GEOTHERMAL ENERGY

A VIABLE ALTERNATIVE ENERGY SOURCE

JANUARY 1981

TODAY'S ENERGY PICTURE IN THE U.S.

- THE U.S. PRODUCES ONLY 3/4 OF THE ENERGY IT CONSUMES
- APPROXIMATELY 1/2 OF OUR OIL COMES FROM FOREIGN SOURCES
- ENERGY USE FORECASTS FOR THE YEAR 2000 AND BEYOND INDICATE THAT ALL FEASIBLE ALTERNATIVE ENERGY SOURCES PLUS CONSERVATION MEASURES WILL BE NEEDED.

GEOTHERMAL ENERGY

CAN REPLACE

PETROLEUM

FOR

ELECTRICAL POWER GENERATION

AND

DIRECT APPLICATIONS

GG-054

RESOURCE TYPES

CONGRESS IS SUPPORTING RESEARCH AND DEVELOPMENT ON THREE TYPES OF GEOTHERMAL ENERGY RESOURCES:

1. HYDROTHERMAL
2. GEOPRESSURED
3. HOT DRY ROCK

THE STATUS OF THE COMMERCIAL DEVELOPMENT OF EACH OF THESE SYSTEMS IS SHOWN BELOW :

		ESTIMATED COMMERCIALIZATION DATE *
HYDROTHERMAL ENERGY	—	LIMITED COMMERCIAL USE NOW
GEOPRESSURED RESOURCES	—	1990
HOT DRY ROCK RESOURCES	—	2000

* ESTIMATES FROM THE FOURTH ANNUAL REPORT OF INTERAGENCY GEOTHERMAL COORDINATING COUNCIL - JUNE, 1980

FEDERAL ASSISTANCE

IS NEEDED TO :

- ACCELERATE HYDROTHERMAL COMMERCIALIZATION
- BUILD FLEDGLING INDUSTRY
- CONTINUE DEVELOPMENT

GG-058

CONGRESS IS SUPPORTING RESEARCH AND DEVELOPMENT ON THREE TYPES OF GEOTHERMAL ENERGY RESOURCES :

1) HYDROTHERMAL

2) HOT DRY ROCK

3) GEOPRESSURED

GEOTHERMAL POTENTIAL IN THE U.S.

	AVAILABLE ENERGY [1]	ESTIMATED COMMERCIALIZATION DATE [5]
HYDROTHERMAL ENERGY	2400Q [2]	LIMITED COMMERCIAL USE NOW
HOT DRY ROCK RESOURCES	1,400,000 [3]	BEGIN MID-1990'S
GEOPRESSURED RESOURCES	430 - 4400 Q [4]	BEGIN MID-1980'S

