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ADVANCES IN GEOTHERMAL ENERGY RESEARCH

AN OVERVIEW

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ABSTRACT

Geothermal energy has been touted as one of the more promising alternate energy sources for meeting projected U. S. energy demands by the close of this century. And yet very little advance in the development of a geothermal industry is readily apparent, save for the steadily growing Geysers electric power station in California. Much of the problem lies in the complex nature of the vastly unexplored resources of geothermal deposits, which occur in a variety of geologic, thermal, and chemical qualities. Much of the problem lies in the prime emphasis of geothermal development solely as a resource for base-load electricity generating capacity with an energy source that may be more significant for direct heat applications. And much of the problem, in common with other alternate energy sources, lies in the institutional problems created by environmental and regulatory requirements for public acceptance.

Research to stimulate the development of geothermal energy is underway in the public and private domains essentially over the entire "fuel cycle" from exploration to utilization. The acceleration of industrial development of the nation's geothermal resources requires parallel advances in the establishment of adequate reserves of commercial-grade resources, demonstrated technologies for utilizing the more abundant lower-grade resources, and resolution of some of the institutional impediments to a cost-effective industry. Significant advances have been made in each of these three major areas of concern. And yet, many more are required before geothermal resources can provide a significant fraction of the nation's energy supply.

A description of advances in geothermal energy research implies that there is a known baseline for comparison. Where does one find such a baseline? This mini-conference can be considered to be the second Special Session on Geothermal Energy held by the American Nuclear Society. The first Special Session was held during the Society's Annual Meeting in Las Vegas, Nevada in June, 1972. The Special Session was a general conference on the state of the art of this emerging energy source, covering three major aspects: the resource, production technology, and potential stimulation methods. A major result of this conference was a proceedings (Kruger and Otte, 1973) which compiled the available technology for geothermal energy development over the entire "fuel cycle" from exploration to utilization. Senator Alan Bible of Nevada, in the Foreward, likened geothermal energy to a sleeping giant among the nation's energy resources. He commended it as a national resource meriting expert attention and noted that it was time to awaken this sleeping giant and put it to work!

It is almost five years since the ANS Special Session on Geothermal Energy. What better baseline than the proceedings of that conference to assess the advances in geothermal energy research? Because of the need for local utilization of geothermal heat, the geothermal "fuel cycle" must be completed at the resource site. Steps in the cycle consist of resource exploration and evaluation, reservoir development, energy extraction, and utilization either by conversion or direct thermal application. The geothermal energy cycle, although simple compared to other alternate energy sources, is actually complex in that geothermal resources occur in several types of geologic, thermodynamic, hydrodynamic, and chemical quality. As a result, major problems in the energy cycle vary by type of resource.

Although geothermal resources are used in some cold climates for space and other heating applications, the primary utilization throughout the world is for electric power production. Electric energy generating capacity in the United States has grown from 396 MW in 1973 to 502 MW in 1976, at an average growth rate of almost 8% per annum. Total world capacity, as noted in Tab , has grown to about the equivalent of one modern nuclear power plant. The average rate over the 3-year period has been 5% per annum, a value that might be considered small for an alternate energy source that has received much attention both nationally and internationally for more than a decade.

Constraints to a rapid development of geothermal energy resources, at least in the United States, exist over the total fuel cycle. The major ones are listed in Table 2. Adequate reserves have not been established; total growth in U. S. capacity has occurred at only one site, The Geysers, where the resource is available as steam, suitable for economic conversion into electric energy. Environmental and regulatory problems have delayed the growth rate of even this high-quality type of geothermal resource. Demonstration of conversion technology of other than vapor-dominated hydrothermal resources is generally deemed to be needed to show adequate cost effectiveness. ~~Research and development~~ has been undertaken as a Federal program since about 1972. During these five years, some research and development, no demonstration plants, and much discussions have been accomplished. However, the ongoing research and development programs of the Federal agencies, the private institutions and industrial organizations, together with planned demonstration projects, announced resource developments and potential legislative and regulatory encouragement, indicate the possibility of a more rapid growth in the utilization of the nation's geothermal resources.

