Geothermal Sustainability, Heat Utilization, and the Advanced Binary Technology Solution

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ABSTRACT

Following the historical events of the oil embargoes of 1973 and 1974, geothermal energy, along with solar, wind and tidal energy, were frequently described as both alternative and renewable. They were alternatives to the widespread use of fossil and nuclear fuels and renewable because of the assumption that the energy was naturally recharged and replenished. Fossil and nuclear fuels, though presently abundant, are considered to be finite—that is, the human race is expected to outlast these sources at present rates consumption.

With the dramatic and unpredicted steam pressure declines reported in 1986 at The Geysers Geothermal Field in northern California, questions were raised regarding the renewable status of geothermal energy. Recent reports, particularly from steam fields in Italy and El Salvador, illustrate that the problem is not site specific, but is technology specific. Development of geothermal energy using steam condensing flash turbines with little or no injection is non-sustainable. It is postulated that if the present generation of geothermal power plants now under construction utilize advanced binary technology, long-term sustainability, environmental benefits, and simplified operations will accrue with little to no change in the steam production cost.

Introduction

Geothermal energy development in the United States has come to a virtual standstill due to low natural gas prices, highly-efficient gas turbines, and utility deregulation. There are no new power plants under construction in the Basin and Range, The Geysers, The Salton Sea, or the Island of Hawaii. Power plants have been decommissioned in The Geysers (PG&E Units 1,2,3, & 4, Coldwater Creek, Bottle Rock), and placed into developmental Limbo in the Cascades region of Oregon.

Development is continuing, however in Mexico, Indonesia, The Philippines, and other parts of Asia and Africa where geothermal resources are competitive. In these countries, national governmental agencies view geothermal resources as a national asset, to be used in the most prudent manner and for the longest possible length of time—not just for the term of the financial investment. This is especially true for the BOT project in which the plant reverts to the government within 15 to 20 years. In these regions, it is important that project administrators consider all available aspects of the reservoir and available technology in order to satisfy the worldwide emerging energy policy. The key is to balance the total amount of heat extracted with the total amount of estimated natural recharge. The historical record clearly shows that fluid production with inadequate or no injection will lead to premature reservoir depletion. Injection of all produced fluids must take place immediately after production and continue for the duration in order to have sustained development.

Heat Mining and Sustainability

The dictionary definition of sustain is "to keep up, to prolong." Wright (1997) uses the term sustainable development to mean that which meets the demand of the present generation without compromising the needs of future generations. The implication for geothermal energy resources is to maintain production in an economic and environmental manner that does not compromise long-term production. The definition of long-term will be debated, but 30 to 50 years should be viewed as an achievable goal using current technology.

The term mining relates to a process of excavation and removal of mineral substances from the earth for commercial gain. It is implicit in this definition that, unless the mineral is removed, there is no commercial gain. History is full of stories of boom and bust cycles in the mineral industry. When the ore is depleted or the vein ends, the mine shuts down.

Heat mining and geothermal sustainability are two terms that have been recently introduced into the geothermal vernacular. Heat mining has been used in describing the action of injecting fluid into hot rock to extract heat. The Hot Dry Rock (HDR) program used a form of heat mining at the Fenton Hill, New Mexico geothermal facility. Recent injection pilot projects in The Geysers have been described as mining the heat from the fluid depleted, but still hot portion, of the geothermal reservoir. The dilemma however is that heat mining has been proposed as the solution to the problem created by heat mining. In the case of The Geysers, heat and fluids were removed at a rate that was much higher than the natural recharge of the system. The $30 million dollar solution now underway, piping waste water from a distance of 30 miles, is expected to slow the steam pressure decline in a cost-effective manner. But these measures, which may not be available in other geothermal areas, underscore the possible fate of many similar reservoirs. In the era of economic-driven development, twenty-six years of production qualified as sustainable energy. In the emerging energy policy of today, longer-term sustainable development is replacing the economic-only goal. The following discussion illustrates the range of reservoir depletion, causes, and efforts underway to lessen the impact.

United States. Prior to 1986, The Geysers geothermal field, the largest in the world, was producing nearly 2,000 MWe. The steam decline, initially reported in 1986, sent shock waves through the geothermal industry and challenged some of the confidence we had in our understanding of the nature of geothermal energy. Initial reports of 30 to 40% per year steam pressure declines initiated unprecedented changes in reservoir management. Plants were shut down, production wells plugged, and power load cycling was implement to reduce the impact of lost production. Efforts are underway to pipe treated wastewater from a distance of 30 miles to artificially recharge portions of the reservoir.

