A Decade of Geothermal Development in the United States 1974 — 1984: A Federal Perspective
— Part 2 —

EDITOR'S NOTE: Part 1 and Part 2 of this series are authored by Bob Blackett, Jim Satrape, and Gene Beeland. The article was prepared and published in the Progress Monitor by the Meridian Corporation of Falls Church, VA under a contract with the U.S. Department of Energy (DOE). It recaps and underscores the positive development that has taken place in both research and field development in the U.S. Geothermal Community from 1974 to 1984. Because of the size of the volume, it will be run in the BULLETIN in three parts. This is part two.

Developments in Power Conversion Technology

Industry is currently commercializing the flash steam technology on its own, with minimal recent assistance from government. DOE, on the other hand, has been concentrating its resources on binary technology in an effort to reduce its cost to a level that will be economically attractive for the use of moderate-temperature reservoirs 150°-200°C (302°-392°F).

Lessons Learned at the GLEF

By the early 1970s when the U.S. federal geothermal program was born, hot water geothermal resources were being successfully utilized in flash steam plants in Mexico, New Zealand, and Japan. Interest in using the hot water reservoirs in this country developed concurrently and focused particularly on Imperial Valley, drawn especially by the high temperatures of the Salton Sea reservoir. This very hot, hypersaline reservoir was the subject of exploratory drilling through the 1960s, and the temperatues found — 260° - 300°C (500° - 600°F) — were uniquely suited to the flash steam technology. However, its unique salinity levels — 250,000 mg/l or over eight times the salinity of sea water — posed operating and materials problems not encountered in the development of the technology abroad. A binary cycle was initially selected as a power plant design for the site, but field tests indicating poor heat exchanger performance due to silicate scaling led to the final design of a four-stage flash/binary process.

DOE's predecessor, ERDA, joined the original team of San Diego Gas & Electric (SDG&E) and field developers Imperial Magma and New Albion Resources Co. (NARCO, a subsidiary of SDG&E) in constructing the first, and highly integrated, cooperative, jointly-funded government/industry geothermal demonstration facility the Geothermal Loop Experimental Facility (GLEF). The facility was completed in 1976 to determine the technical and economic feasibility of generating electricity from highly saline brines.

After operating for two years on the original system, the test data indicated that this was not the best system for the Salton Sea reservoir brines, although many problems had been resolved. A subsequent feasibility and risk study identified the dual stage flash cycle as the optimum technology, with scaling, corrosion, and injection as the major remaining risks. After a year's operation with this technology, a clarifier/filter brine treatment system to reduce injection well plugging was added. Solids removed downstream of the flash tank were added upstream to provide nucleation centers to reduce precipitation as scale. This equipment has proved to be a major breakthrough in utilizing highly saline brines. After generally successful tests of this system, the GLEF operation was terminated in the fall of 1979. A turbine was never added to the facility.

The four-stage flash/binary process demonstrated that relatively clean flashed steam can be produced from the saline brines and that availability factors of at least 60 percent can be achieved. The two-stage configuration demonstrated several successful scale removal techniques and provided evidence that acceptable capacity factors appeared to be feasible with added flash trains.

Thus, it was determined that commercial power generation with flash steam technology using highly saline brines would be technically and economically feasible. The significance and application of the brine treatment system developed at the GLEF to commercialization of this type of resource is discussed below in connection with other developments in brine injection.

Industry's Demonstration of Flash Steam Technology

The first U.S. power plant built to incorporate the flash steam technology was the Southern California Edison/Union Oil Co. 10 MWe plant at Brawley, California, which came on-line in June 1980, several miles from the CLEF site. The fluids of the Brawley reservoir are only somewhat less chemically hostile than those of the Salton Sea reservoir, containing approximately 100,000 mg/l of dissolved solids. Fluid temperature is in excess of 204°C (400°F).

The plant had the benefit of both the GLEF experience and earlier SCE power generation experiments with wells at the Salton Sea. To mitigate problems anticipated due to the impurities in the fluid —not normal to conventional steam plants — and to maintain reliability, redundant systems were installed in the plant and certain systems incorporated special materials. The modular energy conversion system, supplied by Mitsubishi Heavy Industries, Inc., is patterned after a plant in Japan that has been operating since 1973.

The plant offered SCE and co-owners (a consortium of the Los Angeles Department of Water and Power and the municipal utilities of Pasadena, Riverside, and Burbank) a facility for geothermal research, operating experience, and information on geothermal energy utilization with highly saline brines. It provided Union the availability of a plant to demonstrate and maintain a continuously operating brine production and injection system.

Monitoring of the Brawley facility by the Imperial County Department of Public Works detected no adverse environmental impacts. Agricultural operations continue up to the edge of the project site.

In 1982, another SCE 10 MWe flash steam plant came on-line near the Salton Sea. Union was designated as field operator by its partners in large leaseholdings in the area, Southern Pacific Land Co. and Mono Power Co. These companies conducted a field development program including drilling several new wells and construction and operation of fluid production/brine handling test facilities to determine the best methods to produce, handle, and inject the high salinity brines.

This plant has operated relatively smoothly from the start which is in large part due to a closed crystallization system for brine handling developed during these experiments to concentrate the solids. Scaling and corrosion problems are not all resolved at this plant, but operation was optimized by incorporating improvements indicated by operations at the Brawley plant.

After four years of operation, the latter has achieved a cumulative on-line factor of 71 percent, and a cumulative capacity factor of 35 percent. During one 14-month period, these figures were increased to 76 and 44 percent respectively. After two years of operation, the cumulative figures for the Salton Sea plant are 83 and 75 percent. The two plants together have produced approximately 220 million kWh, the equivalent of 370,000 barrels of oil.