GEOTHERMAL RESOURCES

The establishment of adequate U. S. indigenous reserves is considered to be a key factor in providing incentives for a national effort to develop geothermal resources. And yet, if electricity can be generated at a competitive cost, utilities are willing to construct generating facilities as local reserves are proven. Thus, the utilization of geothermal resources for electric power production has no resource threshold. Forecasts of U. S. geothermal electricity generating capacity for 1985

TABLE 1

ELECTRICITY GENERATING CAPACITY FROM GEOTHERMAL RESOURCES

	1973 INSTALLED CAPACITY (MW)	1976 INSTALLED CAPACITY (MW)	GROWTH RATE (%/YR)
UNITED STATES	396	502	7.9
ITALY	406	421	1.2
NEW ZEALAND	170	190	3.7
MEXICO	75	75	0
JAPAN	33	68	24.1
SOVIET UNION	5.7	5.7	0
ICELAND	2.5	2.5	0
TURKEY	0	0.5	-
TOTAL	1089	1265	5.0

TABLE 2

CONSTRAINTS TO GEOTHERMAL RESOURCES DEVELOPMENT

Adequate Resources

- Hydrothermal
- Petrothermal

Cost-Effective Utilization Technologies

- Electricity Conversion
- Direct Thermal Energy Uses

Institutional Impediments

- Environmental Quality Control
- Legal and Regulatory Decisions

have varied considerably, but as noted in Table 3, they have generally declined over the 5-year period to about 2000 to 3000 MWe. The last forecast shown, prepared from data of the western electric utilities (NERC, 1976), is about four times the present installed capacity at The Geysers, indicating an average growth rate of about 17% per annum. Data for California utilities from the 1976 biennial forecasts (Dutcher, 1977) show an estimated growth, under adverse hydro conditions, to 3.86 GWe by 1995, indicating a growth rate of about 11% per annum over the 20-year period.

These forecasts by the electric utilities come at about the same time that the first major assessment of the U. S. geothermal resource base was published by the U. S. Geological Survey (White and Williams, 1975). From the data, summarized in Table 4, the potential for electric energy generation at recoverability costs at about twice present costs was estimated as 42,000 MWe centuries. The potential from essentially undeveloped geopressured and petrothermal (hot, dry rock) deposits are much greater. Certainly, the incentive to develop the U. S. indigenous sources of geothermal energy exists.

White and Williams (1975) identified some 65 potential hydrothermal convection resources suitable for electric energy generation in their estimates and suggested that more than 3 times the energy in these systems would be discovered in other hydrothermal systems. The exploration methods to locate such deposits have been reviewed in several publications (e.g., Kruger and Otte, 1973 and Armstead, 1973). Research needs for establishment of adequate production reservoirs include improvements in resource exploration and assessment. Many of the problem areas noted by Denton and Dunlap (in Kruger and Otte, 1973) remain unadvanced. The location of deep deposits of commercial-grade thermal energy resources, especially where surface manifestations are lacking, is at best a difficult undertaking. Exploration generally encompasses a combination of earth sciences, notably geology, hydrology, geochemistry and geophysics. The final phase of geothermal exploration is the drilling of exploratory wells. Since drilling in hostile high-temperature, hard-rock environments is much more expensive than surface measurements, continued development of the geoscience techniques for synergistic reduction of uncertainty in identifying underground thermal deposits is warranted.

Resource evaluation determines the commercial suitability of geothermal deposits. For this, better down-hole instrumentation to measure reservoir characteristics, corrected for wellbore effects, is sorely needed. Better understanding of geothermal systems to translate these measurements into reliable estimates of extractable reserves is also needed. The techniques being developed to assess hydrothermal systems may need modifications for application to geopressured and petrothermal systems. The former requires attention to the mechanical and chemical energies available in the produced geofluid while the latter requires knowledge of the extractability of energy by artificial circulation systems.