1. ESTIMATES BY U.S. GEOLOGICAL SURVEY,CIRC. 790

2. $1Q=10^{15}$ BTU . THE U.S. CONSUMES 80 Q/YR FOR ALL USES

3. NO RELIABLE RESOURCE ASSESSMENT AVAILABLE

4. VARIATION DEPENDS ON HOW MUCH LAND SUBSIDENCE TO ALLOW

5. GEOTHERMAL ENERGY - PROGRAM SURVEY DOCUMENT, DOE, JAN 1980

GG-060

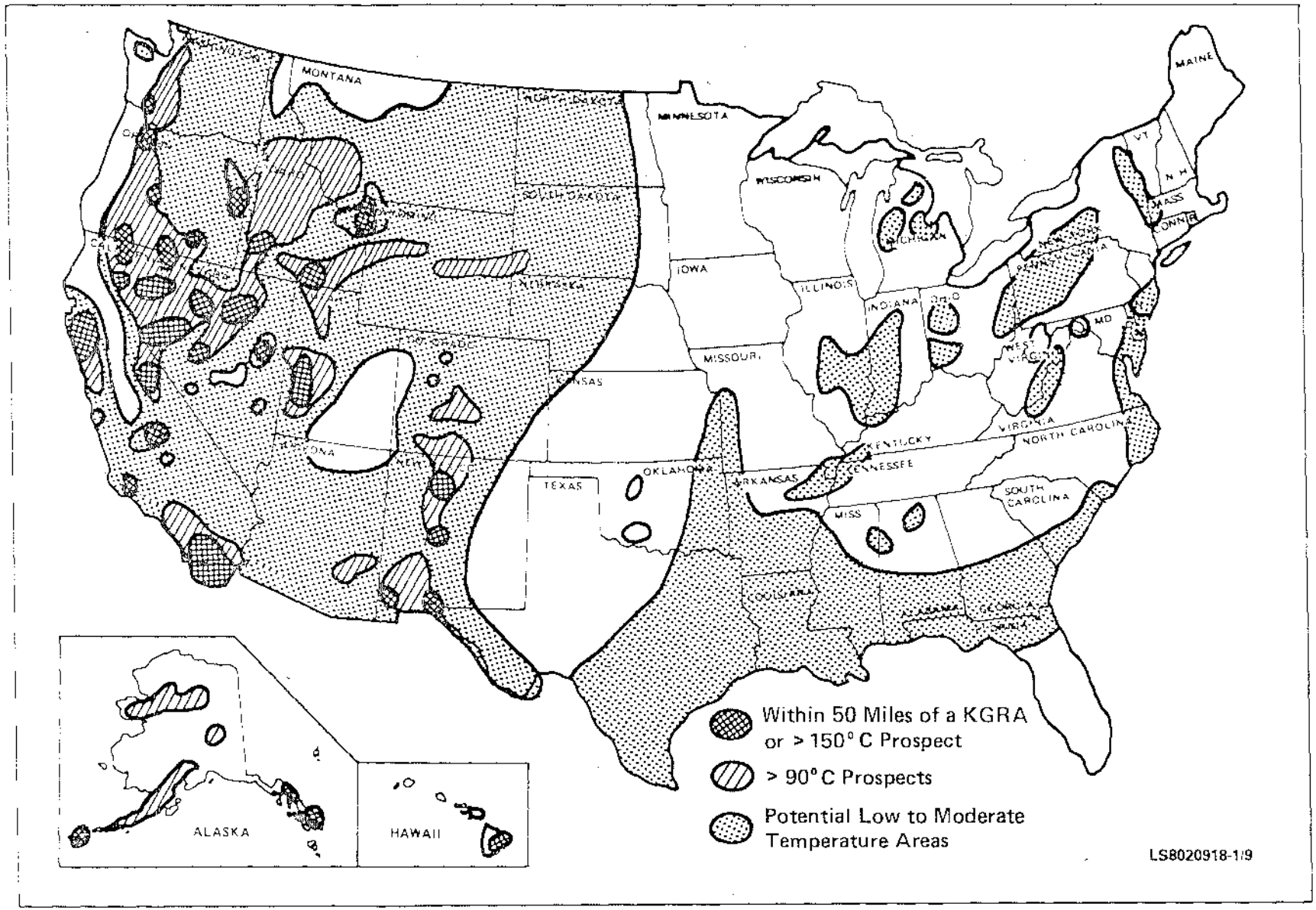
GEOTHERMAL DEVELOPMENT POTENTIAL

	ESTIMATED USE BY YEAR 2000	
	ELECTRICAL (MW)	DIRECT HEAT (10^{15} BTU)
HYDROTHERMAL	12,800	0.57
GEOPRESSURED	2,000	3.0 (methane)
HOT DRY ROCK	700	0.007

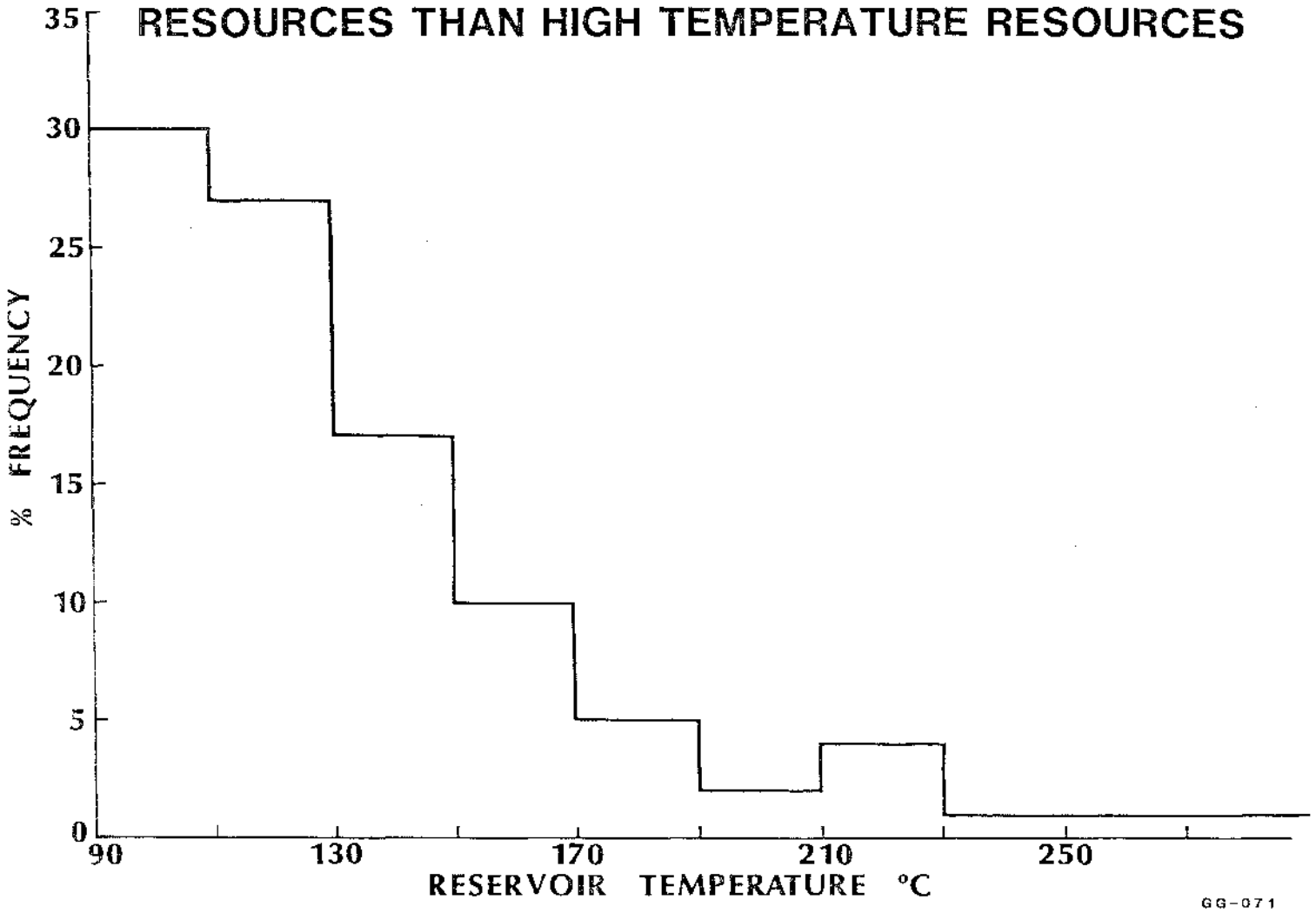
GG-073

Figure 1

GEOTHERMAL RESOURCES ARE WIDESPREAD



THERE ARE MANY MORE LOW TEMPERATURE RESOURCES THAN HIGH TEMPERATURE RESOURCES



STATUS OF GEOTHERMAL DEVELOPMENT IN U.S.

