensive wells]. Small systems at large sites have advantages over remote ones in that the financing is often secured for the entire project. The resource is confirmed for that project, operation and maintenance infrastructures are readily available, a grid either exists or is constructed for the large project, and sufficient base load is available."
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> "A critical distinction between the application of small geothermal plants within a larger site and application in a remote area is the load-following ability of small geothermal systems. Although geothermal plants can follow loads, this ability is limited and cost of a reduced-load factor is high because much of the cost of the geothermal power plant is capital cost. Remote areas and small grids generally have low base loads, so the contrast between achievable capacity factors (low cost per kWh) for large versus small grid applications is major."

TECHNOLOGY FOR SMALL GEOTHERMAL POWER SYSTESM

Vimmerstedt (1998) reports:

> "The most likely technology choices for small geothermal power plants are flash steam and binary cycle. Dry steam systems

> are unlikely to be used in small geothermal plants because dry steam resources are thought to be rare."
>
> "The advantages of flash steam systems in small applications include the relative simplicity and low cost of the plant. In contrast to binary plants, they require no secondary working fluid. However, when the geothermal fluid is flashed to steam, the solids that precipitate can foul equipment, and pose health, safety and disposal problems. If steam contains hydrogen sulfide or other contaminants, it poses an air quality problem when released directly to the atmosphere. Treating non-condensable gases in the condensing design adds complexity, maintenance, and disposal requirements (Forsha and Nichols, 1997). Flash systems are most often used where higher temperatures (above 300°F - 150°C) are available; although, a low-pressure turbine design for lower-temperature flash plants (230°F - 110°C) has been proposed (Forsha, 1994) and feasibility of lower-temperature flash plants have been studied (Pritchett, 1998b)."

The advantage of binary technology is that, in small-size ranges, modular binary units are readily available, and they can operate at lower temperatures (below 300°F - 150°C and down to around 180°F - 82°C). One of the early experimental binary plants, Paratunka on the Kamchatka Peninsula of Siberia, operated at 178°F (81°C). Because the geothermal fluid can be contained in a separate loop, precipitation and environmental effects of the geothermal fluid can be controlled. Conversely, secondary working fluids may be hazardous and difficult to supply. Other disadvantages of binary designs are the higher capital cost and greater complexity of plants (Forsha and Nichols, 1997).

The choice between flash steam and binary designs for small geothermal plants will be site specific, and will depend on resource temperature, chemical composition of the geothermal fluid and maintenance preferences.

ADVANTAGES OF SMALL GEOTHERMAL BINARY POWER PLANTS

Entingh, et al., (1994a) gives some of the reasons why small geothermal binary plants can be successful in "off-grid" or "village power" situations.

1. The plants are very transportable. For 100 to 300 kWe plants, the entire plant, including the cooling system, can be built on a single skid that fits in a standard trans-ocean container.

2. Binary power plants can accommodate a wide range of geothermal reservoir temperatures, 212 to 300°F (100 to 150°C). Above 300°F (150°C) flashed- steam plants usually prove less expensive than binary plants.

3. The demand for electric capacity per person at off-grid sites will range from 0.2 kWe to 1.0 kWe.

4. The design of the power plants and their interactions with the wells includes provisions for handling fluctuating loads, including low-instantaneous loads ranging from 0 to 25 percent of the installed capacity.

5. Power plant designs emphasize a high degree of computer-based automation, including self starting. Only semi-skilled labor is needed to monitor plant operation, on a part-time basis. Complete unattended operation might also be possible, with plant performance monitored and controlled remotely through a satellite link.

6. The system releases no greenhouse gases to the atmosphere. There may be very small leakages of the binary-cycle working fluids, but these do not contain chlorine or fluorine and are non-greenhouse gases.

7. All wells could be drilled by truck-mounted rigs, either heavy-duty water-well rigs or light-duty oil/gas-well rigs. At very remote sites, both drilling rig and power system equipment can be transported by helicopter.

8. Injection well costs can be relatively low. For small systems, because the geothermal flow rates are relatively small, rarely will there be a need to inject the fluid back into the production reservoir. Any shallow aquifer not used for drinking water could be used for reinjection. If the fluids are clean enough to be disposed of on the surface, then the disposal costs can be quite low.

9. Field piping costs are low. All wellheads are located near the power plant module. Inexpensive plastic or carbon steel pipe is used to connect wells.

10. Geothermal direct-heat applications can be attached to these electric systems inexpensively. Applications needing temperatures not higher than 150°F (65°C) might be attached (cascaded) in series to the power-plant fluid outlet line.

11. Critical backup need is estimated to range from one to five percent of the installed geothermal capacity. The very high availability factors for geothermal systems, on the order of 98 percent, substantially

reduce the cost of special features needed to ensure that power is always available. Small critical loads such as medical refrigeration or pumps for drinking water could be supported against brief unscheduled outages by a diesel engine or by small amounts of battery storage.

COSTS OF SMALL GEOTHERMAL POWER PLANTS

Ultimately, the costs of small geothermal power plants will determine their potential market. Reported costs for small plants are rare. Those that do are located at large fields and are in the $0.05 to $0.07/kWh range, for units in the 1 to 5 MWe range (GRC, 1998).

Entingh, Easwaran, and McLarty (1994a and 1994b) developed a model called GT-SMALL for small, binary geothermal systems in the 100 to 1000-kWe size range. They evaluated reservoir temperatures of 212 - 284°F (100 - 140°C), production well depth of 656 - 3,281 ft (200 - 1,000 m), and injection well depth of 656 - 1,640 ft (200 - 500 m). Technical costs at the busbar for this evaluation ranged from $0.047 to $0.346/kWh. An example is shown below for a system cost of $0.105/kWh.

Technical	Resource Temperature	248°F (120°C)
	System Net Capacity	300 kWe
	Number of Wells	2
	Capacity Factor	0.8
	Plant Life	30 years
	Rate of Return on Investment	12%/yr
	kWh/yr produced	2.10 million
Capital Costs	Exploration	$200,000
	Wells	325,000
	Field	94,000
	Power Plant	659,000
	TOTAL	$1,278,000
	Plant cost/installed kW	$2,200
	Annual capital recovery cost	$158,650
O&M Costs	Field	$32,000
	Plant	26,000
	Backup System	5,000
	TOTAL/yr	$63,000

For the range of project sizes investigated, the capital costs represented about 55 to 80% of the cost of electricity generation, and operation and maintenance costs represented about 30 to 45% (Entingh, 1991). The accuracy of GT-SMALL is difficult to evaluate given the scarcity of remote applications of small systems. The $0.05 to $0.07/kWh prices reported in the GRC database are comparable to the modeled cost estimates at the 1 MWe size.

EXAMPLES OF SMALL GEOTHERMAL POWER PLANTS

The generating potential of a geothermal resource can be estimated from the temperature and flow rate as shown in Figure 1 (Nichols, 1986). This figure gives the net power output which accounts for the parasitic loads such as due to the condenser and feed pump power requirements. Single modular units can handle flow rates up to 1000 gpm (63 l/s), with multiple units required to accommodate greater flow rates and produce proportionately larger output power. The output power from two-phase water-steam or steam alone is much greater than the curves shown for liquid in Figure 1. Temperatures above 350°F (175°C) can also be accommodated with high efficiencies by making minor modifications to the modular units. However, it should be pointed out that the conversion efficiency is quite low at the lower temperature and therefore, the cost of power becomes higher. Reservoir temperature is the physical factor to which overall project costs are most sensitive. A schematic of the binary cycle (Rankine cycle) is shown in Figure 2 (Nichols, 1986).

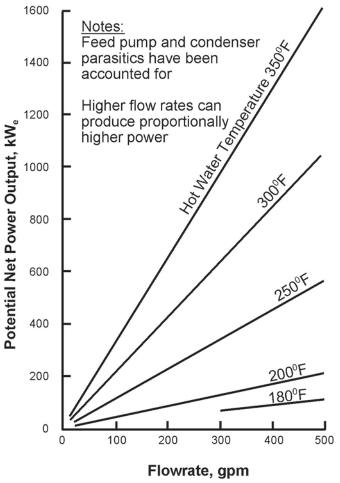

Figure 1. Potential power generation of a geothermal resource (Nichols, 1986).