Lessons Learned at Baca

In 1977, Congress authorized DOE to cost-share a 50 MWe plant with industry to demonstrate commercial-scale flash steam technology and to serve as a "pathfinder" for the regulatory process and other legal and institutional aspects of geothermal development. Such a plant was planned for the Valles Caldera in north central New Mexico, site of the Baca reservoir, with participation by the Union Oil Co. and the Public Service Co. of New Mexico.

Union had conducted considerable exploration in the area for several years, and its successful wells and surface geologic, geophysical, and geochemical surveys indicated that there was very little risk that the reservoir could not support plant requirements. In addition, the U.S. Geological Survey had estimated that the reservoir would support 2700 MWe capacity for power generation. The resource failed, however, for reasons that are still not clearly understood, a failure that has led to disagreement in the scientific community as to the geologic features responsible for the high-temperature, hot water production at Baca.

The result of the reservoir failure to produce as expected was mutual agreement in January 1982 to abandon the project. However, all parties to the project felt that, although it did not serve its intended purpose, many valuable lessons were learned, and considerable experience for future application was gained from it. In addition, the wealth of data gathered at Baca will provide guidance to the National Academy of Sciences Continental Scientific Drilling Project.

Industry's Demonstration of Binary Technology

Concurrently with its involvement with the GLEF, Magma Power Co. designed and constructed a 10 MWe dual binary plant at East Mesa which came on-line in January 1980. The plant is currently operating efficiently, and the power generated is sold to Southern California Edison. However, this level of performance was achieved only after solutions to initial difficulties were found.

This plant utilizes the patented Magmamax process which pumps the hot geothermal fluid through a heat exchanger where isobutane working fluid is vaporized to drive a turbine. The vapor is condensed by cooling and returned to the heat exchanger system. The spent geothermal fluid is injected back into the reservoir to complete an environmentally-benign closed cycle. A second parallel power loop uses propane as a working fluid.

After two years of spasmodic operation, a major reconstruction was undertaken under the direction of the Dow Engineering Co. A new main turbine was installed along with redesigned heat exchangers. Since starting up again in the fall of 1982, the plant has achieved a high availability operation of over 98 percent. A shell-and-tube heat exchanger is employed with the very benign East Mesa reservoir fluid which contains only about 7500 mg/l of solids.

DOE's Binary R&D

DOE efforts to reduce the costs of binary cycle technology are focused on three major components — heat cycle efficiency, optimum working fluids, and downhole pumps that will function properly in the high temperatures and chemical environments of geothermal wells. The Heat Cycle Research Facility (HCRF), a 60 kW experimental binary cycle, has been used extensively to investigate various concepts and/or components. It was first employed at the Raft River Geothermal Site in southeastern Idaho to test a shell-and-tube binary cycle. The principal objectives achieved were: 1) operational experience with a binary cycle facility of a size that would allow the experience gained to be generally applied to full size power plant operation; 2) demonstration that cycle prediction methods and fluid properties result in satisfactorily component and plant performance; and 3) demonstration of the feasibility of running a binary geothermal power plant in an automatic run mode.

The HCRF was then modified to incorporate a sieve tray direct-contact heat exchanger (DCHX) in order to confirm thermodynamic analyses that indicated that direct contact cycles should be able to attain geofluid effectiveness levels essentially equivalent to those produced by shell-and-tube binary cycles. The DCHX units themselves would be less costly than the expensive internal components needed for shell-and-tube exchangers and would have the added advantage that they contain no heat transfer surface to be fouled by the geothermal fluid. However, in this type of heat transfer, working fluid is entrained and dissolved in the geothermal fluid which necessitates recovery of the working fluid to minimize losses.

In tests of the sieve tray DCHX at Raft River and extensive testing of an open column 500 kW DCHX unit at DOE's East Mesa Geothermal Test Facility (GTF), some with pure hydrocarbons and some with fluid mixtures, both achieved excellent heat exchange performance. However, these tests have shown that due to the added costs of working fluid recovery and other ancillary equipment needed to operate the DCHX units, there is no particular economic value in their use with benign fluids that permit the use of moderate-cost heat exchanger tubing. On the other hand, the tests have also shown that if a resource requires the use of exotic tubing materials that would adversely impact the cost of electricity produced, the direct contact heat exchanger could become an economically justifiable alternative. Testing of a hypersaline brine is planned for the future.