- INVENTORY DEMONSTRATES LARGE RESOURCE BASE

- GEOTHERMAL ENERGY NOT YET COMMERCIAL

  (except at a few very high-temperature sites)

  - SMALL NUMBER OF ELECTRICAL DEVELOPERS AND UTILITIES ACTIVE
  - VERY FEW DIRECT-HEAT DEVELOPERS AND USERS ACTIVE

- DOE GEOTHERMAL PROGRAM IS VIABLE

  - ADDRESSES PROBLEMS
  - WORKS WITH INDUSTRY
  - WELL MANAGED

- FY82 HYDROTHERMAL BUDGET HAS BEEN DRASTICALLY CUT, NEEDS RESTORATION

GG-070

HYDROTHERMAL RESOURCES ARE NOT YET COMMERCIAL

EXCEPT FOR THE FEW VERY HIGH-TEMPERATURE OR VERY SHALLOW RESOURCES

- 912,000 KILOWATTS GENERATED AT THE GEYSERS AREA, Calif.
  10,000 KILOWATTS GENERATED AT IMPERIAL VALLEY, Calif.
- ELECTRICITY SOON TO BE GENERATED AT
  IMPERIAL VALLEY, Calif. (50,000 kw)
  ROOSEVELT HOT SPRINGS, Utah (20,000 kw)
  VALLES CADERA, New Mexico (50,000 kw)
- HOMES & BUILDINGS HEATED BY HYDROTHERMAL ENERGY IN
  BOISE, Idaho
  KLAMATH FALLS, Oregon
  OVER 100 OTHER SITES
- TECHNOLOGY DEVELOPMENT AND DEMONSTRATION NEEDED FOR COMMERCIAL EXPLOITATION AT LOWER TEMPERATURE SITES

PROBLEMS IN HYDROTHERMAL DEVELOPMENT

INSTITUTIONAL BARRIERS

- SLOW FEDERAL LAND LEASING
- INADEQUATE OR RESTRICTIVE FEDERAL AND STATE LAWS AND REGULATIONS
- ENVIRONMENTAL RESTRICTIONS

These Barriers are Rapidly being Mitigated

TECHNOLOGICAL PROBLEMS

- LACK OF CONFIRMED RESERVOIRS
- INADEQUATE EXPLORATION METHODS
- HIGH COST OF DRILLING
- LOW WELL PRODUCTIVITY FOR SOME WELLS
- LACK OF ABILITY TO PREDICT RESERVOIR LONGEVITY
- LACK OF MATERIALS AND EQUIPMENT FOR HIGH-TEMPERATURE, HIGH-BRINE ENVIRONMENT
  - Seals, Drill Bits, Pumps, Heat Exchangers
- LACK OF EFFICIENT TURBINE-GENERATORS FOR TEMPS LESS THAN 400° F

LACK OF DIRECT-USE INFRASTRUCTURE

- FOR ELECTRIC POWER GENERATION, MAJOR RESOURCE COMPANIES ARE ACTIVE
- FOR DIRECT USE, FEW DEVELOPERS EXIST, FEW USERS KNOW POTENTIAL

GG-072

THE FEDERAL GEOTHERMAL PROGRAM
DOE & USGS

- **TECHNOLOGY DEVELOPMENT**
  - RESERVOIR ASSESSMENT
  - WELL DRILLING
  - ENERGY EXTRACTION, CONVERSION, STIMULATION
  - GEOCHEMICAL ENGINEERING AND MATERIALS
- **TECHNOLOGY DEMONSTRATION**
  - 50 MWe FLASH STEAM DEMONSTRATION PLANT - BACA, NM
  - 50 MWe BINARY CYCLE DEMONSTRATION PLANT - HEBER CA
  - 3 MWe WELLHEAD GENERATOR DEMONSTRATION PLANT - PUNA, HA
  - 5 MWe BINARY CYCLE DEMONSTRATION PLANT - RAFT RIVER ,ID
- **RESOURCE IDENTIFICATION, ASSESSMENT, AND EXPLORATION**
  - USGS EVALUATION - CASCADES, - OR & WA
  - INDUSTRY COUPLED CASE STUDY PROGRAM - WESTERN US
  - STATE COUPLED PROGRAM - 28 STATES
  - USER COUPLED DRILLING PROGRAM - 50 STATES
- **COMMERCIALIZATION**
  - OUTREACH
  - DIRECT HEAT APPLICATIONS
  - FEASIBILITY STUDIES
- **GEOTHERMAL LOAN GUARANTY**
- **ENVIRONMENT**

GG-074

INDUSTRY SUPPORTS DOE'S HYDROTHERMAL PROGRAMS

RESOURCE CONFIRMATION

TECHNOLOGY DEVELOPMENT

GEOTHERMAL LOAN GUARANTY

COMMERCIALIZATION PLANNING

GG-059

DOE GEOTHERMAL PROGRAM IS VIABLE

- PROGRAM ADDRESSES CURRENT PROBLEMS
  - Technology Development and Demonstration
  - Resource Inventory
  - Cost-Shared Exploration and Development
  - Loan Guaranty
- WORKING RELATIONSHIP WITH INDUSTRY
  - Program Has Industry Support
- TOP MANAGEMENT COMPETENT

HYDROTHERMAL BUDGET FOR FY 82 CUT BY CARTER ADMINISTRATION

- HYDROTHERMAL NEEDS FEDERAL SUPPORT TO BECOME COMMERCIAL
- HYDROTHERMAL HAS MUCH GREATER POTENTIAL FOR POWER ON LINE BY YEAR 2000 THAN GEOPRESSURED OR HOT DRY ROCK
- RESTORATION OF BUDGET RECOMMENDED

NATURE OF GEOTHERMAL ENERGY

Geothermal energy is a clean and safe alternative energy source that can, under proper exploitation conditions, be considered to be renewable. Because the deep interior of the earth is very hot and because of heat generation in the crust of the earth due to decay of natural radioactive elements in rocks, a very large amount of heat is continually conducted to the earth's surface and is radiated away into space. In a number of geological situations this heat becomes concentrated at depths shallow enough that it can be tapped by drilling, to allow hot geothermal fluids to be brought to the surface for generation of electric power or for direct uses of the heat such as industrial heat or space heating.

- Hydrothermal resources include thermal water and steam trapped in fractured or porous rocks. A hydrothermal system is classified as either hot-water or vapor-dominated (steam), according to the principal physical state of the fluid. Hydrothermal resources are presently used both for electric production and for direct applications.

- Geopressured resources consist of water at moderately high temperatures and at pressures higher than normal, hydrostatic pressure due to the fact that they are confined and must support part of the weight of the overlying rock column. In some areas such as the Gulf Coast, this water contains dissolved methane. Geopressured resources in sedimentary formations in Texas and Louisiana are believed to be quite large. Geopressured formations also exist in

sedimentary basins elsewhere in the U.S. Commercial-scale utilization of these resources may begin in the late 1980's.