The Geysers geothermal area has been described as a mature, fully developed field. Barker and others (1992) note that accelerated development (150 MW/year from 1982 to 1989) was accompanied by 100 to 200 percent increases in reservoir pressure decline and production decline rates. Haizlip and others (1995) show that the well-reported steam pressure decline in the principal reservoir of The Geysers is further compounded by the introduction of "edge steam" from adjacent reservoirs with a higher non-condensable gas content. The combination of these two produces a lower quality steam that is more costly to process. Shook and Faulder (1991) state that although an optimum injection well strategy can be configured in The Geysers, well spacing and specific reservoir rock properties must be fully understood to prevent thermal breakthrough.

The costs of the decline not only include lost revenue from lower production, but increased costs associated with reservoir management and monitoring programs, funded largely by the U.S. DOE. Menzies and Pham (1995) estimate that by the year 2010, electric power generation at The Geysers will be about 475 MWe.

El Salvador. The Ahuachapan geothermal field located in El Salvador has an installed capacity of 95 MWe. Production began in 1981, but steam pressure declines began in 1982, when fluid injection was halted due to thermal breakthrough from the injection to the production zone. All produced fluids were dumped into the ocean. Recent mathematical modeling has indicated that in order to achieve a sustainable level of development, the plant must adopt a large-scale fluid injection program (Parini and others, 1995). Several prospective wells have been identified. At present, the Ahuachapan geothermal power plant operates at an average load factor of 45%.

Italy. Barelli and others (1995a) report that intense reservoir production at Larderello—Valle Secolo resulted in steam pressure declines to 0.5 MPa in the late 1970's. Injection, initiated in 1979, reduced the decline, and allowed the pressure to rise to the present value of 0.7 MPa. Both values are considerably below the initial reservoir pressure of 3.0 MPa, recorded in 1942. Here, there is an ongoing debate over the respective benefits of constant flow rate vs. constant pressure operations. It is concluded that the best practice is to operate at constant flow rate for the first years when the reservoir pressure drops to its optimum value. After that it will be kept constant for the duration of the geothermal field life.

Barelli and others (1995b) describe the steam pressure decline in the Travale-Radicondoli geothermal field in Italy and the efforts underway to improve its productivity. According to the authors, the three shallow-depth reservoirs (a, b, and c) have all experienced some form of pressure decline due to lack of injection and inflow from adjacent cooler, meteoric waters. In this case, it is believed that the solution is to drill deeper to reservoir d, located 3 to 3.5 km below the present reservoirs. The shallow reservoirs will eventually be abandoned.

Indonesia. The Kamonjang geothermal field has only been operating since 1983, but has a reported annual decline rate of about 3% (Sudarman and others, 1995). The field has been producing about 140 MWe, using steam condensing turbines, since 1987. Injection wells have been drilled into the center of the reservoir, there is some temperature decline associated with injection, and makeup wells are routinely drilled. The developers are presently satisfied with the performance of the reservoir and plans are underway to expand the capacity to 220 MWe.

Discussion

Steam condensing plants have historically been the preferred method of producing electrical power from high-temperature geothermal resources on the basis of lower consumption of steam for each kilowatt hour produced. The inherent problems associated with steam production, including non-condensable gases and hydrogen sulfide abatement have been partially solved. Historical data from the United States, Italy, and El Salvador, where fluid injection is not practiced, demonstrates that this manner of production is consistent with