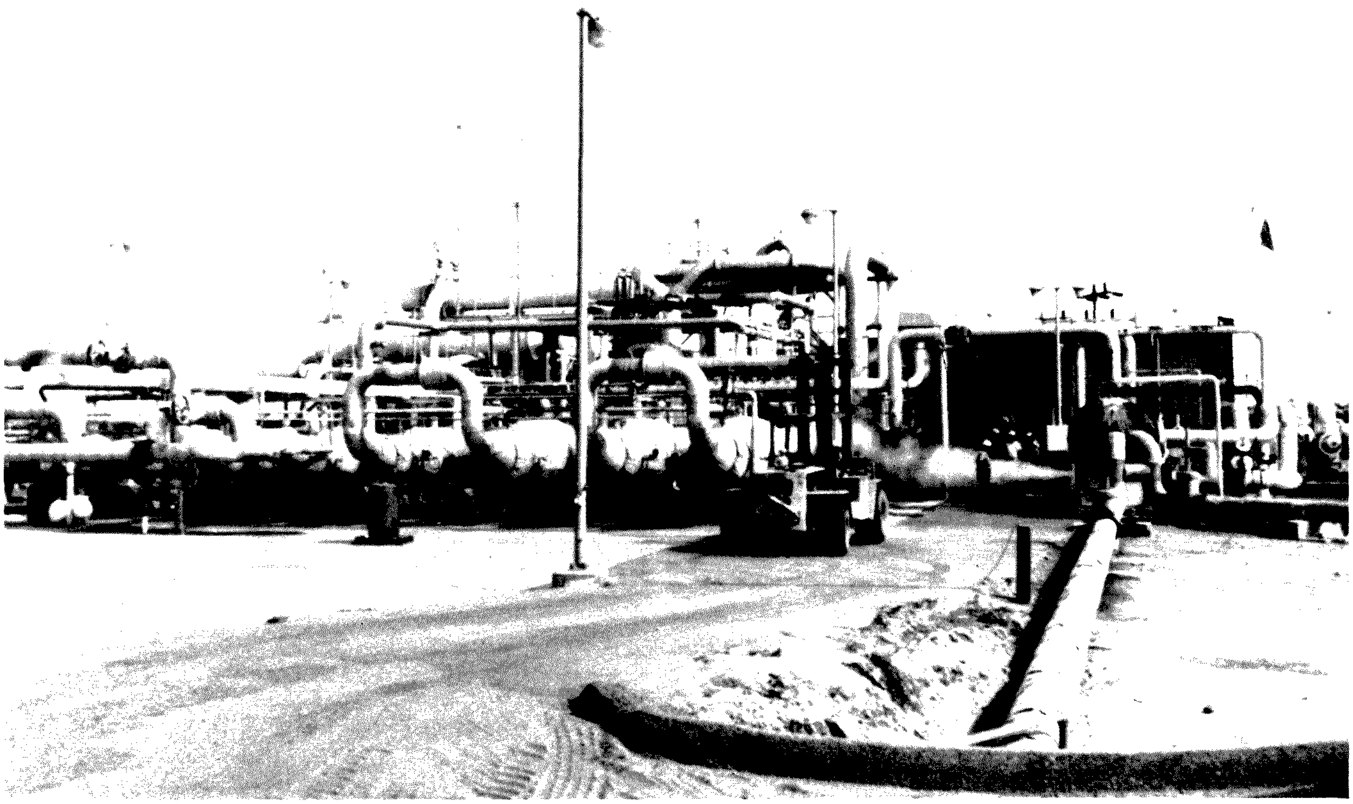
The HCRF has now been moved to the GTF where it is operated currently as a supercritical cycle. Condensing of the working fluid is accomplished by a single countercurrent flow heat exchanger with the working fluid in the tubes. After tests with the condenser in a vertical attitude, tests will be performed at other positions.

Early conclusions from these tests include:

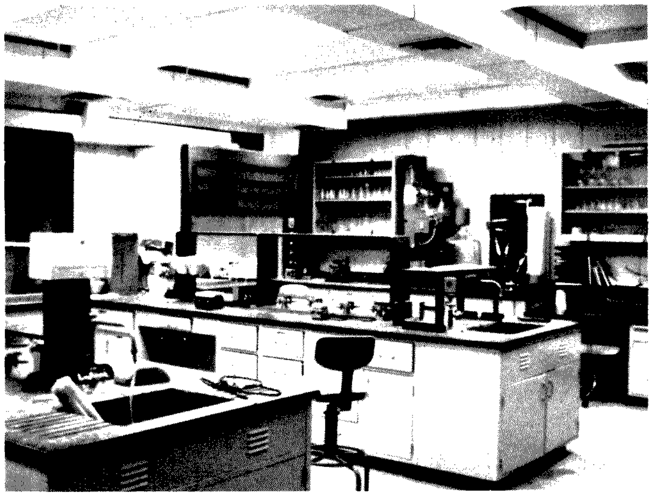
- A geothermal power system utilizing a hydrocarbon mixture as a working fluid with a supercritical cycle is operable.
- The thermodynamic and transport properties of the DOE-funded National Bureau of Standards computer code EXCST are the most accurate in predicting the thermal behavior of the heat exchangers.

A larger binary unit — 5 MWe — was also installed at the Raft River site to test performance with isobutane and state-of-the-art components. Completion of the plant coincided with reduced federal budgets, and only short-term tests were conducted. On the basis of calculated results, the performance of the system was approximately as predicted, and component problems were determined to be the cause of a somewhat lower power output than anticipated. The tests indicated that the system is technically viable and permitted formulation of recommendations for future use of this type of equipment.

DOE also funded development of another type of binary plant called the "gravity-head" system. In this technology, the primary heat exchanger is utilized downhole in the production well, an arrangement projected to allow



Magma Power Co. geothermal binary power plant at East Mesa, being enlarged from 10 to 12.5 MWe.



Chemical laboratory available to the public at DOE Geothermal Test Facility (GTF) at East Mesa, California. Open to private and institutional experimenters at a nominal charge, the facility also provides geothermal fluid and support services for tests of heat extraction and energy conversion equipment and materials. The laboratory is equipped with modern, sophisticated equipment such as an atomic absorption spectrophotometer and a gas chromatograph.

better matching of inlet/outlet conditions, and thus to increase the net power output by about 50 percent over that of conventional binary plants under equivalent conditions and costs. This equipment may see commercial operation in the near future.

Improvements in electric submersible pumping systems have resulted in a demonstrated downhole running life of one year for low horsepower units operating in 177° C (350° F) brine. A prototype pressurized lubrication system to prevent brine intrusion and loss of lubricating oil from the motor and protector sections has been successfully tested. Second generation pressurized lubrication systems have been designed, and a prototype metal-sheathed power cable is currently undergoing destructive and nondestructive laboratory testing. This cable has the potential for eliminating brine intrusion into the power delivery system through the use of a hermetically-sealed cable from the surface to the downhole motors.