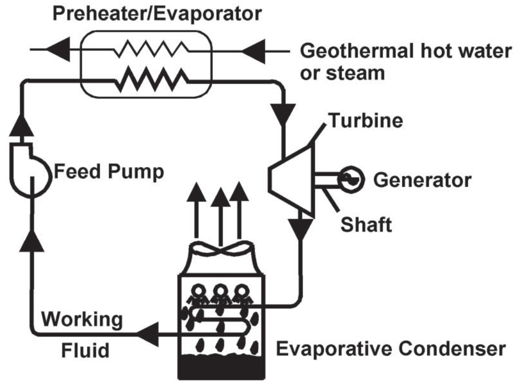

Figure 2. Schematic of the binary cycle (Rankine cycle) (Nichols, 1986).

Additional details of binary plant efficiency and operating characteristics can be found in Ryan (1982, 1983 and 1984).

There are approximately 50 geothermal power plants in the world at or below 5 MWe, including some bottoming cycle plants associated with large plants. Some of these are described in more detail in the following section.

1. **Amedee Geothermal Venture binary plant** (Fig. 3), located in northern California near Susanville was placed in operation in 1988. The plant consists of two units of one MWe each with a total net output of 1.5 MWe. The resource temperature is 219°F (104°C), and well depth of 850 ft (260 m) with a maximum flow rate of 3,200 gpm (205 l/s). The plant uses R-114 working fluid and cooling ponds for makeup water. The units were designed by Barber-Nichols Engineering Company of Arvada, Colorado. They have an availability is 90% and the system is remotely monitored by telephone line.

   Geothermal fluids from two wells are used to operate the plant, and surface discharge is used to dispose of the spent fluid. This is possible because the geothermal fluids have a very low salinity and a composition the same as area hot spring water.

Figure 3. Amedee Geothermal Venture 2-MWe binary plant.

2. **Wineagle Developers binary plant** (Fig. 4), also located in northern California near Susanville was placed in operation in 1985. The plant consists of two binary units of total gross capacity of 750 kWe and a net output of 600 kWe. A 1,300-ft (400-m) deep well is pumped to produce 1000 gpm (63 l/s) of 230°F (110°C) water. The spent fluid at 1,000 ppm total dissolved solids, is disposed on the surface. It has an availability of 98%, a gross efficiency of 8.5% and a capacity factor of 109%. The units were designed by Barber Nichols Engineering Company of Arvada, Colorado and the installed cost was about $2,100/kWe (Nichols, 1986).

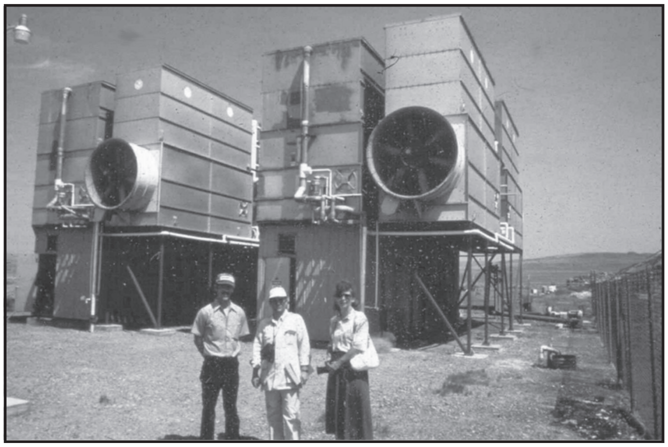

Figure 4. Wineagel Developers 750-kWe binary plant.

   The plant is completely automated. The entire plant, including the well pump, is controlled by either module. By pushing one button on the module control panel, the plant will start, synchronize to the power line and continue operation. If the power line goes down, the module and the downhole pump immediately shut down, since no power is available for its operation. When the power line is re-energized, the modules restart the downhole pump, then bring themselves on line. The two, identical power plant modules are mounted on 10-ft by 40-ft (3-m x 12-m) concrete slabs. Each unit is self-contained and includes the heat exchanger, a turbine generator and controls (Fig. 5). The fans on top of the units are evaporative condensers.

3. **TAD's Enterprises binary plants units No. 1 and No. 2**, located at Wabuska, Nevada, were placed in operation in 1984 and 1987 respectively (Fig. 6). They are rated at 750 kWe and 800 kWe, and are supplied heat from two geothermal wells at 220°F (104°C), pumped at 850 and 950 gpm (54 and 60 l/s) respectively. They use water cooled condensers fed from a cooling pond. The operation is automatic and unmanned, with maintenance only as required. The units were manufactured and supplied by ORMAT International, Inc. of Sparks, Nevada.

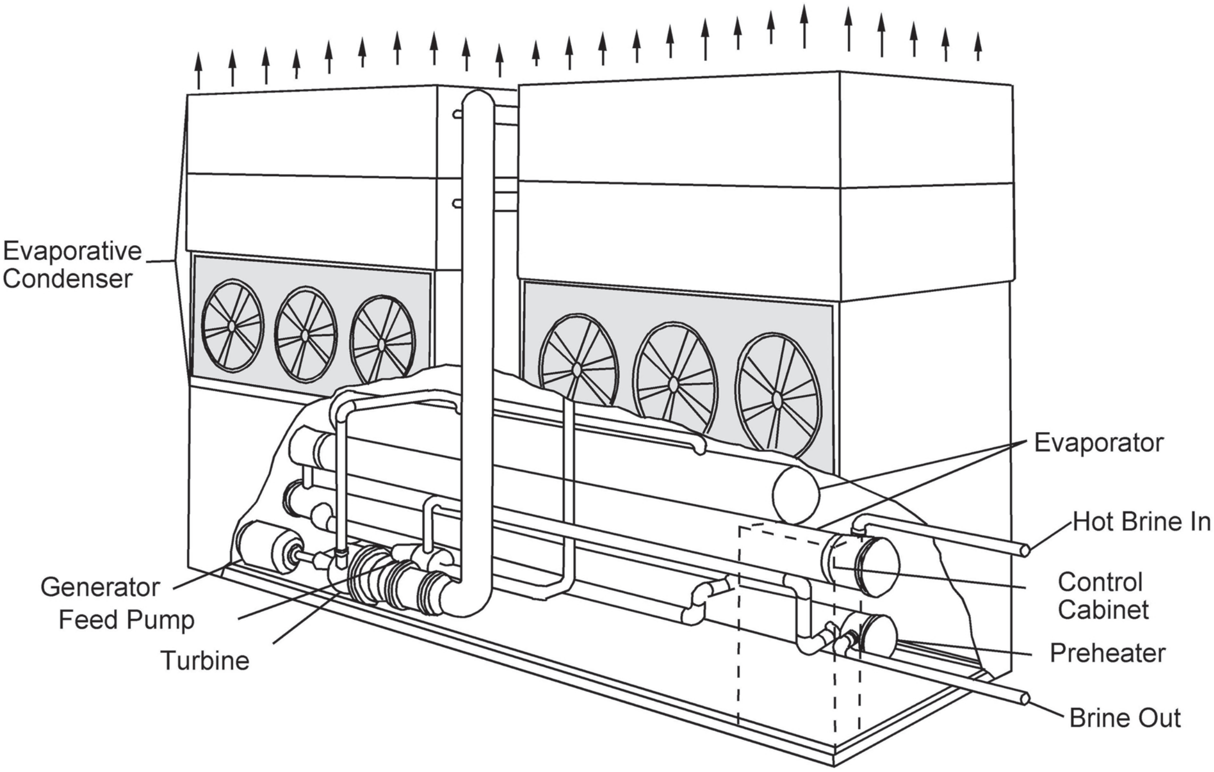

Figure 5. Schematic of one of the Wineagle modular units (Nichols, 1986).

Figure 6. TAD's unit No. 1 - 750-kWe modular binary power plant unit.

The units originally used Freon 114 as the working fluid. From 1985 to 1990, there were minor maintenance outages, and very cold weather in 1990, during a power trip caused freezing in the condenser and pumps. The plant was repaired and operated until 1996, when the unavailability of Freon 114 caused a shutdown from 1996 to 98. It was then converted to Iso-Pentane and reconditioned in 1998. Commercial operation was re-established in 1998. As it turns out, the Iso-Pentane working fluid does not mix with water; thus, water leakage is not a problem as it was with Freon 114. Gene Culver (1987) of the Geo-Heat Center conducted an evaluation of unit No. 1 while it was still using Freon 114. He found that the parasitic load (well pump, feed pump circulation water pump and other loads) amounted to 241.6 kWe and the net thermal efficiency ranged from 6.5% to 9.4%, depending on the cooling water temperature (which varied from 65 to 55°F - 18 to 13°C).