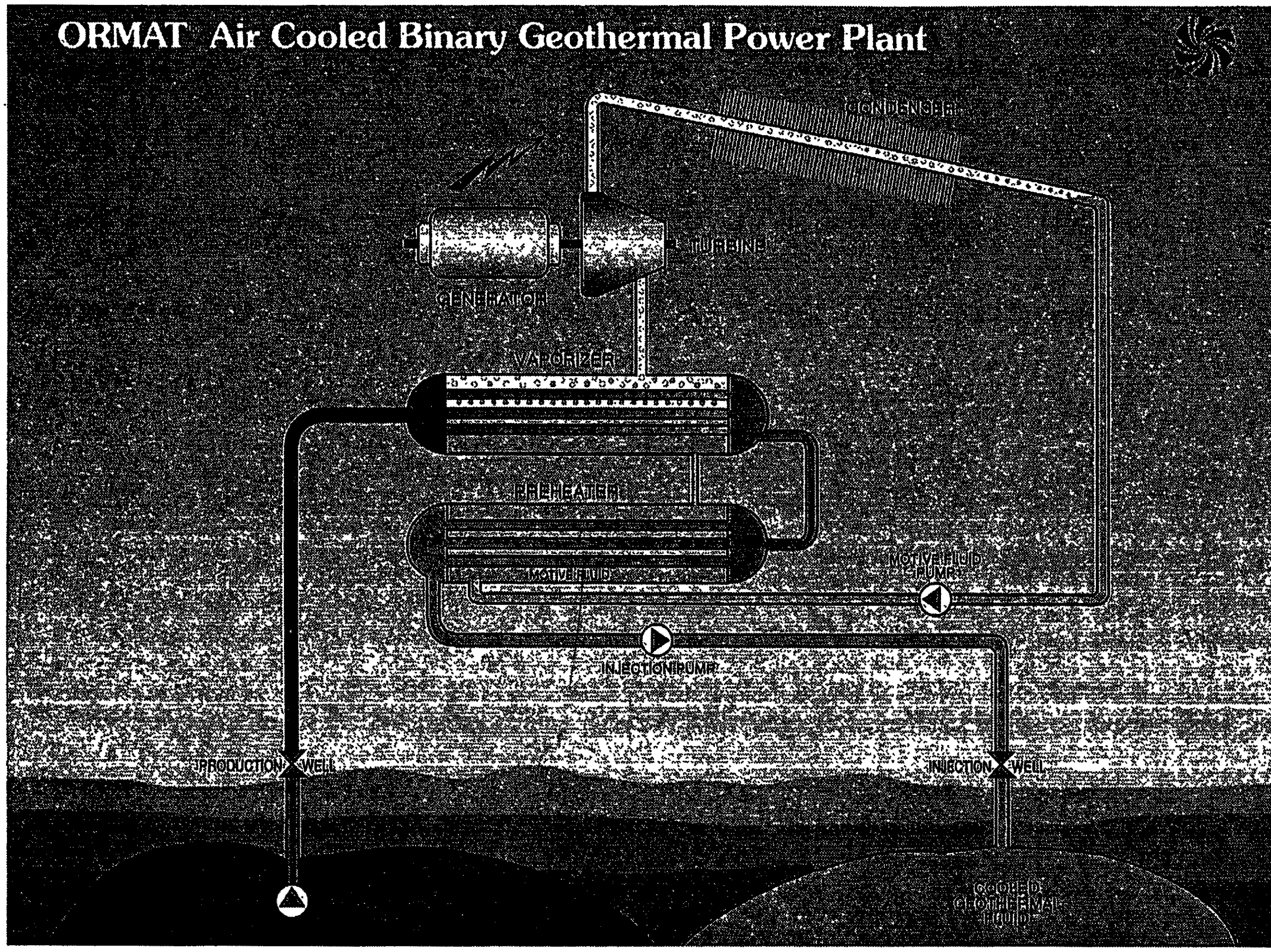

Figure 1. First generation air cooled binary geothermal power plant.

heat mining, not long-term sustainable development. Lack of available brine for injection from some steam fields componds the problem. The Indonesian steam fields are relatively new and do incorporate fluid injection, but are still experiencing a 3% steam production decline. Iceland has incorporated the societal values of conservation and longevity into reservoir management practices.

Sustainable geothermal production must incorporate the concept of harvesting, not mining heat. Harvesting implies the extraction of heat and fluid that is equal to or less than the recharge rate of the geothermal reservoir. Air-cooled binary power plants, as illustrated in Figures 1, 2, and 3, have several advantages over conventional steam plants. They are, by design, closed loop systems that inject all produced fluids, including carbon dioxide and hydrogen sulfide into the reservoir. No reservoir fluids are used or lost in the cooling system, which prolongs the life of the reservoir. Recent technological achievements in advanced combined cycle steam/binary technology have produced units that are now competitive with steam condensing units (Schochet, 1997). Steam consumption rates of 16 to 18 lb./kwhr. have been achieved. With the ability to operate an air-cooled, closed loop power plant using geothermal fluids ranging in temperature from 100°C to 300°C, and plant availabilities of 98% or more, at steam consumption rates equivalent to condensing units, it appears that the technology required for geothermal sustainability has been developed.

Iceland. No geothermal reservoir in Iceland has ever been abandoned because of depletion. Stefansson and others (1995) point out that prudent geothermal management incorporates societal values associated with reservoir longevity and sustainable production. Rapid development and eventual depletion of geothermal reservoirs (heat mining) for purely financial gains are not incorporated into management strategies. Injection, production, and new technology are balanced to provide long-term benefits for geothermal energy.