Proof of Binary Concept in Large Scale Plant

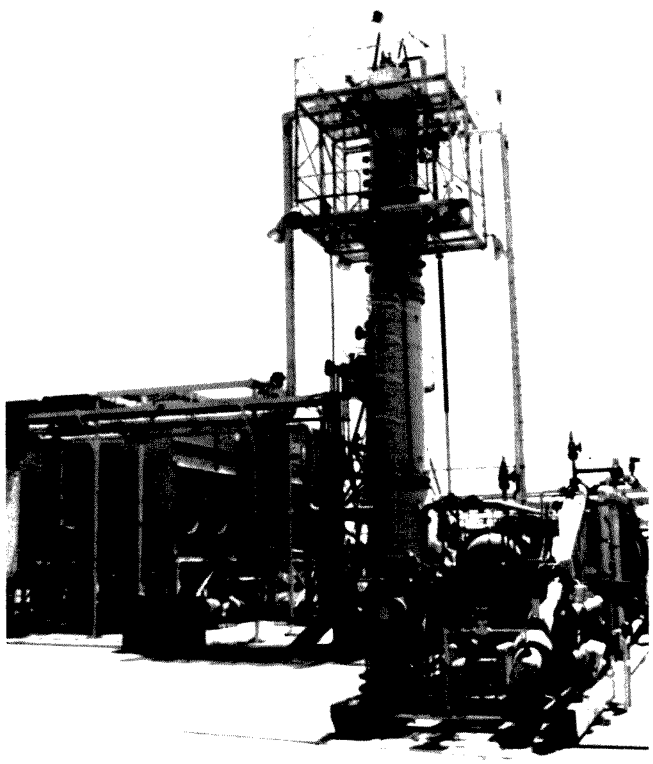
All of the more promsing binary technologies developed through nearly a decade of R&D — and some specifically designed for the plant — are incorporated in the 45 MWe proof-of-concept binary plant at Heber (Figure 4). The turbine roll at the plant was expected in the spring of 1985, and construction reported on schedule and within budget. The plant will be the largest of its kind anywhere in the world, and is designed to establish the economics and prove the operational viability of binary cycle technology. It is expected that the information obtained will be transferable to a wide range of moderate-temperature, low-salinity hydrothermal reservoirs. (*EDITOR'S NOTE: The plant was completed and began operation in June 1985*).

Funding for the plant was provided primarily by San Diego Gas and Electric Co., manager of the project, and DOE, although contributions have also been made by the Electric Power Research Institute (EPRI), the State of California, the State's Department of Water Resources, the Imperial Irrigation District, and Southern California Edison. EPRI and SCE, along with DOE, are non-owner participants.

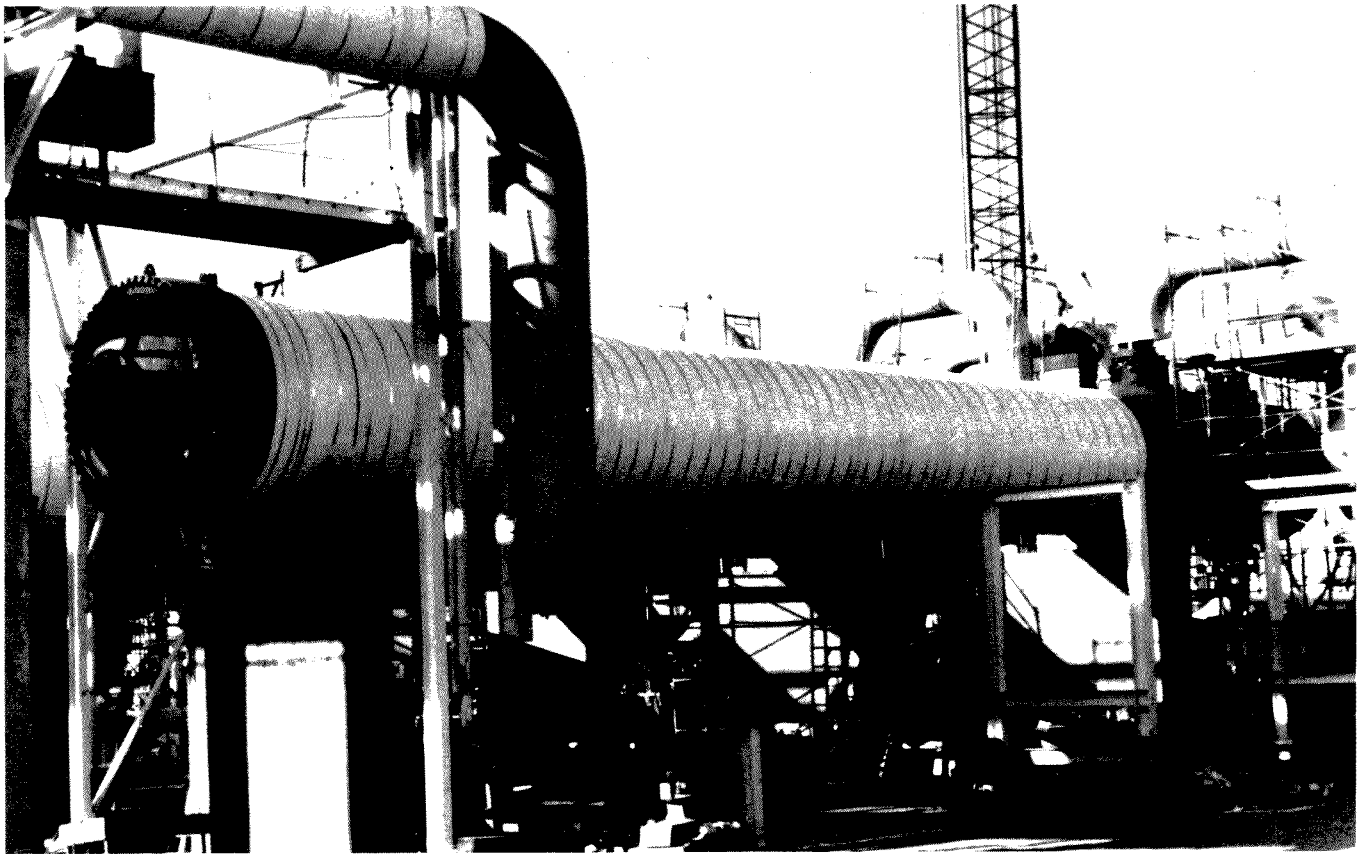
The plant will use a supercritical Rankine cycle with a 90-10 mixture of isobutane and isopentane as the initial working fluid. The shell-and-tube heat exchangers and condensers are the major capital-intensive components, representing about 30 percent of the total investment in plant construction. As the result of an extensive cost reduction study, major economies were effected.