- Hot dry rock resources consist of relatively unfractured and unusually hot rock at accessible depths that contain little or no water. To extract usable power from hot dry rock, the rock must be fractured and a confined fluid circulation system created. A heat transfer fluid (water) is then introduced, circulated, and withdrawn. Commericial-scale utilization of hot dry rock resources may begin in the 1990's.

At the present time, there are few confirmed geothermal reservoirs in the U.S. because of lack of an aggressive exploration and development industry. A few very high-temperature hydrothermal resources can be exploited economically for electric power generation but the vast majority are still uneconomic. Considerable technology development and demonstration are needed in order to decrease exploitation costs, and this topic is discussed further in the pages that follow.

Known areas of geothermal resource potential are shown on Figure 1. The known resources shown on this map are almost exclusively hydrothermal, except for the geopressured resources along the immediate coast of Texas and Louisiana and a few other smaller basins. There is no adequate assessment of the hot dry rock resource base to date. Figure 2 shows the distribution of known resources as a function of temperature. Note that as temperature decreases, the number of resources increases very rapidly (exponentially). Because of this observed distribution it is important to pursue the technology

development and demonstration that will allow lower temperature resources to be economically exploited for electrical power production.

Geothermal resources are worldwide in occurrence and are generally present in geologically active areas that are also sites of volcanic and earthquake activity. Table 1 shows the electrical generation capacity for geothermal energy worldwide. All of this production comes from hydrothermal resources. The U.S. is the leader in geothermal electrical power production with 922 megawatts (MWe)[1], 912 of which come from a single field, The Geysers area about 80 miles north of San Francisco, California.

Worldwide use of hydrothermal resources for direct application is considerable. For example, a considerable portion of the homes and buildings in the Paris basin in France are heated geothermally, and the government shares the cost of drilling for geothermal fluids and for installation of surface equipment. In the U.S. there is little direct use of geothermal energy. There is no industry infrastructure to foster its use. Table 2 shows a summary of nonelectric (direct) use on line in the U.S. to the end of 1979.

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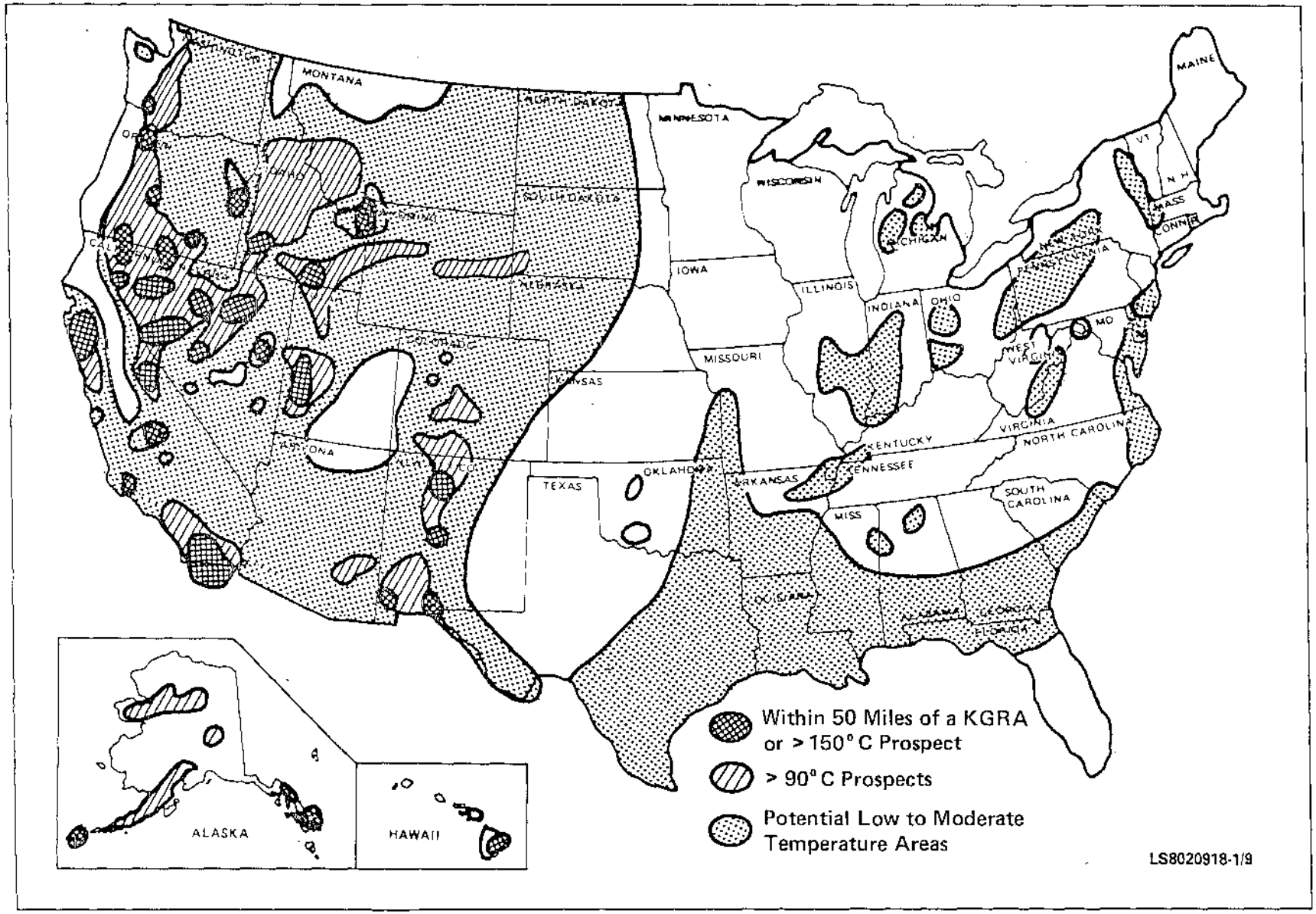
1 megawatt = 1 MWe
= 1 million watts