As part of its expansion plans, the Sudanis Regional Heating Company is inaugurating a new power well. The Reykjavik Peninsula contains many geothermal reservoirs, but overusage can create problems. The ORMAT system helps maintain constant pressure in the reservoirs. According to Albert Albertsson, Technical Director, "The reservoir is water dominated, water filled. The water table in the reservoir goes down every year. In order to keep constant pressure, or in other words, constant water level, in the reservoir, we have to reinject. And this condensate from this excessive steam is now reinjected. By doing this, we are keeping almost constant pressure in the reservoir."

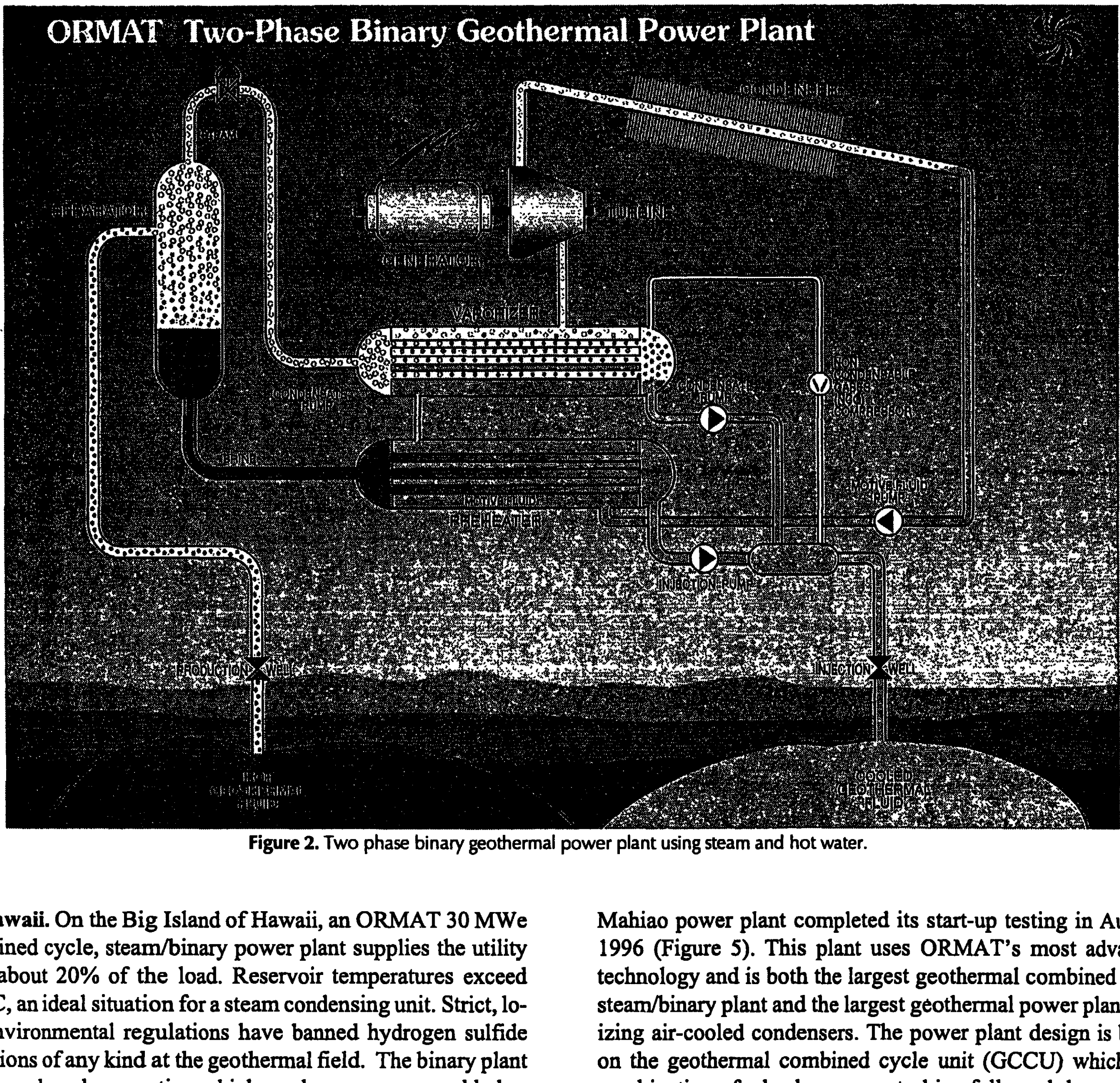

Figure 2. Two phase binary geothermal power plant using steam and hot water.

Hawaii. On the Big Island of Hawaii, an ORMAT 30 MWe combined cycle, steam/binary power plant supplies the utility with about 20% of the load. Reservoir temperatures exceed 300°C, an ideal situation for a steam condensing unit. Strict, local environmental regulations have banned hydrogen sulfide emissions of any kind at the geothermal field. The binary plant is a closed cycle operation which produces no measurable hydrogen sulfide gas (see Figure 3).