The development of geothermal engineering practice has grown markedly in the five-year period (Kruger and Ramey, 1975, 1976). Techniques for drilling, production, and reservoir engineering have been adapted from the disciplines of petroleum engineering and hydrogeology. Investigations of potential geothermal reservoirs other than dry steam have resulted in improvements in well completion, production testing, and measurements of reservoir volume, porosity and permeability. Advances have been reported in the areas of reservoir physics and chemistry, well testing, field development, stimulation techniques, and mathematical modelling of geothermal reservoirs. Some of the advances in reservoir physics include the description of geothermal reservoirs as irregularly fractured-rock systems rather than as simple formations of porous media, heat transfer properties under non-isothermal production, analysis of well tests under various production conditions, and the use of tracer components for reservoir evaluation. Several field development studies have been reported. They include the many fields in the Imperial Valley of California, the Raft River project in Idaho, the Roosevelt field in Utah, the HGP-A well in Hawaii, and several fields in Italy. Studies seeking stimulation of geothermal reservoirs

TABLE 3

FORECASTS OF GEOTHERMAL ENERGY GENERATING CAPACITY FOR 1985

SOURCE	CAPACITY (MWe)
U. Alaska, Seattle Conf., Sept. 1972	182,000
DOI, U. S. Energy thru 2000, Dec. 1972	Not Considered
NPC, U. S. Energy Outlook, Dec. 1972	3,500-19,000
FEA, Proj. Independence, Nov. 1974	20,000-30,000
ERDA, National Plan, June 1975	10,000-15,000
Oregon St. Univ., Portland Conf., July 1975	2,500-5,000
ERDA, Definition Report, Oct. 1975	6,000
DOI, U.S. Energy thru 2000 (Rev.) Dec. 1975	3,000
NERC, Elec. Utility Gen., June 1976	2,078

TABLE 4

SUMMARY OF GEOTHERMAL RESOURCE BASE OF THE UNITED STATES*

	Estimated Heat Content (10^{18} Cal)	
	Identified	Potential
Hydrothermal Convection Systems		
Vapor-Dominated (Steam)	26	50
High T - Hot Water (T > 150°C)	370	1,600
Mod T - Hot Water (90° - 150°C)	345	1,400
Total	740	3,000
Hot Igneous Systems		
Magma and Hot Rock	25,000	100,000
Geopressured Basin Part of Regional Conductive Systems	10,920	44,000
Total Resource Base	36,660	147,000

*From White and Williams (1975)

include methods for individual well stimulation by explosive and hydraulic fracturing and by injection recharge or artificial circulation systems. Results from the LASL project in New Mexico (Blair et al, 1976) indicate that hydrofracturing may be successful in opening low permeability geothermal resources. Further research is needed to determine the characteristics and optimum means for extraction of petrothermal deposits. Studies on heat extraction from fractured rock by circulating fluids are proceeding in several programs. Advances have occurred in detailed mathematical and numerical modeling of geothermal reservoirs, both for individual reservoirs and for specific effects, such as heat transfer or field subsidence. Reservoir models have been developed for vapor-dominated fields at The Geysers and Larderello, and for liquid-dominated fields, such as at Wairakei, New Zealand, Long Valley, California, and the geopressured fields along the Gulf Coast.

Utilization of geothermal fluids is generally considered to be the production of electric power. And yet it has been widely noted that non-electric applications may be the long-range benefit of geothermal resource development. The research activity in both of these forms of utilization has not progressed very far in the past five years. Developments of The Geysers electric power station are continuing in increments of 110 MWe as additional quality steam supply is proven. In 1972 the technology for higher-quality liquid-dominated geothermal energy conversion by surface flashing to steam was at hand in Wairakei, New Zealand, and in preparation at Cerro Prieto, Mexico. A description of the vapor turbine (binary cycle) conversion technology was given by Anderson (in Kruger and Otte, 1973). Plans to demonstrate the economic feasibility of a nominal 25-50 MWe power plant using a binary cycle system have been developing slowly. Tests of major components, such as downhole pumps and heat exchangers, are slowly evolving from the research funded by the National Science Foundation, the Electric Power Research Institute (EPRI), and joint programs between the Energy Research and Development Administration (ERDA), and private industry. A parallel set of research results are expected for the chemical problems of geothermal brines such as scaling and corrosion in surface equipment, non-condensible gases in operational and environmental aspects, and reinjection of spent brines.