4. **Empire Geothermal Project binary plant**, San Emidio desert near Empire, Nevada, was placed in operation by OESI in 1987 (later called OESI/AMOR). The plant consists of four one-MWe modules, supplied by ORMAT International, Inc. of Sparks, Nevada (Fig. 7). The units use water-cooled condensers with a spray pond. The rated net output is 3.6 MWe, and the units produced from 15 to 7.5 GWh annually through 1996. Two production wells at 278°F (137°C) were initially used. By 1989, injection into the reservoir started to cool the wells and by 1996, the wells were only producing 237 and 253°F (114 and 123°C) respectively, with energy output significantly reduced. In 1994, Integrated Ingredients dedicated their new onion and garlic processing plant and used a well at 266°F (130°C) pumping up to 900 gpm (57 l/s) from the same reservoir. They founded the local community of "Grunion" due to the large number of employees on site (Lund and Lienau, 1994).

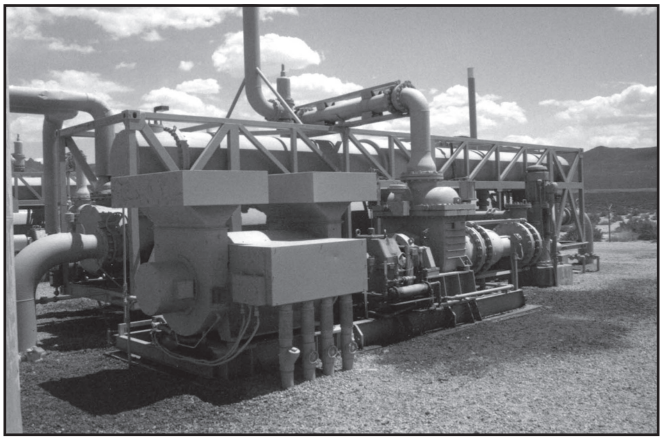

Figure 7. OESI/AMOR II binary plant near Empire, Nevada.

The resource was acquired by Empire L.P. in 1996. The cooler production wells were then shut-in and additional geothermal fluid supplied at 306°F (152°C) from a new well. A three-cell cooling tower was also added which resulted in the net output increasing to 3.85 MWe in 1998. The power plant is, thus, operating above design capacity, and produced almost 18 GWh in 1997. The onion/garlic dehydration plant is still operating at full capacity using the same resource.

5. <u>**Cove Fort Geothermal No. 1**</u>, Sulphurdale, Utah, was commissioned in 1985 with a steam turbine added in 1988. This 4.8-MWe power plant is comprised of four ORMAT Energy Converter (OEC) modular units and one back-pressure steam turbine. The OEC units operate on condensing steam from the exhaust of the back pressure steam turbine. The four modular binary units, with a capacity of 0.8 MWe each or 3.2 MWe total, are housed in a single building which also contains the computer unit controls (Fig. 8) (GRC, 1985). The binary units operate on dry steam from two production wells producing from 1,200 feet (365 m). The combined production from both wells is in excess of 100 tons per hour. The geothermal steam is at 280°F (138°C) and the units are water cooled. The field and plant were developed by Mother Earth Industries and the city of Provo Municipal Utility is the power purchaser. Real-time system and operating data are received by the city of Provo's main control center, facilitating remote performance monitoring and service diagnosing.

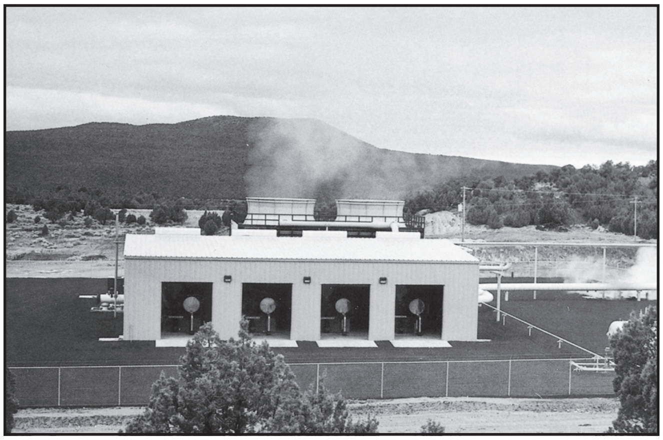

Figure 8. Cove Fort Geothermal No. 1 - 4.8-MWe combined power plant.

6. <u>**Soda Lake Geothermal Power Plant No. 1**</u>, Fallon, Nevada, commenced generating power in 1988. This is a 3.6-MWe binary power plant comprising three ORMAT OECs modular units (Fig. 9). The power plant operates on a liquid dominated resource at 370°F (188°C). The power plant was designed and built on a turnkey basis by ORMAT, is owned by Constellation Developments, Inc. (CDI) and ORMAT Energy Systems, Inc. (OESI), and is operated by OESI, with power sold to Sierra Pacific Power Company SPPC. The geothermal field was developed by Chevron Resources. The units are water cooled and produce a net generated power of 2.75 MWe (Krieger, 1989). Two hundred tons of geothermal fluid per hour are delivered to the plant. The plant output voltage is 43.8 kV.

Figure 9. Soda Lake 3.6-MWe binary power plant No. 1.

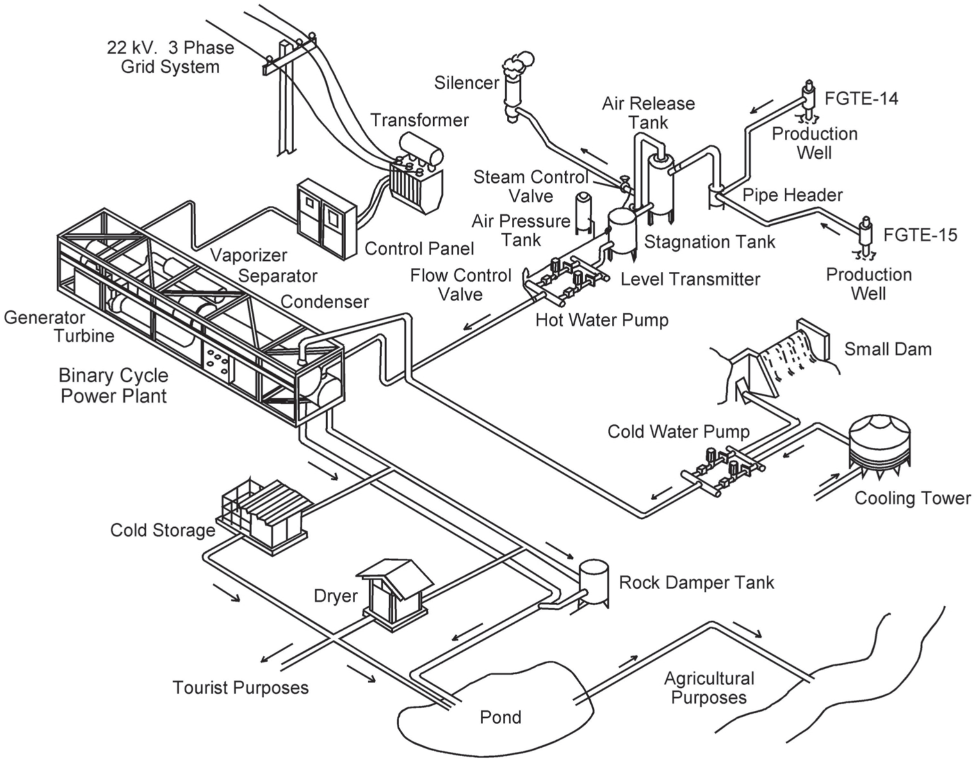

Figure 10. Pictorial diagram of Fang, Thailand 300-kW binary power plant.

7. **Fang Geothermal binary power plant**, located near Egat, Thailand, was commissioned in 1989. This is a single-module 300-kWe plant that has a water cooled condenser with once-through flow (Fig. 10 - after Ramingwong and Lertsrimongkol, 1995). The net power output varies with the season from 150 to 250 kWe (175 kWe average). This is a multipurpose project which in addition to electricity production, the geothermal fluid also provides hot water for refrigeration (cold storage), crop drying and a spa. The artesian well provides approximately 130 gpm (8.3 l/s) of 241°F (116°) water. The well requires chemical cleaning to remove scale about every two weeks. Plant availability of 94% and the estimated power cost is from 6.3 to 8.6 cents/kWh. This is very competitive with diesel generated electricity which runs 22 to 25 cents/kWh. Plant was supplied by ORMAT International, Inc. of Sparks, Nevada.