Figure 4 shows that dry steam from the reservoir enters the first turbine and is exhausted to the tube-in-shell heat exchanger, where it heats the binary working fluid. Normally, the steam would be condensed in a cooling tower and partially exhausted and lost to the atmosphere. Unless strictly monitored and controlled, an unlawful release of hydrogen sulfide gas is likely. In addition, these fluids represent part of the geothermal reservoir and this kind of disposal will eventually lead to steam pressure declines. In the Hawaii case, optimum energy extraction occurs in a series of heat exchangers that harvest the energy. For the last three years, all produced fluids have been injected back into the reservoir to maintain pressure and, it is believed, to sustain long-term development.

Leyte, Philippines. Constructed on the basis of a competitive award under a BOT energy contract, the 125 MWe Upper Mahiao power plant completed its start-up testing in August, 1996 (Figure 5). This plant uses ORMAT's most advanced technology and is both the largest geothermal combined cycle steam/binary plant and the largest geothermal power plant utilizing air-cooled condensers. The power plant design is based on the geothermal combined cycle unit (GCCU) which is a combination of a back pressure turbine followed downstream by conventional ORMAT Energy Converters (OEC) operating on an organic Rankine cycle (Figure 6). In addition, the heat energy in the brine is recovered in a binary plant using a separate OEC. In this plant, geothermal fluid is maintained at above atmospheric pressure without the use of vacuum pumps or ejectors, saving power and maintenance expenses, and handling non-condensables. Air-cooled condensers are used resulting in a lower plant profile, no water consumption, no chemicals, no blowdown disposal treatment, and no cooling tower plumes. This combination allows total injection of the spent brine and provides pressure support and reservoir longevity. Hydrogen sulfide abatement is facilitated without vacuum pumps, and gases can be injected with the spent brine without chemical treatment and waste disposal. A similar system has operated successfully at the Hawaii Puna Plant. Finally, the system allows automatic operation and simplified maintenance. This de-