Figure 1

GEOTHERMAL RESOURCES ARE WIDESPREAD



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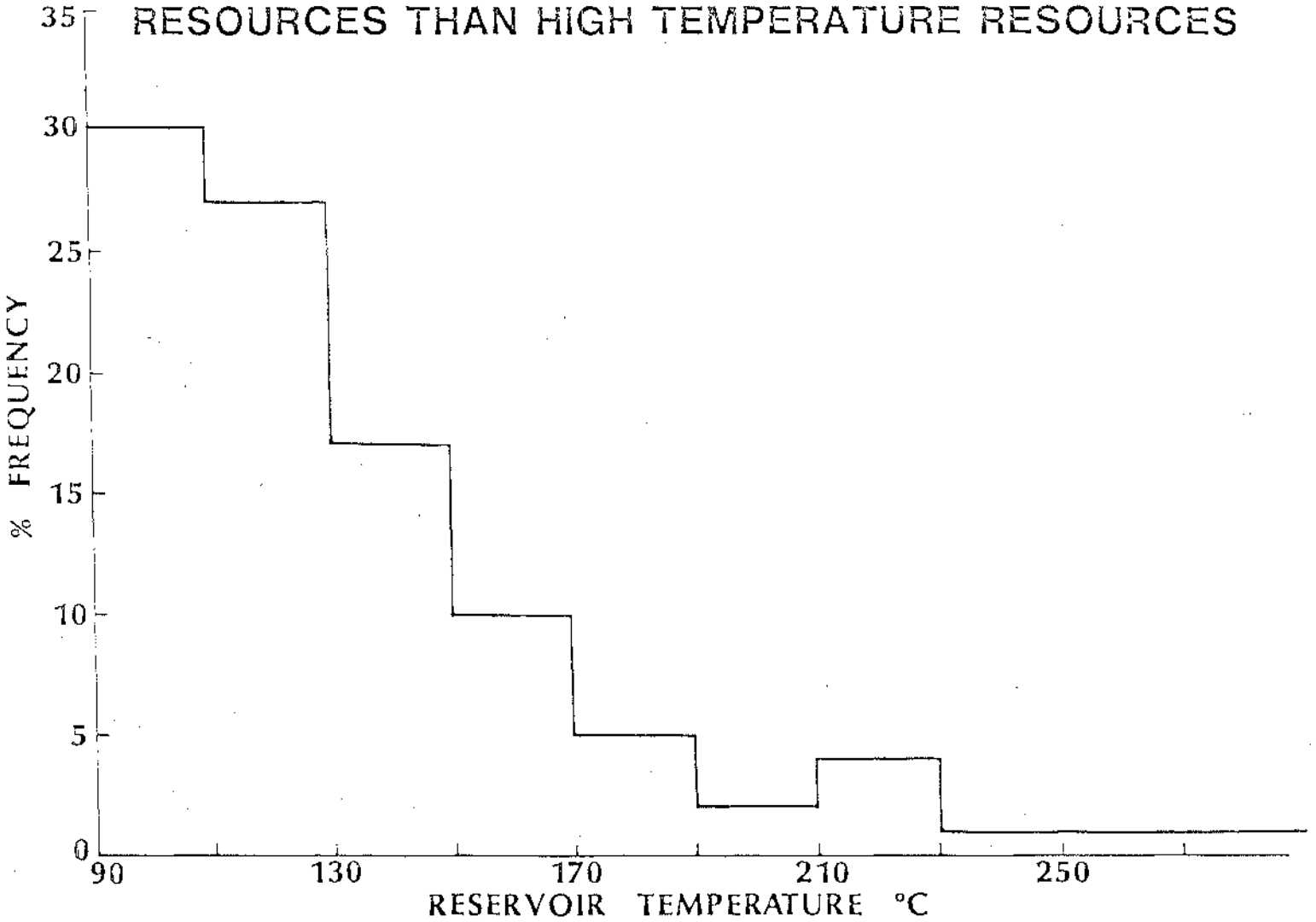

Table 1

WORLDWIDE GEOTHERMAL ELECTRICITY GENERATION
(to 1985)

Country	Present Capacity (MWe)	Planned Expansion (MWe)
China	4.5	--
El Salvador	60.0	385.0 -- 240 guaranteed
Iceland	62.0	--
Indonesia	0.3	--
Italy	420.6	400.0 -- 100 guaranteed
Japan	165.0	367.0 -- 255 possible -- 112 guaranteed
Kenya	--	35.0
Mexico	150.0	150.0 -- 100 possible -- 50 guaranteed
New Zealand	202.6	150.0
Philippines	224.2	710 planned
Taiwan	0.3	--
Turkey	0.5	14.0
USSR	5.0	58.0
United States	922.0	1401.0
TOTAL	2217.0	3670.0
GRAND TOTAL		5887 MWe

PROBLEMS IN GEOTHERMAL DEVELOPMENT

A number of problems currently exist in development of geothermal resources and these can be broadly classed as 1) institutional, 2) technological, and 3) infrastructure. Each type of problem adversely affects the economics of geothermal utilization, and each needs to be solved in order for an aggressive geothermal industry to develop in the U.S.

Institutional Problems. These have to the present time included: a) slow leasing schedules for geothermal lands by the Bureau of Land Management and the Forest Service; b) federal laws, regulations and tax structure that were not conducive to development; c) state laws and regulations that are, in many states, either inadequate, nonexistent or unnecessarily restrictive and often make ownership of the resource difficult to determine (in some states geothermal fluids are treated as a water resource whereas in others they are treated as a mineral resource); and d) environmental regulations that are unnecessarily restrictive. Recent changes in laws and regulations and directives for streamlining by President Carter have made substantial progress in removing these barriers, but more remains to be done, particularly on a state level.