8. **Nagqu Geothermal binary plant**, Tibet, Peoples Republic of China, was installed and commissioned in 1993. This plant is an air-cooled module rated at 1.3 MWe, with a gross output of 1.0 MWe, which was funded by UNDP. Geothermal fluid is supplied from two wells at 230°F (110°C) with a fluid flow of 1,100 gpm (69 l/s). The plant is located at 14,850 feet (4,526 m) elevation, and thus the air-cooled condenser had to be sized and especially adapted for the thin air at the site which doubled the size of the condenser compared to a similar plant at sea level (Cuellar, et al., 1991). In addition, the long overland transportation of the equipment from the port of arrival in China also called for special design of the equipment packaging for over land transport. Electrical and control equipment had to be especially designed to withstand the rigorous environmental conditions at the site. The plant was provided by ORMAT International, Inc (Fig. 11).

Figure 11. Nagqu 1.0-MWe power plant in Tibet at 14,850 ft. (4,526 m) elevation.

The power plant initially operated for 6,400 hours, and then was shutdown due to failure of the downhole pumps. The cable failed after 15 days of operation and the seals after seven months of operation. The wells were then operated without pumps and experienced severe scaling. The downhole pumps were replaced and the plant recommissioned in August of 1998. It is currently operating satisfactorily.

This is the only completely stand-alone, off-grid geothermal power project in operation. The town of Nagque, which is a political, cultural, economic and traffic center of the North Tibet Plateau, has a population of about 20,000. Prior to 1993, there were 10 diesel generators with a total nominal capacity of 1.68 MWe supply electricity to the area. This capacity could only satisfy the lighting needs of the local organizations and some inhabitants, lasting only 4 to 5 hours every night due to high production cost. The others had to light their houses with candles or buttered lamps. This shortage seriously restricted the further development of the local economy. The geothermal plant, estimated to provide a net power of 840 kWe, will assist the local economic development (Cuellar, et al., 1991).

A two MWe power plant is report at Langiu (Yangyi ?) is reported installed in Tibet near the Yangbaijain geothermal field in Tibet (Wang, 1998).

9. **Eastern China experimental binary plants**. Recognizing the importance of geothermal energy as an alternative new and renewable energy source, experimental geothermal power stations were set up in eastern China from 1970 to 1982 (Cai, 1982 and Wang, et al., 1995). These plants are summarized in the table below. It became clear that the capacity of all the experimental geothermal power stations was too small and the efficiency too low due to the low temperature of the thermal water for power generation. At present, only Dengwu and Huitang are still in operation (part time), and the remaining were shut down in the early 1990s.

10. **Tu Chang binary power plant**, Taiwan, connected to the grid in 1987. This is a 300 kWe, water cooled ORMAT OEC that uses a liquid dominated resource at 266°F (130°C) (Fig. 12). The project is owned and operated by the Industrial Technology Research Institute and the power is sold to the Taiwan Power Company. It has a CO_2 recovery system, as the noncondensable gases are two percent by weight. The project, including the 1,640-foot (500-m) deep well, cost $2 million and the power is sold at four cents/kWh.

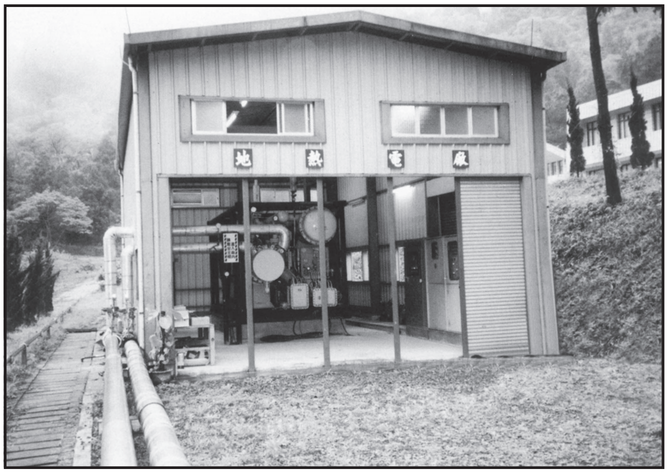

Figure 12. Tu Chang 300-kWe binary power plant, Taiwan.

11. **Tarawera binary plants, Kawerau**, New Zealand, were commissioned in late 1989 and officially opened in early 1990 after a record short construction time of 15 months (Tilson, et al., 1990). The two ORMAT energy convertors (OEC) (Fig. 13) receive waste water from Kawerau 21 flash plant at about 342°F (172°C) and 116 psi (8 bar) (Freeston, 1991). Heat rejection from the plant is by a forced draft air condenser situated above the OEC units. Each unit has a gross output of 1.3 MWe; a total of 2.6 MWe, of which about 13% is used by auxiliaries, pumps, fans, etc.,

Plant Name	Province	Date Commissioned	Type	Capacity	Water Temp.
Dengwu No. 1	Guangdong	1970	FS	86 kW	196°F (91°C)
No. 2	Guangdong	1977	B	200 kW	196°F (91°C)
No. 3	Guangdong	1982	FS	?	196°F (91°C)
Huailai	Hebei	1971	B	200 kW	185°F (85°C)
Wentang	Jiangxi	1971	B	50 kW	153°F (67°C)
Huitang	Hunan	1975	FS	300 kW	198°F (92°C)
Yingkou	Liaoning	1977	B	100 kW	167°F (75°C)
Zhaoyuan	Shandong	1981	FS	200 kW	196°F (91°C)

B = binary (isobutane, ethyl chloride, normal butane or freon-11), FS = flash steam giving approximately 2.2 MWe available for the Bay of Plenty Power Board (BOP) grid. The monitoring system allows unattended operation that ensures that unscheduled outages can be quickly reported. The plant performance is also monitored by the manufacturers in Israel, who provide weekly reports directly to the BOP offices in Whakatane. Tilson, et al., (1990) reported no deposition in the heat exchangers and, with little maintenance required, load factors for the first six months of operation were over 90%, with 96.6% availability. The unit average output was about 1,800 MWh per month for the initial operation. The OECs utilize separated geothermal water which previously ran into the Tarawera River. The installation of the OECs, thereby, contributes to environmental conservation by reducing pollution.

Figure 13. Tarawera 1.25-MWe binary unit at Kawerau, New Zealand.

12. **TG2 binary power plant**, Kawerau, New Zealand, was installed and linked to the grid in 1993. This 3.5-MWe gross output ORMAT OEC module uses 342°F (172°C) geothermal brine at 325 tons/hr (Fig. 14). The air-cooled unit also utilizes separated geothermal fluid which previously ran into the Tarawera River. The power plant is owned and operated by Bay of Plenty Electric Power Board.

13. **Kirishima International Hotel back pressure unit**, Beppu, Kyushu, Japan, was installed in 1983. The unit is 100-kWe non-condensing flash unit (Fig. 15). A condensing- type turbine was considered, and even though the gross output would be about 240 kWe with the same steam flow, and the increase in the net output would be only 50 kWe because of the increase in the parasitic loads (Ohkubo and Esaki, 1995). In addition, the simplicity of maintenance was also a reason to selected the non-condensing unit. Steam from two wells, runs through a separator, providing an inlet temperature of 260°F (127°C) at 36 psi (2.45 bar) at 6 tons/hour. Hot water from the separator is used for outdoor bathing, space heating and cooling, hot water supply, heating of a sauna bath and for two indoor baths.

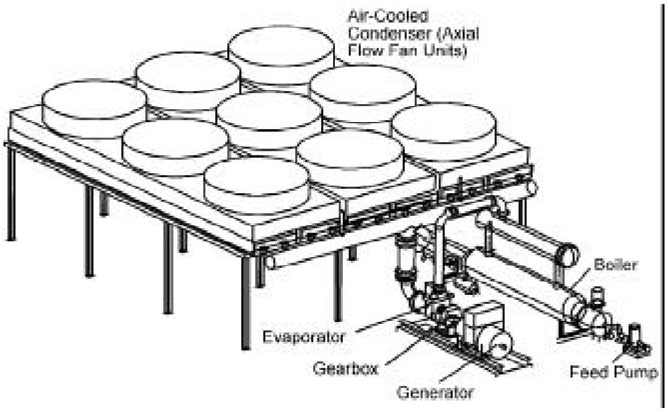

Figure 14. Diagram of TG2 3.5-MWe binary unit at Kawerau, New Zealand.

Figure 15. Kirishima International Hotel 100-kWe back pressure unit and separator.