SDG&E's contract with Union Oil Co. of California and Chevron Resources Co. features a phased approach to the development of the geothermal reservoir. The initial geofluid delivery, which will be sufficient to permit filling and check-out of the in-plant brine handling equipment, will be periodically increased to full load requirements in early 1986 if the plant and fluid production are operating as expected.

A major uncertainty has surrounded the specifications for a hydrocarbon turbine due to the lack of existing machines of similar size. A four-stage, 3600 RPM, double flow, axial turbine was purchased from the Elliott Company, a division of United Technologies, which will provide a net plant output of about 45 MWe with a gross rated output of 70 MWe. An Electric Machinery Co. generator with brushless excitation will be used with it.



Heat Cycle Research Facility, currently located at the GTF.



Shell and tube heat exchanger at Heber 45 MWe binary plant. Eight of these 160-ton, 27-meter-long by 2-meter diameter devices are used to transfer geothermal heat to an organic working fluid. Tubes are made of high chromium ferritic stainless steel to minimize corrosion and scaling.

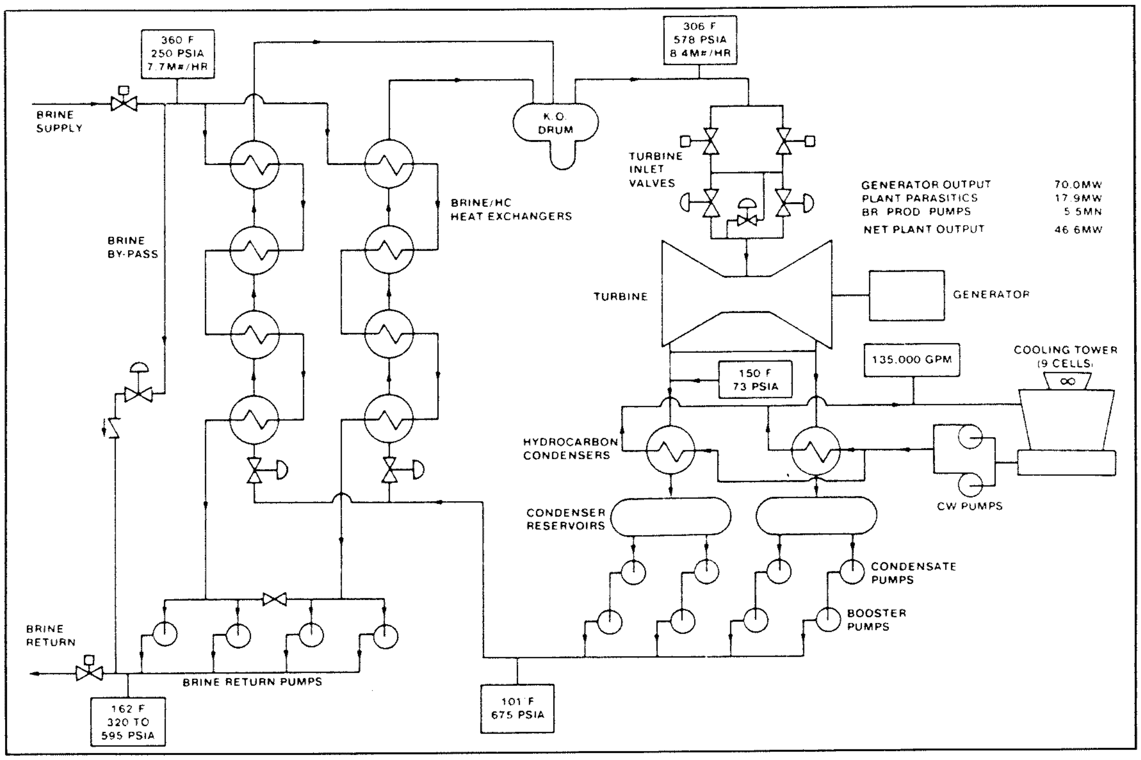


Figure 4
Heber 45 MWe Binary Plant Diagram with full load stream conditions at 55°F WBT.

Developments in Direct Use Technologies

In 1978, DOE created the Project Opportunity Notice (PON) program to stimulate direct use of low temperature — less than 93°C (200°F) — hydrothermal resources. Since projects were unable to obtain private financing due to immaturity of the technology, the PON program was designed to provide federal cost-sharing with the private sector. Twenty-three projects were selected to serve as field experiments to demonstrate the technical and economic feasibility of direct heat systems. (Table 5).

The program produced five successful district heating systems in Boise, Idaho; Elko, Nevada; Klamath Falls, Oregon; Pagosa Springs, Colorado; and Susanville, California. All of them have been, or will be, expanded since DOE participation ended. Two other proposed district heating systems — in Roxbury, Idaho, and Monroe City, Utah — were not realized due to an inadequate resource. Another system — in the Moana area of Reno, Nevada — has been delayed due to contractural difficulties, but is expected to be successful in the future.

Six successful institutional space heating projects resulted from the PON program, serving a school, YWCA, prison, and hospitals. Only two projects of this type failed due to drilling failures, one was only marginally operable, and one was cancelled due to archeological finds in the area.

A large commercial greenhouse, a 50-acre aquaculture project, and a cascade application to combine agriculture and aquaculture round out the achievements of the PON program. One vegetable processing application failed due to inadequate resource flow.

The completion rate of the projects of almost 70 percent is significantly higher than the national average for geothermal well completions — 47 and 22 percent respectively in 1980 and 1981. According to DOE project managers, the success rate of the PON projects is the result of these factors.