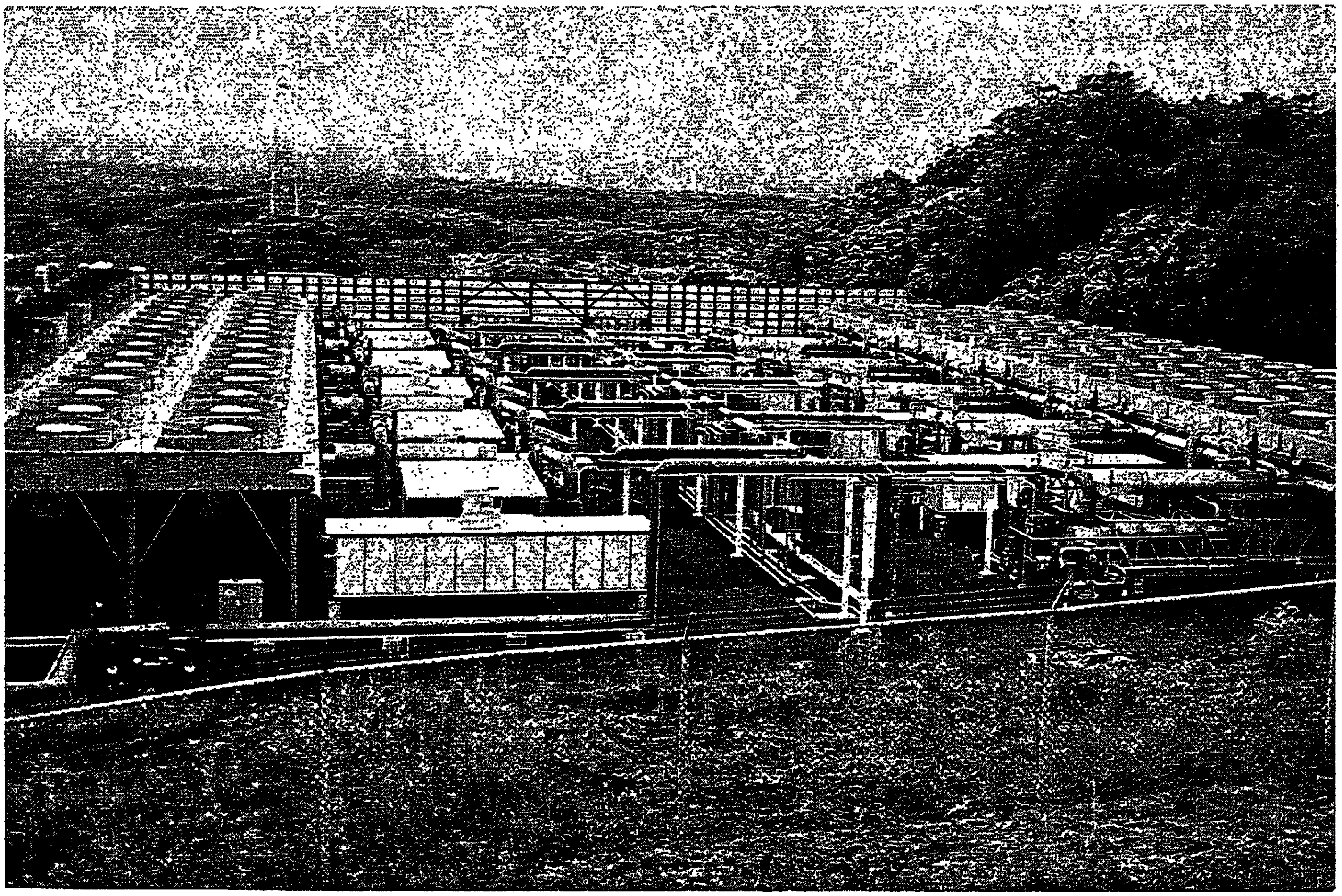

Figure 3. The Puna Geothermal Power Plant, Puna District, Hawaii.

sign and implementation ushers in a new phase of dedicated geothermal technology that has the capability to reduce the environmental impacts, the operational complexity, and the operating and maintenance expenses of utility-size power plants, as evidenced by the fact that the technology was used to win the competitive contract.

Conclusions

The concept of 'heat mining' is inconsistent with the concept of sustainable geothermal development. Sustaining a reservoir involves consideration of long-term reservoir management and the heat harvesting concept. Examples from the United States, El Salvador, and Italy, show that mining will lead to a rapid steam pressure decline. Heroic and costly measures, such as massive fluid injection and deeper reservoir drilling, may allow additional utilization for this generation of geothermal development. On the other hand, reservoir management practices such as those described in Iceland, coupled with technological advances of combined-cycle binary and integrated combined cycle technology as illustrated for Hawaii and Leyte, appear to be elements the next generation of geothermal power plants need to employ to insure sustainable development.

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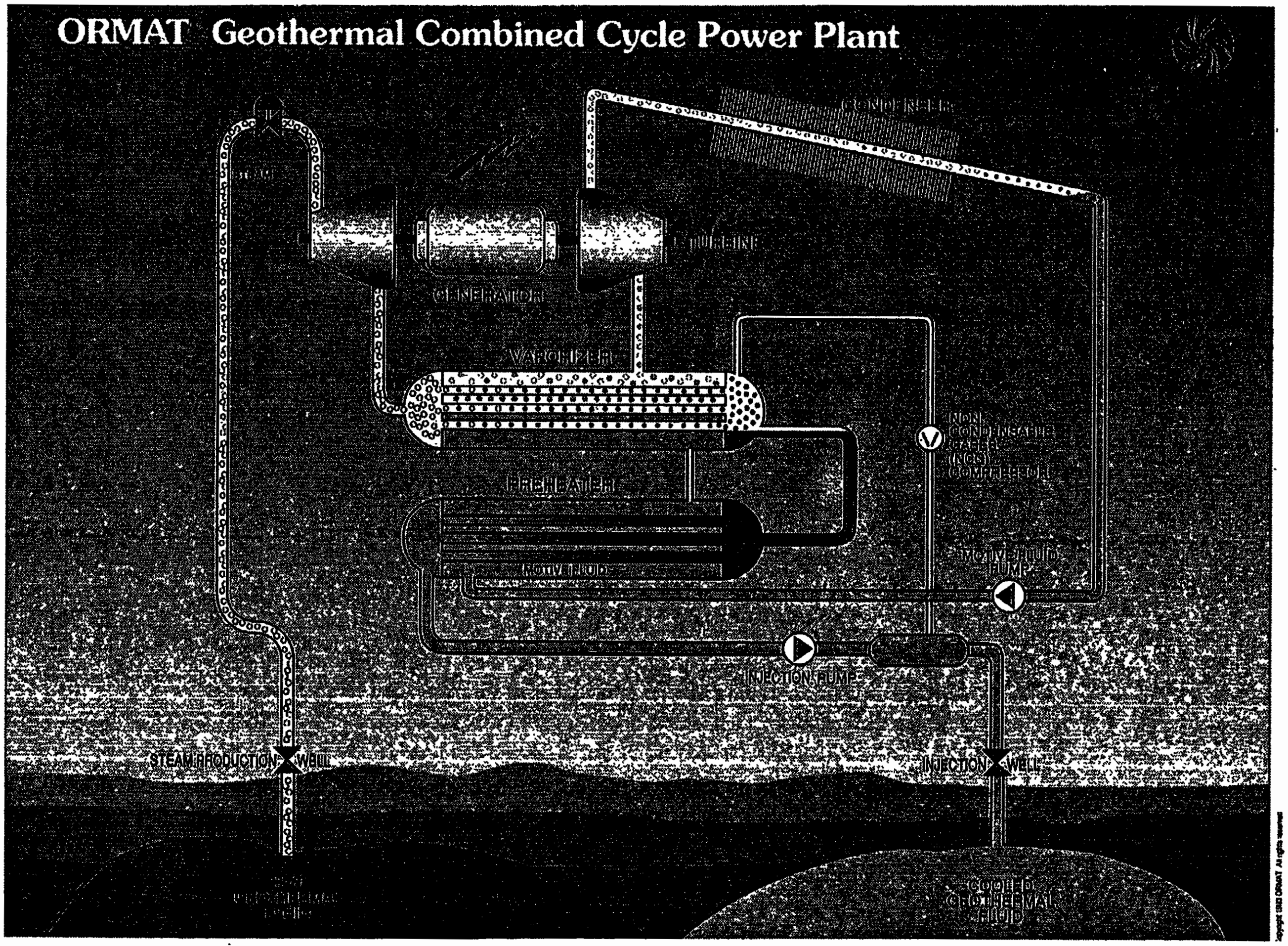