The electricity from the unit is used for the base load in the hotel such as sewage water treatment, lighting in the hallway and lounge, kitchen refrigerators, and provides 30 to 60% of the hotel load according to the season and time of day. Whenever the hotel load exceeds the capacity of the unit, the hotel receives power from the grid. The unit was furnished by Fuji Electric Co., Ltd. of Japan.

14. **Kokonoe Kanko Hotel condensing flash unit**, Kokonoe, Kyushu, Japan, was installed in 1998. This is the most recent installation of a small-scale geothermal power plant in Japan (Esaki, 1998). The condensing unit with a geared turbine (about 8,000 rpm) is installed on the premises of this resort hotel, and when the hotel load is below the unit capacity, which it is most of the time, they sell power to Kyushu Electric Power Company. The installed capacity is 2,000 kWe, with major parastic loads of 356 kWe (hot well pump, vacuum pump for gas extraction, cooling tower fan and auxiliary cooling water pump) or about 17% of the gross output giving a net output of 1,644 kWe. The reason for the high parasitic load is that a vacuum pump (164 kWe), not a set of steam jet ejectors, is employed for gas extraction to reduce noise during the operation because the plant is located adjacent to a campsite of the hotel.

The steam temperature and pressure at the turbine inlet is 271°F (133°C) at 44 psi (3.0 bar). The turbine exhaust pressure is 3.1 psi (0.21 bar). The steam flow supplied from two small production wells is 23 tons/h with 2.0% by weight of non-condensable gas. The unit was supplied by Fuji Electric Co. Ltd. of Japan.

15. **Hachijojima Island condensing flash unit**, 400 km south of Tokyo, was complete in early 1999. Hachijojima is a remote island with power supplied from several diesel power plants. The unit has a gross output of 3,300 kWe and parasitic load of 9% of the gross output with the non-condensable gas abatement system in operation, and 7% with the abatement system shut down (Esaki, 1998). It is expected that the fuel transportation cost will be drastically reduced once the plant has been in operation. The plant, supplied by Fuji Electric Co. Ltd., cost about $10 million or $3,000 per installed kWe, and electricity will be supplied for about 20 cents/kWh.

The steam temperature and pressure at the turbine inlet is 338°F (170°C) at 118 psi (8.2 bar). The flow rate is 30 tons/h with 1.56% by weight of non-condensable gas. The plant is equipped with a hydrogen sulfide abatement system to comply with the regulation of the Tokyo Metropolitan Government which prescribes the concentration of 0.1 ppm, in this case at the cooling tower cell.

16. **The Bouillante geothermal flash condensing power plant**, Guadeloupe, was placed in operation in 1986. The plant site is at Cocagne on the western coast of the isle of Basse Terre, some 1,600 feet (500 m) south of the center of Bouillante and some 9 miles (15 km) from the Soufriere volcano. The operation of the power-plant is mainly automatic and the electric output will meet 6% of the Guadeloupe electric power demand at a cost lower than that obtained with diesel generators. Numerous modernization and improvements were undertaken in 1995 and 1996 (Correia, et al., 1998). Three automated controllers monitor plant activity and manage all operation. The plant, located within a residential district, was designed so as not to produce noise greater than the ambient noise of the city.

Geothermal wells on the island produced temperatures of 446 to 482°F (230 to 250°C) at depths of 2,000 to 8,200 ft. (600 to 2,500 m) with a steam to water mixture of 20 to 80% (Jaud and Lamethe, 1985). A study was made of the various means to produce electric power, and binary cycles were rejected due to silica deposits on the heat exchange surface, thus a condensing turbine was selected. The plant was then supplied with a water-vapor mixture which is near 400°F (200°C) at the surface with an output of approximately 150 tons/hour. Two saturated steam flows were used at 87 and 14.5 psi (6 and 1 bar). The high pressure steam from the separator is conveyed to the turbine and the separated geothermal water at about 320°F (160°C) is sent to a flash vessel to produce low-pressure steam. The exhaust steam is then condensed by cooling seawater in a direct-contact condenser with a barometric pipe. The residual geothermal water at 212° (100°C) is mixed with the water coming from the condenser and is discharged to the sea (Fig. 16). Approximately 30 tons per hour of steam are produced by the high-pressure separator and 12 tons per hour of steam is produced by the low-pressure separator.

During operation, the turbine is mainly supplied with two high- and low-pressure steam flows. However, it can operate with only the high pressure steam flow; thus, enabling repair and maintenance operations to be carried out on the flash vessel without having to stop power production completely. The gross output is 5.0 MWe and the net output of the unit is 4.2 MWe, which is enough power for the cities on the west coast of the island of Basse-Terre. Plant availability during late 1997 and early 1998 averaged 95% (Correia, et al.,1998).

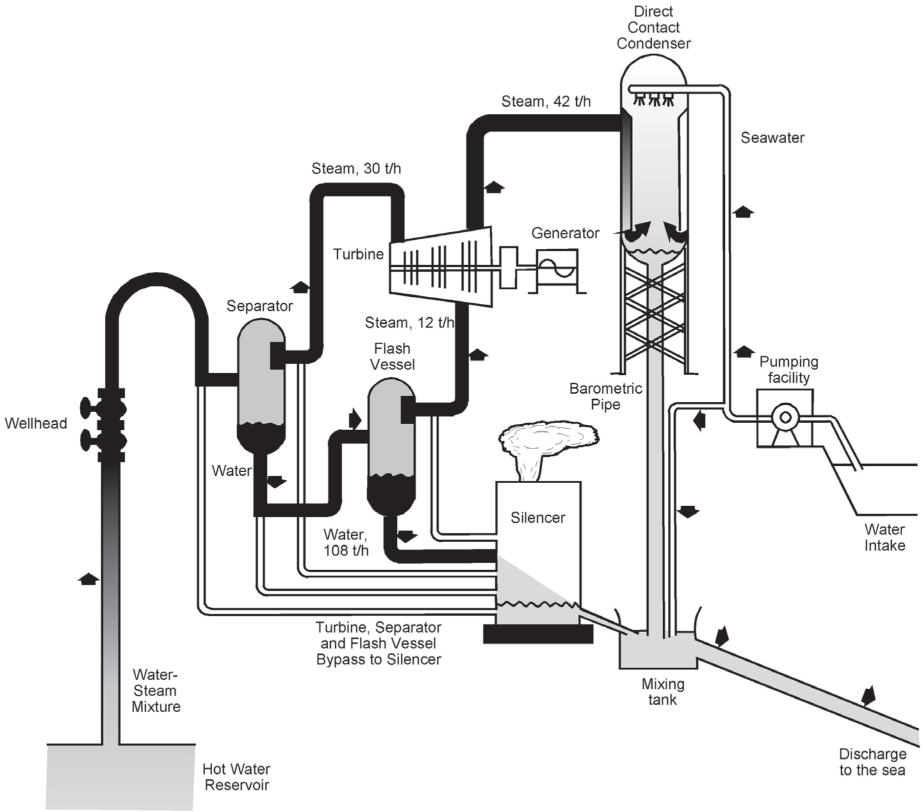

Figure 16. Diagram of the Bouillante geothermal power plant.

17. **CGPV flash steam plant**, Pico Vermelho, island of San Miguel, Azores, Portugal, was installed in 1980 (Fig. 17). The reservoir temperature was as high as 400°F (200°C) at a depth around 1,600 feet (500 m). The Mitsubishi back-pressure steam turbine, using a single-flash system with a rated capacity of 3 MWe, never produced more than 0.8 MWe, due to the insufficient supply of steam from the small diameter PVI well (depth 2,660 feet - 811 m) (Ponte, 1998). In the first years after plant start-up, the production of CGPV was variable; however, stable production figures have been achieve only since about 1993. The main operation difficulty has been calcium carbonate scaling, which requires that well PV1 be cleaned out every month. Annual production varied from 4 to 5 GWh during 1994 to 1997. Availability average is about 95% and the load factor average about 70%.

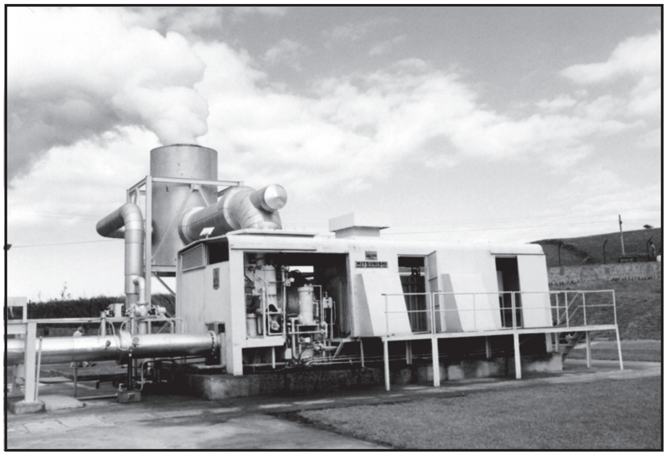

Figure 17. Pico Vermelho 3-MWe flash steam plant, Azores.