- completion selection of only the most promising projects
- selection criteria for the projects (resource, project team, application, and economics)
- technical assistance provided by DOE's Field Operation Offices
- exposure of each project to the experience of other projects at project review meetings.

It is difficult to assess the overall success of the PON program in stimulating direct use projects. DOE field managers report considerable contact with potential developers, but whether privately-funded projects are the direct result of the program cannot usually be determined. However, one project, the aquaculture/agriculture operation at Navarro College in Corsicana, Texas, is spawning offshoot commercial applications. While the two-acre prawn-greenhouse-catfish cascade system at the college was not designed to pay back its own costs, a similar 250-acre commercial operation is planned for Burnes, Oregon, and funding is being sought for a freshwater shrimp, catfish, and crayfish operation in southern Arkansas. The geofluid will also heat a greenhouse and eventually a cannery in the latter 3000-acre complex.

Subsequent to the PON program, DOE entered a cooperative agreement with the state of New York and state utilities to provide partial funding for a geothermal heating system for two schools in Auburn, New York. This sytstem, which is still under construction, is the first direct use of geothermal energy in the Northeast. Other communities in the area are watching development of this project with considerable interest.

In order to further stimulate interest in direct applications of geothermal energy, DOE has awarded a technology transfer contract to the Geo-Heat Center at the Oregon Institute of Technology. It is working with potential users, consultants, industry organizations, engineers, and state energy offices upon request to provide direct technical/economic feasibility analysis for those actively involved in geothermal development.

This is an outgrowth of DOE's earlier Geothermal Program Research and Development Announcement (PRDA) progam which consisted of a number of studies of the engineering and economic feasibility of specific direct use applications. A large body of valuable information on direct use technologies resulted.

Development in Injection Technology

Geothermal electric power production and most direct use applications involve the production of large quantities of geothermal fluids. Surface disposal is only theoretically possible in cases where the geothermal fluid is pure enough to avoid adverse environmental consequences. In other instances, the fluid must be disposed of by subsurface injection.

If the spent fluid is not injected into the producing reservoir, the system may be depleted, resulting in insufficient fluids for production, subsidence, or both. While injection into the producing reservoir will recharge the system, short-circuiting of the fluid to the production zone before sufficient heat is transferred to it from the formation must be avoided. The resulting production temperature decline could be disastrous for the energy conversion process.

These problems have been studied extensively since the inception of the federal geothermal program. Mathematical modeling, primarily at Lawrence Berkeley Laboratory and Stanford University, has been used to attempt to understand flow and heat transfer mechanisms in geothermal reservoirs. The use of tracers in reservoirs has been valuable in understanding the behavior of injected fluid. Much R&D has been devoted to tracer studies, resulting in improved tracing agents and a better understanding of the tracer/formation interaction. Injection/backflow (or "huff-puff") tests, performed by the University of Utah Research Institute and the Idaho National Engineering Laboratory, have yielded information on injection behavior using individual wells and short-term tests. This avoids the high cost and extremely long duration of borehole to borehole experiments.

TABLE 5

DOE DIRECT USE FIELD EXPERIMENTS
(Cost-Shared with Private Sector)

PROJECT/LOCATION	USE	STATUS
AQUAFARMS COACHELLA, CA	• Aquaculture	• Supplying heated water for 50 acres of ponds filled with prawns, catfish, carp, and Japanese koi.
BOISE GEOTHERMAL BOISE, IDAHO	• District Heating System	• City system. Operating and adding Customers.
DIAMOND RING RANCH HAAKON COUNTY, SD	• Space Heating; Agriculture	• Was operated, but unused while ranch for sale and unoccupied.
DOUGLAS HIGH SCHOOL BOX ELDER, SD	• Space Heating	• Discontinued when school could not provide well. Drilling failure.
EL CENTRO COMMUNITY CENTER EL CENTRO, CA	• Space Heating & Cooling; Domestic Hot Water	• Wells needed rework. No additional funds available from city. Wells plugged and abandoned. Site restored.
ELKO HEAT CO. ELKO, NV	• District Heating System	• Privately-owned company. Operating and adding customers.
HAAKON SCHOOL PHILLIP, SD	• Space Heating	• Operating and cascading to business district customers.
HOLLY SUGAR CORP. IMPERIAL VALLEY, CA	• Industrial Processing	• Well plugged and abandoned due to inadequate reservoir flow.
KELLY HOT SPRINGS, CA	• Space Heating	• Discontinued due to historical value of archaeological finds in the area.
KLAMATH FALLS GEOTHERMAL KLAMATH FALLS, OR	• District Heating System	• Part of system operated for 4-month test during spring of 1984. Will be operated during 1984-85 heating season as further test. Institutional problems being resolved.
KLAMATH COUNTY YMCA KLAMATH FALLS, OR	• Space Heating; Water Heating	• Operating.
MADISON COUNTY REXBURG, ID	• District Heating System	• Discontinued. Inadequate resource temperature (70°F).
MONROE CITY, UTAH	• District Heating System	• Discontinued. Inadequate resource flow, deteriorated market, and increased cost.
NAVARRO COLLEGE CORSICANA, TX	• Aquaculture; Agriculture	• Operating. First harvest produced catfish, prawns, and 400 pounds of tomatoes.
ORE-IDA FOODS, INC. ONTARIO, OR	• Industrial Processing	• Discontinued. Inadequate resource flow. Bottomhole temperature 380°F.
PAGOSA SPRINGS, CO	• District Heating System	• Operating.
ST. MARY'S HOSPITAL PIERRE, SD	• Space Heating	• Operating on direct-use and with heat pump from 108°F resource.
T.H.S. HOSPITAL MARLIN, TX	• Space Heating; Domestic Hot Water	• Operating and easily meeting heating needs.
UTAH ROSE, INC. SANDY, UT	• Agriculture	• Operating and effecting considerable savings in fuel costs.
UTAH STATE PRISON DRAPER, UT	• Space Heating; Domestic Hot Water	• Operating on natural carbon dioxide artesian lift.
WARM SPRINGS HOSPITAL DEER LODGE COUNTY, MT	• Space Heating Domestic Hot Water	• Operating.
MOANA RENO, NV	• District Heating System	• Project undergoing reorganization.
SUSANVILLE GEOTHERMAL SUSANVILLE, CA	• District Heating System	• Operating and adding customers; plans to cascade to industrial users.