Technological Problems. Recent economic studies by companies involved in hydrothermal electrical power generation have indicated that only the very few highest-temperature resources can be economically exploited today. Public Service Company (PSC) of New Mexico, which is involved in construction of a 50 MWe flash steam demonstration plant at Baca in north-central New Mexico, along with Union Oil Company and DOE, have projected their power generation

costs to be 36 mills/kwh in levelized constant dollars. This plant will become operational in 1982 on a resource whose temperature is 550°F. By contrast, power that will be generated by DOE's other large demonstration plant, an organic binary cycle power plant in the Imperial Valley of California, is projected by San Diego Gas and Electric (SDG&E) to cost 75 mills/kwh on the same levelized constant dollar basis. Power costs being reported for coal and nuclear generation are both in the range 30 to 44 mills/kwh on the same basis. This makes the Baca plant cost competitive, but not the Imperial Valley plant. The reasons for high costs on the proposed SDG&E binary plant are straightforward. At 365°F, the binary plant requires approximately 2-1/2 times the brine flow rate as the 550°F flash plant. This higher brine flow dictates larger piping, valves and reinjection pumps. The lower temperature necessarily means a 20 percent lower thermal efficiency, which requires approximately 20 percent larger condensers, cooling towers, water-circulating pumps and 20 percent more make-up water. In addition, the lower vapor pressure of the 365°F brine causes wells to be low in productivity unless they are pumped. The binary plant will use approximately 5MWe of parasitic power for downhole pumps which are not required for the 550°F resource, plus an additional 2MWe of parasitic power for injection pumps. Capital costs for downhole pumps add $2.5 million in initial cost and will require frequent maintainance and replacement. It is clear that moderate-temperature resource utilization with current technology is not competitive with coal or nuclear.

High hydrothermal costs can be attributed primarily to high drilling costs, low reservoir temperature (requiring more wells) and/or low well

productivity. The prospect for improving economics through technological progress is excellent, especially for the moderate-temperature resources (which constitute 80% of the inferred 140,000 MWe recoverable resource). Better exploration techniques, better ways to predict reservoir lifetime, materials development for use in geothermal equipment, drilling technology development, reservoir stimulation for the purpose of increasing well flow, downhole pumps and more efficient conversion systems have a realistic potential for cutting moderate temperature utilization costs in half, which is why the development of geothermal technology is an important part of the Federal geothermal program.

There is very little use presently being made of low- and moderate-temperature hydrothermal resources for direct heat purposes. The main reasons for this appear to be 1) lack of enough knowledge of the resource itself to attract users, and 2) the present high risk level and high costs associated with reservoir confirmation. By contrast, utilization of a low-temperature hydrothermal resource, once it is discovered and confirmed, usually consists of reasonably straightforward engineering.

Lack of resource knowledge occurs on two levels of detail: 1) on a regional scale, the locations of low- and moderate-temperature resources are poorly known; 2) on a site-specific scale, the lateral limits, depth, temperature, productivity, and longevity of very few low- and moderate-temperature hydrothermal reservoirs are known. Very little surface exploration and drilling have been done by the private sector.

The present high risk level for reservoir confirmation stems partly from

the lack of resource knowledge stated above and partly from the fact that present surface surveying techniques are not well enough developed to ensure a high level of probability that a drill hole will intercept a resource. Hydrothermal reservoirs are never uniform or continuous, and dry holes can be drilled in the middle of the best of resources. Better techniques for and more experience in siting wells are needed to decrease the risk of drilling an unproductive well.

The high costs of reservoir confirmation result mainly from the high cost of drilling, as discussed previously. Drilling costs have been increasing faster than the inflation rate over the past several years.

Infrastructure (Direct Heat Uses)

Present developers of electrical power generation from high-temperature reservoirs are generally large companies that can finance reservoir confirmation by spreading the high risk and cost over many projects. However, these large companies are usually not interested in development or utilization of lower temperature reservoirs because of the relatively small scale of such projects. Small developers, the ones most likely to be interested in low- and moderate-temperature geothermal resources, are unable to spread risk and cost in the same way that a large company can. A single unproductive well can mean financial disaster for them. For these reasons, it is not expected that the direct heat user in the private sector will be able to perform needed reservoir confirmation for low- and moderate-temperature hydrothermal resources by himself in the near future. Without federal assistance there will continue to be very little use of this large hydrothermal resource base that exists in the United States.

HISTORY OF THE FEDERAL GEOTHERMAL PROGRAM

Although geothermal energy has been used in the United States since 1894, serious commercial interest did not begin until the late 1960's. The genesis of Federal geothermal activity can be said to have been the U.S. Geological Survey's (USGS) limited assessment, in 1969, of geothermal resources. This assessment was drawn from basic research conducted by the USGS on a limited scale since 1945 as a part of its charter to assess national resources. At about the same time, the Bureau of Reclamation was looking at geothermal resources as a means of mineral extraction.

By 1971 there was momentum enough to start a geothermal program in the Atomic Energy Commission. The AEC Act had been amended to mandate research into energy sources other than nuclear power. The Division of Applied Technology included Coal, Electrical Storage, Solar, and Geothermal offices. Even though the main emphasis was placed on geothermal technology, there was an attempt to relate the program to industrial applications. At approximately the same time, the National Science Foundation considered geothermal energy in its Research Applied to National Needs project. NSF thereafter became the lead agency for geothermal activities. In 1973 the USGS, AEC, and NSF prepared the first coordinated Federal geothermal program plan.

In early 1975 all of AEC's and the bulk of NSF's programs were transferred to the Energy Research and Development Administration (ERDA), created by the Energy Reorganization Act of 1974. The Non-Nuclear Energy Research and Development Act of 1974 gave ERDA considerable additional authority, including incorporation of the geothermal program previously established by the Geothermal Research, Development, and Demonstration Act of

1974. ERDA was given programmatic geothermal functions, and also was given the authority to coordinate all geothermal activities of Federal agencies. DOI retained its traditional role of national resource assessment and leasing of Federal lands.

Originally ERDA's orientation to geothermal energy was primarily technological. Although demonstration projects were envisioned, no funds were appropriated by Congress for them. The ERDA activities were aimed at electric power production, almost entirely to the exclusion of direct heat, nonelectric uses. A formal commercialization program was established only with the organization of the Department of Energy (DOE) in 1977; however, the concept of involving industry in geothermal development had been implicit from the beginning of Federal involvement in geothermal activities. In 1975, ERDA's Division of Geothermal Energy (DGE) had started to phase in commercialization activities with industry, but kept these activities closely tied to basic research. In 1979, the Division of Geothermal Resource Management was created under the Assistant Secretary for Resource Applications of DOE; research and development continued in DGE under the Assistant Secretary for Energy Technology. Late in the year, it was announced that DGE would be moved to Resource Application as well, and one group was once again formed. This one group, known as the Division of Geothermal Energy exists today in Resource Applications.