18. **CGRG (phase A), binary plant**, island of San Miguel, Azores, Portugal, was installed in 1994. The units consist of two dual ORMAT turbo-generators of 2.5 MWe each, with auxiliaries, transformers, switch gear, emergency diesel generators, fire fighting system and a connection line to the grid. The organic Rankine cycle uses normal pentane as the working fluid. Two wells, CL-1 and CL-2, for the project are about 400°F (200°C) at 5,000 feet (1,500 m). The larger well, CL-2, delivers 152 tons/hour at a wellhead pressure of 116 psi (8 bar) with a steam flow of 39 tons/hour. Until the middle of 1994, the net power output was maintained near 4.8 MWe (Ponte, 1998). However, well production rates and plant output began to decline, indicating that wellbore scaling was restricting flow in both wells. Therefore, the wells were cleaned out in early 1995, using a drilling rig. With both wells back in production, the plant was operated at a net output near 4.4 MWe. Well production decline in mid-1995 required a new clean out; thus, after this operation, a scale inhibitor system

was installed and put in continuous operation in both wells. In 1997, the output was 42.3 GWh, the availability factor was 99.5% and the load factor 96.5%.

The actual installed geothermal power production meets 20% of San Miguel Island's electricity demand, which represents 50% of the Azorean total demand. The CGRG plant is presently being expanded (Phase B) with the installation of additional capacity of two-4 MWe ORMAT binary plants (Fig. 18). With the addition of Phase B, it is expected that nearly 45% of the electricity demand of San Miguel will be met.

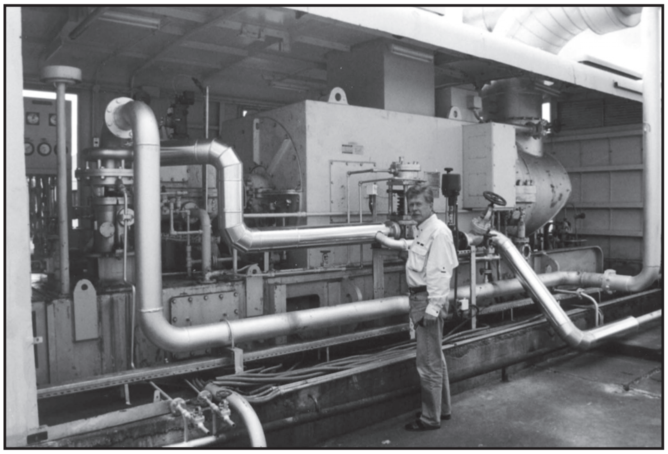

Figure 18. CGRG binary plant, Phase B (2x4 MWe), San Miguel, Azores.

19. **Mulka Station and Birdsville power plants**, Australia. The first successful geothermal power plant in Australia, a Mulka cattle station, was put into operation in 1986. This unit is a 20-kWe binary cycle and flash steam, 415 V, II phase unit located in South Australia. A 150-kWe, binary plant has been constructed at Birdsville, Queensland. This power plant uses 210°F (99°C) water from the town's well. This well, flowing for 75 years, produces about 6,800 gpm (30 l/s) at a shut-in pressure of 176 psi (1,213 kPa) from a depth of about 3,900 feet (1,200 m). The cycle efficiency is only 5% and parasitic losses reduce this to 4%. The energy demand for the town varies from 60 to 150 kWe. The geothermal power alone suffices when demand is low, but peaking with diesel power is needed when the demand increases. The system has been operating since 1992 and has achieved a service factor of about 50% (Burns, et al., 1995).

20. **Back pressure turbine**, Bjarnarflag, Namafjall, Iceland, was installed in 1969. Based on exploration in northern Iceland, a field temperature of 482 to 500°F (250 to 260°C) was utilized to provide power to the area through the Laxa Power Works, to gain experience in geothermal power generation, and to reduce the use of imported and expensive fuel in their diesel plants (Fig. 19). In order to minimize the construction time, a second-hand 2.5-MWe BTU back-pressure industrial turbine-alternator set was purchased in England (Ragnars, 1970). The design and erection of the power plant were carried out in seven months.

The turbine itself was of simple design, with one Curtis wheel and only two rows of blades on the rotor. It runs on geothermal steam at 130 psi (9 bar) at the inlet valve, a steam rate of 35 to 37 lbs/kWh (16 to 17 kg/kWh), with a back pressure of 0.7 psi (0.05 bar). The rating is 3.4 MWe. The installed cost at the time (1970) was $50/kW and the power generated at 0.45 to 0.55 cents/kWh delivered to the network. The field also supplies steam to the Kisilidjan diatomite plant, located adjacent to the site. The total electrical production of the Bjarnarflag power plant in 1993 was 8.9 GWh.

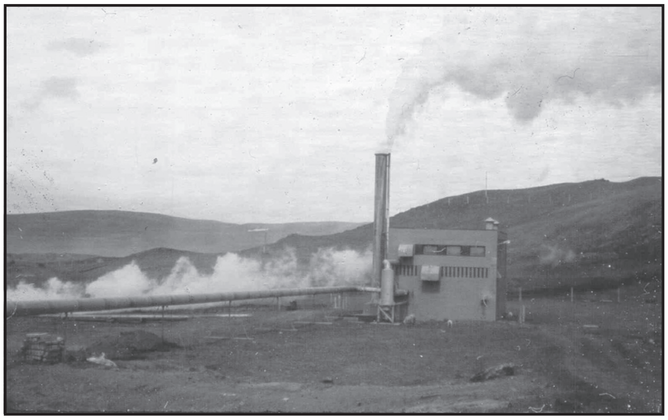

Figure 19. The Bjarnaflag back-pressure 2.5-MWe power plant, Iceland.

21. **Svartsengi binary- geothermal power plant**, Reykjanes Peninsula, Iceland, was commissioned in 1989 as the first stage of a 12-MWe power plant. The Sudurnes Regional Heating Corporation operates a combined thermal and electric power plant that supplies district heating and electricity to 10 communities on the Reykjanes Peninsula west of the capital,

Reykjavik (Lienau, 1996). The thermal output is 125 MWt and the electric output is 16.4 MWe, with part of the load going the Keflavik airport and a U.S. military base. The heating plant was built by the National Energy Authority in 1974 and in 1976-77, a preliminary power plant of 3 MWe was commissioned. In 1978, the first 1-MWe turbogenerator was commissioned. Both of these units no longer are in operation. In the period of 1989 to 1993, seven binary power units totaling 8.4 MWe were commissioned. Three 1.2-MWe binary ORMAT water cooled turbines were installed in 1989, utilizing steam which had previously flowed unharnessed from the chimneys of the power station. These units produced an additional 90 GWh per year, including about 15 GWh for the station. In 1993, four additional 1.2-MWe air-cooled binary turbines were put into operation. This raised the installed power at the station to 16.4 MWe with production at 110 GWh per year, including 17 GWh for the plant's own use. Thus, 8.4 MWe power is produced from binary units and 8 MWe from a single-flash steam turbine. The heat rejected from the water-cooled condenser of the ORMAT units is used to preheat the district heating water and then disposed into the Blue Lagoon a popular outdoor bathing facility. The flash steam turbine uses 320°F (160°C) fluid, and the reject fluid at 217°F (103°C) is used in the binary units and finally rejected at 77°F (25°C) to the heat exchange column (Figure 20).

22. **Integrated geothermal power plant**, Aluto Langano, Ethiopia, was synchronized to the Ethiopian national power grid in 1998. This is the first geothermal power plant using integrated stream and binary power technology in Africa. The plant consists of one 3.9-MWe ORMAT combined cycle unit operating on geothermal steam and one 4.6-MWe ORMAT air-cooled OEC operating on both geothermal brine and low-pressure steam (Fig. 21). The high pressure steam is at 174 psi (12 bar) with a temperature of 370°F (188°C) for the two-phase geothermal fluid at 43.7 tons/hour (30.6 tons/hour steam), and the low pressure fluid is at 72.5 psi (5 bar) with a temperature of 305°F (152°C) at 120.5 tons/hour brine (28 tons/hr steam). The 8.5-MWe geothermal power plant was constructed by ORMAT under a turn-key EPC contract, and is owned and operated by the Ethiopian Electric Light and Power Authority (ORMAT literature).