Vertical crystallizer tanks of a flash steam plant near the Salton Sea. This technology was developed at the GLEF especially to tap the Salton Sea reservoir's very desirable high temperature and 3,000 to 4,000 MW_e electric generation potential. The crystallizer/clarifier concept will be used at many other high salinity sites. *(Courtesy of Goslin Birmingham, Inc.)*

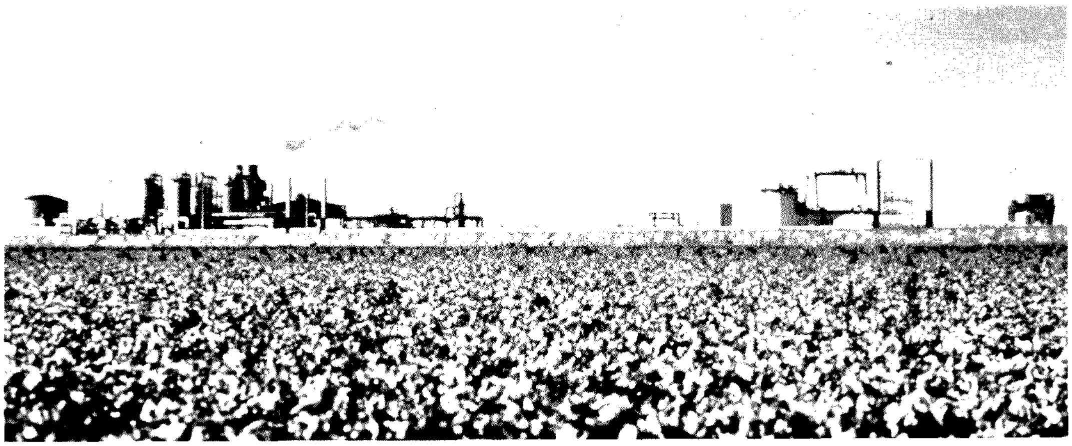
The other major problem in brine injection is the precipitation of scale from the brine which, in an injection well, will block the flow paths and require either expensive workovers or the drilling of a new well. The Geothermal Loop Experimental Facility provided the opportunity to identify problems in working with highly saline brine and to develop solutions for both electric power plants and injection systems. The reactor-clarifier treatment system used at the GLEF has removed some of the barriers to development in the highly saline areas in the Imperial Valley. Plants currently under construction near Niland are using modifications of the technology developed at the GLEF.

Experiments have shown that suspended solids are not constant from a given well, varying from day to day and even hour to hour. In order to obtain useful information on brine chemistry, DOE is supporting R&D at Battelle Pacific Northwest Laboratories for continuous monitoring instrumentation of suspended solids in the brine as well as other on-line control instruments.

Improvements in Environmental Control

The type, severity, and acceptability of environmental impacts from geothermal development are very site-specific, depending on the geothermal fluid characteristics; the topographic, geologic, hydrologic, and tectonic features of the site; other development in the area; the pre-existing quality of the environment; and the type of geothermal utilization system. Potential environmental problems and effective control technologies of geothermal energy utilization are identified in Table 6.

Figure 5 shows a schematic of a hydrogen sulphide abatement system in operation at The Geysers Geothermal field.