The announced plans of a demonstration binary cycle plant in the Heber area of Imperial Valley by EPRI in conjunction with San Diego Gas and Electric Company and other utilities, and possibly with ERDA, represents an earliest date of 1980 for viable economic feasibility. This first demonstration plant might be operated for a while before commitments for other units are undertaken. The growth of utilization of liquid-dominated geothermal resources may not occur until late in the next decade.

Perhaps an alternate means of accelerating the development of geothermal resources for electric energy generation could result from research for small-size, portable (e.g. skid-mounted) generators. Such generators, in sizes from 1 to 15 MWe could be installed as individual geothermal wells are brought on-line. Development of this concept will also require research into the gathering of high-voltage lines rather than hot water and steam lines. When field capacity exceeds 50 to 100 MWe, construction of a stationary power plant can proceed while the mobile plants are in operation. The mobile plants can be "recycled". Possible but untested advanced technologies for such generators include the total-flow turbine, the bladeless turbine, and the helical-screw expander.

From a consideration of efficiency, non-electric utilization of geothermal energy should be a prime contender. The overall efficiency of utilization of geothermal resources for electric power production is at best less than 15 percent, in many cases less than 10 percent. Efficiencies can be many times higher in such applications as space heating, water heating, air conditioning, refrigeration, greenhouse heating, lumber or crop drying, and industrial process steam. An analysis of the energy cost-intensiveness of such applications by Reistad (1975) indicated a significant fraction of U. S. energy consumption could be satisfied by geothermal energy. From an economic point of view, the optimum situation would be a total utilization of the geothermal resource combining an array of non-electrical applications, both municipal and industrial, with an electric power generating station. How to achieve demonstration of economic feasibility on non-electric applications and how to interest electric or public utilities in selling hot water remains an area of research in institutional problems.

Many other technical-institutional problems remain. One of these is the problem of environmental protection. Table 5 shows an array of the land, water, and air quality factors affected by geothermal resource development. These have been described by Bowen (in Kruger and Otte, 1973) and reviewed in several symposia (e.g. NSF, 1974 and Lake County APCD, 1975). The major problems that continue unresolved include land-use planning, H_2S abatement, visual and noise pollution, subsidence potential, and cooling tower drift.

Another technical-institutional problem that deserves major attention is the problem of cooling water requirements, especially in this time of awareness of the limit of water supply on a national basis. Many geothermal resources occur in arid or semiarid regions, and many of these in sedimentary basins subject to subsidence upon withdrawal of water. Planning for optimum management of both the geothermal fluid and makeup surface waters for cooling requirements should be undertaken now.

Institution problems abound in geothermal energy development. They involve public acceptance, vested interests, historical precedents, existing regulations from other resources, overlapping jurisdictions, and economic, financial, legal, social, and environmental factors (Kruger, 1976). The solutions to these problems are also complex; they may require broad public interaction, changes in regulations and legislation, and perhaps changes in traditional investment and marketing procedures. These areas, too, may be fruitful for advanced research efforts, for in the long run the solution to these problems may dictate the rate of orderly development of geothermal resources.

TABLE 5. ENVIRONMENTAL IMPACTS OF GEOTHERMAL POWER PRODUCTION

LAND	WATER	AIR
LAND UTILIZATION ~2 km^2/100 MW	DISPOSAL OF DRILLING FLUIDS	RELEASE OF STEAM AND OTHER GASES DURING DRILLING AND TESTING
DRILLING OPERATIONS ~20 WELLS/km^2	NEED FOR SUPPLEMENTARY COOLING WATER	NOISE POLLUTION
POWER PLANT CONSTRUCTION 1 PLANT/100 MW	BUILD-UP OF SALT CONCENTRATIONS	RELEASE OF H_2S AND OTHER NON-CONDENSABLE GASES
STEAM GATHERING LINES ~0.2 KM/100 MW	DISPOSAL OF CONDENSOR COOLING WATER STEAM CONDENSATE ~3.5 MGPD/100 MW	POTENTIAL CHANGES IN MICROMETEOROLOGY
CONDENSATE REINJECTION LINES AND PUMPS	POTENTIAL MINERAL AND THERMAL POLLUTION OF FRESH SURFACE WATERS	POTENTIAL FOR WELL BLOWOUT
POTENTIAL FOR LAND SUBSIDENCE SEISMIC ACTIVITY		

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