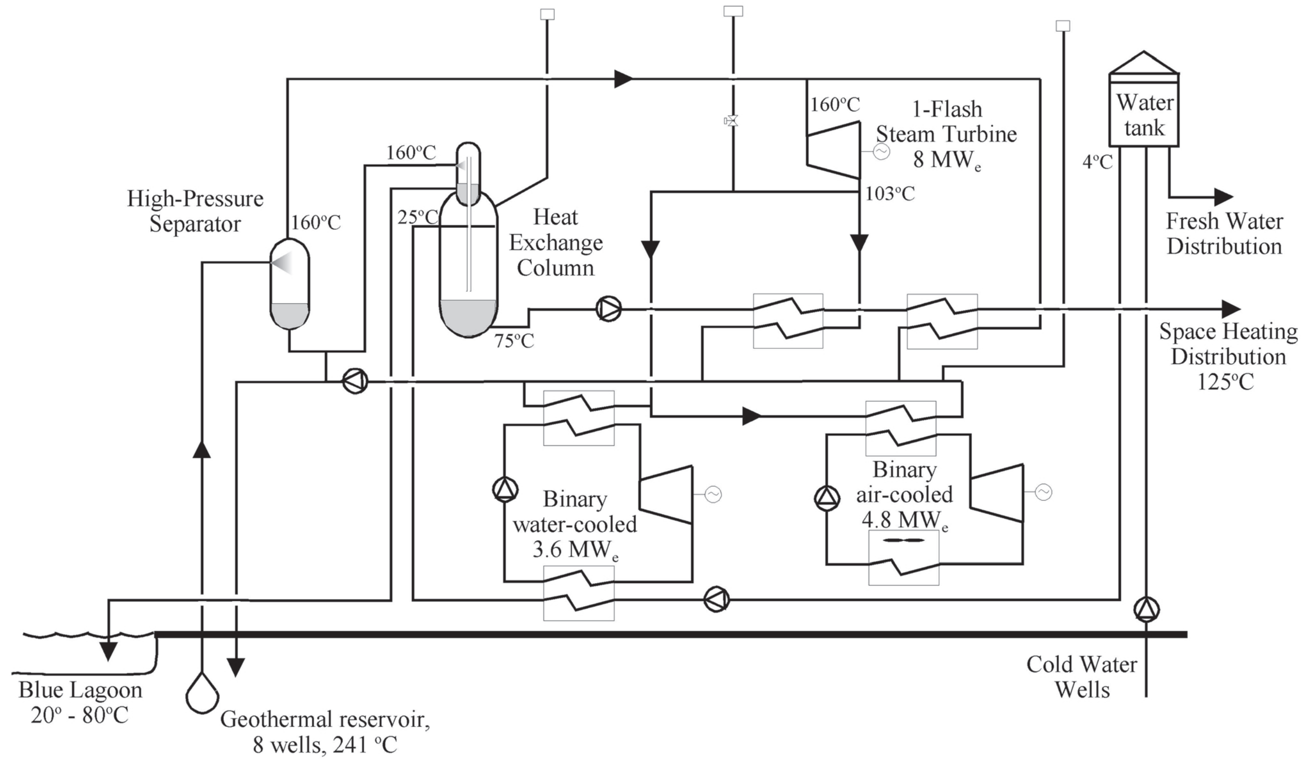

Figure 20. Flow diagram of the Svartsengi, Iceland power plant.

Figure 21. Integrated 8.5-MWe geothermal power plant, Ethiopia.

23. **Travale 21 binary power plant**, Comune di Radicondoli, Italy, was installed and commissioned in 1991. This 700- kW ORMAT OEC modular unit (Fig. 22) utilizes a water dominated geothermal source of 230°F (115°C), and the spent hot water is then used to heat greenhouses. The plant is owned and operated by Ente Nazionale per l'Energia Elettrica (ENEL), the Italian utility company (ORMAT literature).

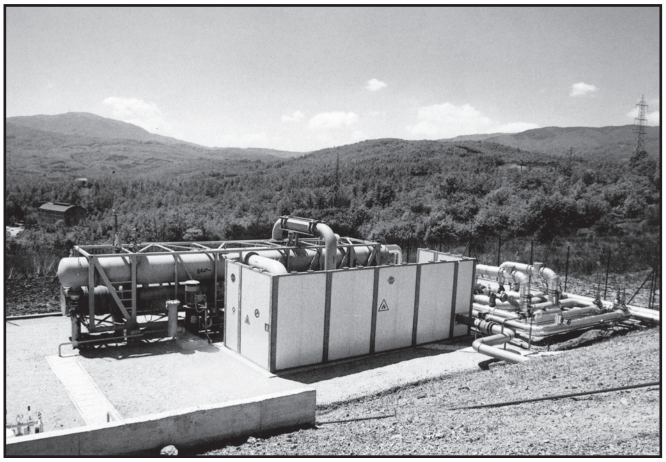

Figure 22. Travale 21 geothermal binary power plant, Italy.

24. **Bagnore dry steam power plants**, Mt. Amaita, Italy, were commissioned in 1959. Bagnore 1 and 2 are 3.5 gross MWe dry steam geothermal plants using approximately 266°F (130°C) geothermal resource. They are owned and operated by ENEL (GRC database).

25. **Latera power plants**, Latera, Italy, are reported as under construction. They consist of a 3.5-MWe flash plant and a 2-MWe binary plant (GRC database).

26. **Binary geothermal power plants**, Los Azufres, Michoacan, Mexico, were commissioned in 1993. Two 1.5-MW ORMAT OEC unit are installed in two separate locations in the Los Azufres geothermal field (Fig. 23). They are air-cooled units using 347°F (175°C) geothermal separated brined at a flow rate of 141 tons per hour using wells U-11 and U-12. The plants are owned by Comision Federal de Electricidad (CFE) (ORMAT literature).

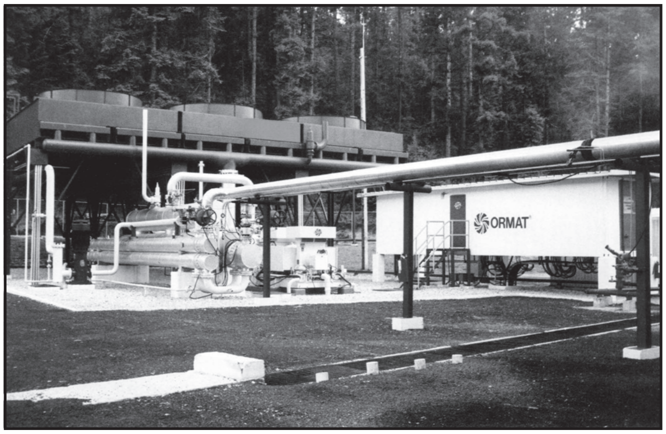

Figure 23. 1.4-MWe binary power plant, Los Azufres, Mexico.

27. **Flash power plants**, Los Azufres, Michoacan, Mexico, were commissioned between 1982 and 1992. There are ten 5.0-MWe (gross) flash steam back pressure geothermal power plants operating in this field. Five Mitsubishi units using wells U-1 through U-5, one Toshiba unit using well U-6, one General Electric unit using well U-7 and three Ansaldo-Makrotek units using wells U-8 through U-10 (GRC database and Gerardo Hiriart, CFE). Their net output ranges from 4.2 to 5.0 MWe and they produce around 43 GWh/year (Quijano-Leon and Gutierrez Negrin, 1995). The resource temperatures vary from 509 to 662°F (265 to 350°C) with inlet temperature of 338°F (170°C) and pressure of 116 psi (8 bar). Well depths range from 2,740 feet (835 m) to 6,873 feet (2,095 m). The estimated cost of each project was $4 million.

28. **Flash power plants**, Los Humeros, Chignautla, Mexico, were commissioned between 1990 and 1993. There are seven 5.0-MWe (gross) flash steam back pressure geothermal power plants operating in this

field. All are Ansaldo-Makrotek units using wells U-1 through U-7 (GRC data base and Gerardo Hiriart, CFE). Their net output ranges from 3.7 to 4.8 MWe and they produce between 33 and 42 GWh/year (Quijano-Leon and Guterrez Negrin, 1995). The resource temperatures vary from 608 to 644°F (320 to 340°C) with inlet temperature of 338°F (170°C) and pressure of 116 psi (8 bar). Well depths range from 5,250 to 7,300 feet (1,600 to 2,225 m). The estimated cost of each project was $4 million.