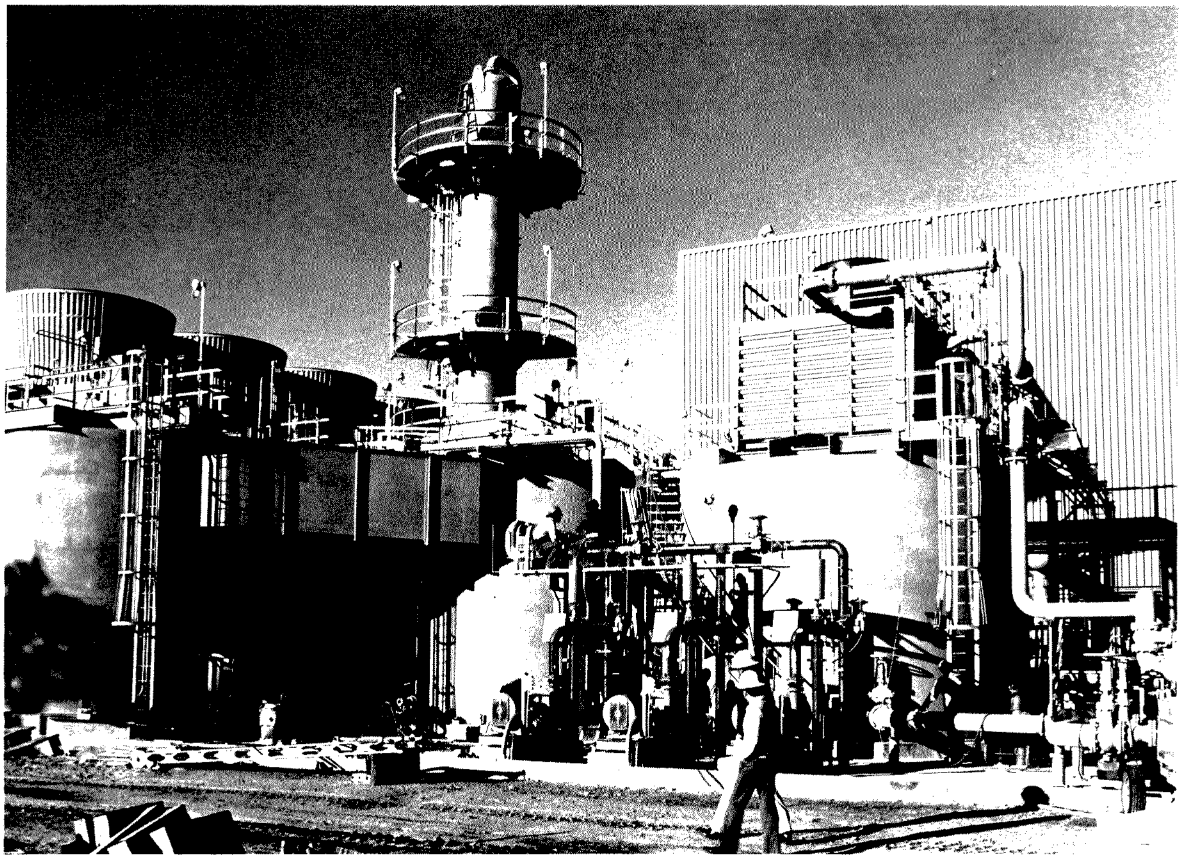


Irrigated fields grow up to boundry of 10 MW_e Salton Sea geothermal flash plant. The onset of geothermal development in the Imperial Valley created much concern about the potential adverse effects it might have on the Valley's agricultural economy. Many local organizations, government agencies, and individuals participated in the five-year Imperial Valley Environmental Project, initiated in 1975 and funded by a predecessor to the Department of Energy. The project developed the impartial information needed to guide geothermal development in the area and prevent damage to the Valley's ecology or economy.

Table 6

POTENTIAL ENVIRONMENTAL PROBLEMS IN THE GEOTHERMAL DEVELOPMENT AND EFFECTIVE SOLUTIONS

PROBLEM	SOURCE/CAUSE	ABATEMENT/CONTROL/DISPOSAL METHODS	STATUS
Air emission	• H_2S emission from The Geysers production areas and power plants	• Stretford Scubbing Process	Most commonly used in recent years
		• Dow RT-2 Technology Process	Existing plants at The Geysers being retrofitted with process — reduced cost and no need for toxic waste disposal
		• Bechtel Upstream Boilers	New technology as yet untried commercially
		• H_2S control methods developed and tested by DOE	
		— EIC Copper Sulfate System	Not economical
		— UOP Catalytic Oxidation Process	Successful test
		— Sheinbaum Direct Chlorination Process	Economically competitive with other processes
		— Research Cottrell/Ion Physics E-Beam	Mixed results
Liquid discharges	• Spent geothermal brine	• Usually subsurface injection	Injection technology available, improvements in economics and environmental acceptability needed
	• Cooling water	• Prior surface treatment if needed	
	• Liquids from air pollution abatement and solid waste treatment	• Surface discharge of uncontaminated fluid when suitable water body is available	
	• Spills		
Wastes for land disposal	• Residual sludge from abatement systems	• Sanitary landfill for innocuous wastes	Techniques available
	• Scale material	• Hazardous waste disposal for those deemed by state/federal regulation to be hazardous	
	• Drilling muds		
	• Rock cuttings		
	• Oils (e.g., drilling lubricants)		
Subsidence	• Large volume withdrawal of geothermal fluids	• Proper site selection	Techniques appear to be effective
		• Appropriate well spacing	
		• Controlled fluid extraction and injection rates	
		• Effective monitoring	
Seismicity	• Fluid extraction or injection	• Careful siting	Techniques appear to be effective
		• Knowledge of local seismic history	
		• Controlled fluid extraction and injection rates	
		• Effective monitoring	
Noise	• All operations in which steam is released to the atmosphere (e.g., well testing, steam separation, "stacking" or excess steam)	• Mufflers and silencers	Equipment is meeting noise requirements at The Geysers
	• Air drilling	• Blood line	"Temporary" noise is sometimes exempt from regulation



A Stretford H_2S emission control system on PG&E Unit 15 at The Geysers. *(Courtesy of Pacific Gas and Electric Co.)*

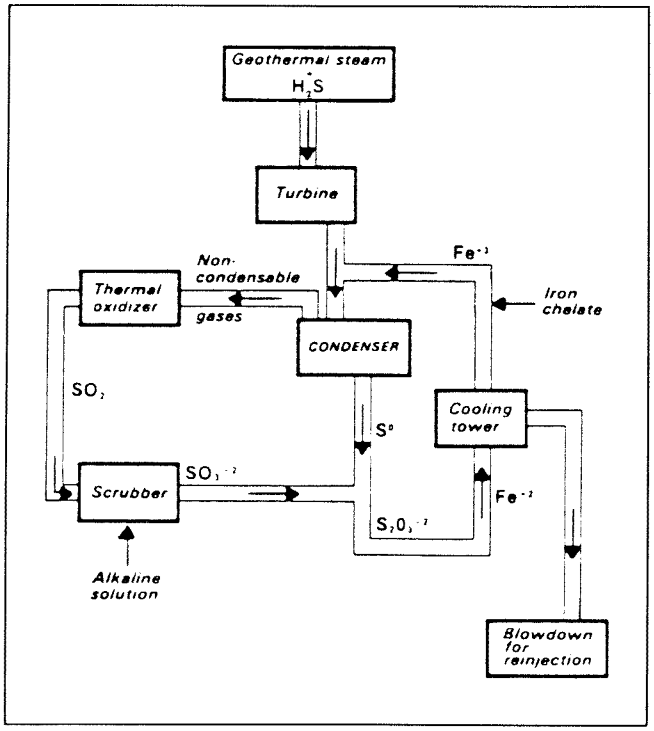


FIGURE 5

Dow RT-2H_2S abatement system in use at The Geysers. The process converts the gas to a soluble sulfur compound that is injected back into the formation, and produces no toxic wastes. *(Courtesy of Dow Chemical Co.)*