Figure 4. Combined cycle binary power plant as installed on Hawaii.

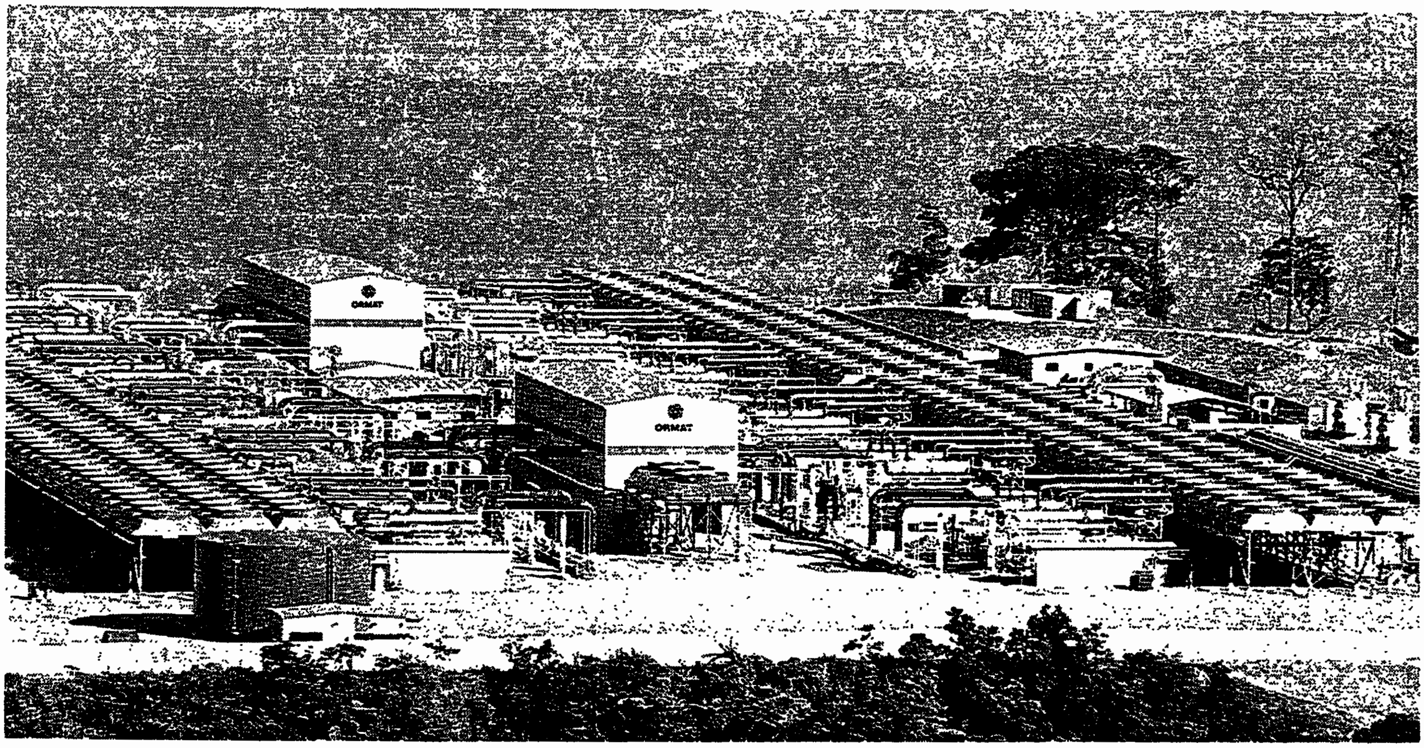

Figure 5. Upper Mahiao, Leyte, Philippines Combined Cycle Power Plant.