Other Federal entities also have certain responsibilities for geothermal energy development, and these are summarized in Table 2 with details shown in Table 3. Table 4 shows funding levels for these Federal programs.

Table 2

SUMMARY OF NONELECTRIC USE ON-LINE, 1979*

AREA OF USE	NUMBER OF USERS	FUNDING ($000) FEDERAL	STATE	LOCAL	PRIVATE	BTU/YEAR (10^9)
SPACE AND PROCESS USES	180	63,992	6,692	6,014	1,071	1,386.2
BATHS AND POOLS	90		2	9	73	51.8
ENHANCED OIL RECOVERY	1				unknown	10,000.0
TOTAL	271	63,992	6,694	6,023	1,144	11,438.0

*Based on data in the Geothermal Progress Monitor, Issue Number 1, December 1979.

Table 2

BASIC RESPONSIBILITIES OF FEDERAL AGENCIES

Produce Energy

- DOE/RA
- DOC/EDA
- DOD
- HUD
- USDA/FmHA

Stimulate Energy Production

- DOE/RA
- DOC/EDA
- HUD
- USDA
- DOT

Support Energy Production (Institutional Aspects)

- DOE/RA
- DOE/Env
- DOE/FERC
- EPA
- DOI/BLM
- DOI/USGS
- DOI/FWS
- USDA/FS

Make Federal Geothermal Resources Available

- USDA/FS
- DOE/RA
- DOI/BLM
- DOI/USGS

Reduce Costs and Risks (Research and Development)

- DOE/RA
- DOE/ER
- DOE/Env
- EPA
- DOI/BOM
- DOI/USGS
- DOI/FWS
- DOD

Improve Resource Estimates

- DOE/RA
- DOI/USGS
- DOI/WPRS

Table 3

DETAILED ACTIVITIES OF FEDERAL, NON-FEDERAL AND PRIVATE SECTORS

ACTIVITY	FEDERAL AGENCY'S ROLE	STATE AND LOCAL GOVERNMENT'S ROLE	PRIVATE ROLE
PRODUCE ENERGY	DOE/RA o Guarantee Loans o Cost-Share Field Demonstration Projects	o Cost Share Projects o Construct Facilities	o Cost Share Projects o Construct Facilities
	DOC/EDA o Award Grants on Projects		o Provide Capital
	DOD o Construct Facilities For Own Use		o Provide Management
	HUD o Award Grants for Projects		
	USDA/Farmers Home Administration o Award Grants for Projects		
STIMULATE ENERGY PRODUCTION	DOE/RA o Disseminate Information o Give Technical Assistance o Award Planning Funds to States o Provide Reservoir Confirmation Assistance	o Disseminate Information o Plan o Provide Appropriate State Geothermal Rights Laws	o Broker Projects
	DOC/EDA o Award Grants for Planning	o Provide Tax Incentives	
	HUD o Allocate Planning Funds		
	USDA o Allocate Planning Funds		
	DOT o Administer Tax Incentives		

Table 3 (Con't.)

ACTIVITY	FEDERAL AGENCY'S ROLE	STATE AND LOCAL GOVERNMENT'S ROLE	PRIVATE ROLE
SUPPORT ENERGY PRODUCTION (INSTITUTIONAL ASPECTS)	DOE/RA o Provide Environmental Assessments and Impact Statements on DOE Projects (including Loan Guarantee Projects) o Make Recommendations on New Legislation o Facilitate International Technology Exchange DOE/Environment o Review EAR's and EIS's o Write Environmental Development Plans o Write Area Environmental Assessments DOE/FERC o Issue Power Production Decisions on Geothermal Power Projects EPA o Formulate Environmental Regulations DOI/BLM o Undertake Environmental Reviews before Leasing DOE/USGS o Monitor Environmental Impacts after Leasing DOI/FWS o Provide Environmental Reviews as Requested by DOE, BLM, USGS, and FS	o Formulate State Environment Regulations o Issue Required Permits and Approvals o Formulate Public Utility Commission Regulations and Decisions o Cooperate with Federal Environmental Review Processes o Cooperate with Federal Permitting Procedures	o Provide Environmental Data Requested o Apply for Permits and Approvals

Table 3 (Con't.)

ACTIVITY	FEDERAL AGENCY'S ROLE	STATE AND LOCAL GOVERNMENT'S ROLE	PRIVATE ROLE
REDUCE COSTS AND RISKS (RESEARCH DEVELOPMENT AND DEMONSTRATION) Con't.	DOE/Energy Research • Perform A Basic Research DOE/Environment • Environmental Technology EPA • Develop Environmental Technology DOI/Bureau of Mines • Perform Geothermal Brine Research • Develop Standard Test Methods for Geothermal Materials • Field test Site-specific Materials DOI/USGS • Improve Resource Assessment and Exploration Concepts DOD • Perform Construction Materials/ Corrosion Research		
IMPROVE RESOURCE ESTIMATES	DOE/RA • Explore Potential of Hot Dry Rock Resources • Conduct Cost-Shared Hydrothermal Reservoir • Assessment with States DOI/USGS • Characterize various types of geothermal systems • Assess resources on a regional basis and update and refine national inventory DOI/WPRS • Explore Resources	• Conduct State Resource Assessments • Cost-share Federal Reservoir Assessments	• Conduct Reservoir Assessments • Cost-Share Federal Reservoir Confirmation • Provide Wells of Opportunity

Table 3 (Con't.)