29. **Flash power plant**, La Primavera, Jalisco, Mexico, was commissioned 1997. This unit, a single flash back pressure plant, is built and supplied by Ansaldo-Makrotek and uses well U-1 (GRC database and Gerado Hiriart, CFE). The resource temperature is 672°F (356°C) and the inlet temperature is 346°F (174°C) at a pressure of 125 psi (8.6 bar). The well depth is 9,794 feet (2,985 m). The approximate total project cost was US$ 6 million. There is also a report of a second 5-MWe plant installed; but, no data are available (Quijano-Leon and Guterrex Negrin, 1995).

Two 5.0-MWe plants are also being installed at the Las Tres Virgenes geothermal field on Baja California (Cadenas and De la Torres, 1998).

30. **Geothermal Power Monobloks**, Indonesia, installed in 1978 and 1981. Two skid-mounted General Electric turbine generator modules have been utilized in Indonesia supplied by Geothermal Power Company of Elmira, New York. The first, a 250-kWe unit, was installed at Kamojang in West Java. The second, a 2.0-MWe unit, was installed at Dieng, Central Java and in 1981 (Fig. 24). This monoblok weighting 30 tons, was then moved by Pertamina of Indonesia to the Sibayak geothermal site in North Sumatra, where it was installed as the first geothermal power plant on that island. These units were non-condensing, skid mounted steam turbine and generator with switch gear and control system all mounted in one package. The skid mounted package has a stainless steel outer covering for protection from corrosion due to the H_2S gas in the steam (Geothermal Power Co.literature)(Shulman, 1982).

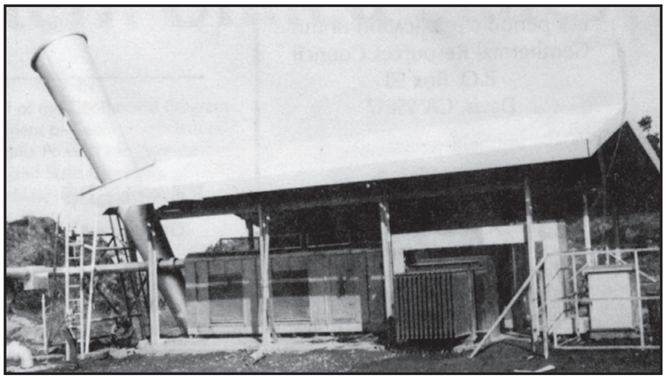

Figure 24. 2.0-MWe geothermal power monoblok with diffuser exhaust and pad-mounted transformer, Dieng, Indonesia.

31. **Binary geothermal power plant**, Copahue, Neuguen, Argentina, came on line in 1988. This was a 670-kW ORMAT OEC demonstration plant that uses isopentane as the working fluid (Fig. 25). This was the first geothermal plant located in South American and was at 6,560 feet (2,000 m) on the slopes of the Andes in western Argentina. It was a water-cooled unit using low pressure steam at 331 to 340°F (166 to 171°C). A well supples 6.7 tons/hour of saturated steam with 8% non-condensable gases from a well depth of 3,280 feet (1,000 m). The annual energy production was 3.5 GWh/year (Pesce, 1995). The plant went off-line in 1996 as it could not compete with natural gas which is an abundant and cheap resource in the region (Pesce, 1998).

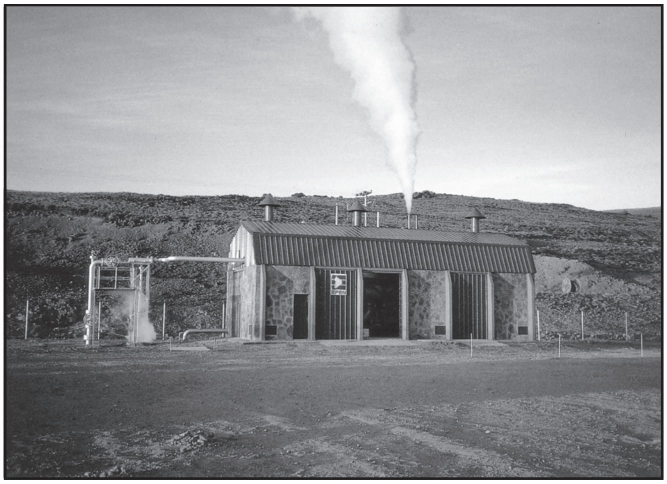

Figure 25. 670-kWe binary power plant, Copahue, Argentina.

32. **Single-flash pilot plant**, Milos, Greece, installed in 1985. A 2.0-MWe plant was installed in a effort to focus on the island's geothermal-electric potential. The plant was a single-flash, condensing type with a turbine initially designed to operate with steam at 116 psi (8 bar). It operated for several months with a fluctuating output load, due to the substantial variations in load demand of the island, rarely exceeding the 2.0 MWe. Between December 1986 and December 1988, the plant operated about 7,600 hours and produced a total energy of 7.33 GWh (Koutinas, 1990). Operating troubles were experienced with scaling from heavy metal sulphides, silica and silicon compounds, and thus the plant was modified with the addition of a high pressure cyclone separator (362 psi - 25 bar), a steam scrubbing system and various other auxiliary equipment. The plant was finally shut down in 1988, as strong opposition against its operation was encountered among the inhabitants and local organizations of the island (Fytikas, et al, 1995).

33. **Binary power units**, Lakeview, Oregon, installed in 1984 and 1985 by Jack Woods. Three SPS binary power units rated at 370 kWe each and three ORMAT binary units rated at 300 kWe (Fig. 26) were installed in Hammersly Canyon. The temperature of the resource was 204°F (96°C). Another binary unit at 40 kW was installed south of Lakeview near Goose Lake by Rockford (Fig. 27). None of the units are now operating, and the three SPS units have been moved to Animas, New Mexico where they are being using for a greenhouse operation.

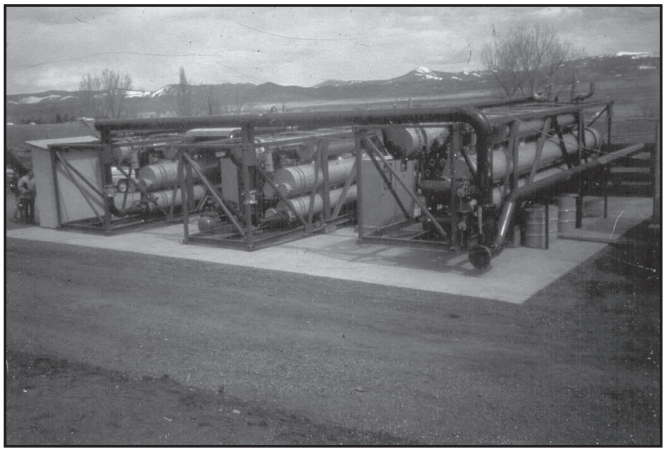

Figure 26. ORMAT 300-kWe unit at Lakeview, OR.

Figure 27. 40-kWe unit south of Lakeview, OR.

34. **Experimental binary power plant**, Paratunka, Kamchatka, Russia, commissioned in 1967 (Moskvickeva and Popov, 1970). This was one of the first geothermal binary power units installed in the world, rated at 680 kWe and used 178°F (81°C) water (Fig. 28). It was dismantled by 1985.

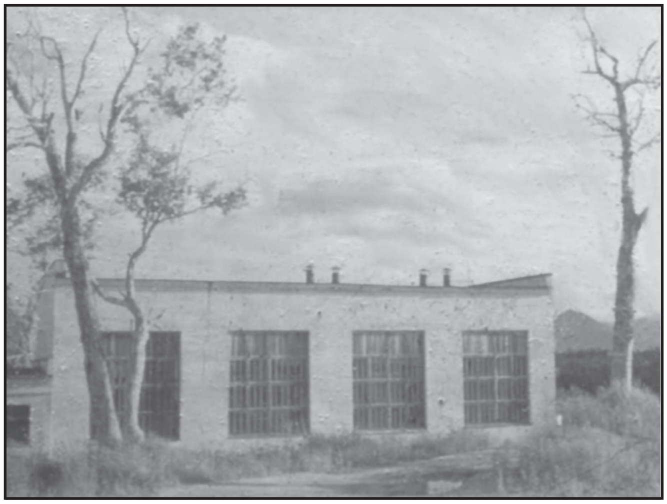

Figure 28. Paratunka, Russia 680-kWe binary power plant.

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