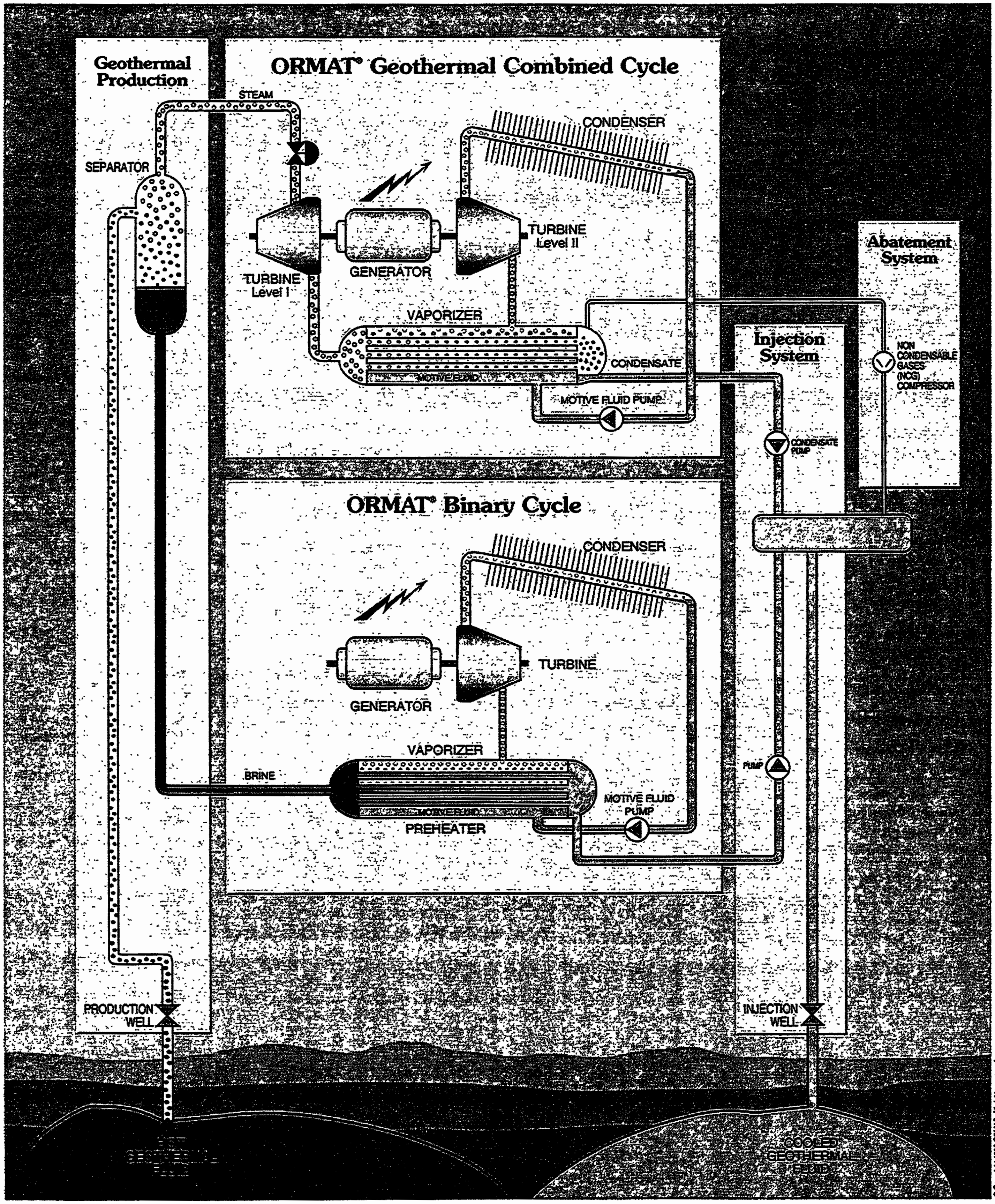

Figure 6. Advanced integrated geothermal combined cycle power plant.

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