ACTIVITY	FEDERAL AGENCY'S ROLE	STATE AND LOCAL GOVERNMENT'S ROLE	PRIVATE ROLE
SUPPORT ENERGY PRODUCTION (INSTITUTIONAL ASPECTS) Con't.	USDA/FS o Provide Environmental Reviews and Assessments for Forest Service Lands o Consent to Leasing on FS Lands o Review Development Permits and Approvals		
MAKE FEDERAL GEOTHERMAL RESOURCES AVAILABLE	DOE/RA o Set Production Goals o Promulgate Regulations DOI/BLM o Leasse Competitive BLM and FS land o Process Noncompetitive Lease Applications DOI/USGS o Review Development Plans o Provide Permits and Approvals o Evaluate Resource Areas to Determine Competitive Lease Sales USDA/FS o Process Noncompetitive Lease Applications o Review Permits and Approvals	o Cooperate with Federal Leasing Procedures o Issue Permits and Approvals	o Apply for Lease Applications o Bid on Competitive Leases o Meet Requirements for Permits and o and Approvals
REDUCE COSTS AND RISKS (RESEARCH DEVELOPMENT AND DEMONSTRATION)	DOE/RA o Build Hydrothermal Demonstration Plants o Undertake Materials Research and Development o Undertake Drilling Research and Development o Develop Environmental Technology o Develop Geopressured Technology o Develop Hot Dry Rock Technology o Undertake Geochemical Engineering Research and Development o Improve Reservoir Evaluation and Exploration Technology	o Conduct Research	o Conduct Research o Provide Insurance o Assume Risks

Table 4

FEDERAL FUNDING FOR
GEOTHERMAL ENERGY
(in $ thousands)

ORGANIZATION UNIT	ACTUAL FY 1977	ACTUAL FY 1978	ACTUAL FY 1979	ESTIMATED FY 1980	REQUESTED FY 1981
Department of Agriculture					
U.S. Forest Service	40	678	775	750	739
Department of Defense					
Navy	758	542	924	17,100	17,800
Air Force	15	0	13	21	2,400
DOD Total	773	542	937	17,121	20,200
Department of Energy					
Energy Technology	53,326	105,962	142,637	138,428	142,000
Resource Applications			9,737	9,026	10,000
Office of Energy Res.	1,900	2,800	3,200	3,400	4,000
Environment	3,862	3,896	3,167	2,303	2,949
Geothermal Loan Guaranty Fund (Administrative Expenses)	380	410	189	1,180	1,091
DOE Total	58,468	113,068	158,930	154,534	160,040
Department of Interior					
Fish and Wildlife	200	200	200	74	74
Bureau of Land Mgmt.	2,500	2,300	2,585	2,600	2,600
Bureau of Mines	528	550	1,050	800	400
Water and Power Res.Serv.	2,557	1,800	555	910	60
Geological Survey, Geothermal Res. Program	9,384	10,184	12,043	10,092	7,569
Geological Survey, Geothermal Evaluation and Lease Regulation	1,512	1,854	2,194	1,994	1,994
DOI Total	16,681	16,888	18,627	16,470	14,423
Environmental Protection Agcy.	600	670	750	750	750
National Science Foundation	200	175	70	0	0
Total Federal Geothermal Program Budget	76,782	132,021	180,089	189,696	196,152

THE FEDERAL PROGRAM

(Emphasis on the DOE Geothermal Program)

The principal barriers to development of geothermal energy by industry are: 1) the lack of confirmed reservoirs; 2) uncertainty about reservoir performance during extended production; 3) the lack of economic technologies for all but the highest quality resources; 4) the ambiguous status of ownership of geothermal fluids; 5) the slow pace of current leasing, permitting and licensing procedures; 6) the site-specific acceptability of waste fluid disposal and other environmental control measures; and 7) user inexperience with the resource. Divided among various agencies and offices, the Federal geothermal program works, whenever possible, in close communication with energy companies and other potential users of the geothermal resource.

Technology Development

Methods for geothermal exploration has been adopted from those used in mining and petroleum exploration, and so no cost-effective, geothermal-specific exploration architecture yet exists. Once a resource is discovered, there are not adequate methods to assess reservoir producibility or lifetime, and these uncertainties make it difficult for developers and utilities to obtain development capitol. Geothermal energy recovery is accomplished with technology similar to oil and gas industry technology, but geothermal temperatures and fluid characteristics, exceeding those for which oil field equipment was designed, shorten equipment lifetimes and pose safety hazards. Surface heat recovery equipment adapted to geothermal use from existing steam

technology is expensive and inefficient especially for lower resource temperatures. And environmental problems cause unique difficulties.

Technology specifically tailored to geothermal conditions is needed. The objective of the geothermal technology development program is to solve these problems. The program consists of four major areas: reservoir assessment technology, well drilling and completion technology, energy extraction and conversion technology, and geochemical engineering and materials.

The purpose of reservoir assessment technology is to more accurately predict, locate, and measure reservoirs. Relying on the industry to point out key technical problems, the government carries out research in exploration technology, reservoir engineering, and logging instrumentation and interpretation.

The purpose of well drilling and completion technology is to reduce the cost of geothermal drilling and to improve well completion techniques. In stage one, improvements in drill bits, downhole motors, and drilling fluids will demonstrate the technology that will make a 25 percent reduction in drilling costs possible by 1983. In stage two, a new drilling system is expected to enable a 50 pecent reduction in geothermal drilling costs by 1986.

The purpose of energy extraction, conversion, and stimulation technology is to reduce electric generating costs, particularly for moderate-temperature geothermal fluid. Extraction and conversion technologists improve performance and reduce costs of binary heat exchangers. Stimulation technologists develop new equipment and techniques for use in high-temperature geothermal environ-

ments, to improve formation permeability and therefore well productivity.

Numerous studies have determined that binary cycles, which use an organic working fluid to transfer heat from the geothermal fluid to the turbine-generator, offer the greatest potential for reducing the costs of generating electricity from the moderate-temperature geothermal resource; thus the DOE conversion technology program is heavily oriented toward binary conversion cycles. Direct contact heat exchangers and advanced design are areas of particular interest. The gravity head binary system is expected to yield a significantly higher utilization efficiency by improving heat transfer characteristics and reducing parasitic loads consumed by feed pumps.

The extraction of heat from geothermal fluids requires the handling and disposal of large volumes of water. Because the chemistry of geothermal waters is to a large extent site-specific, the problems of scale control, erosion, and corrosion require a detailed design to balance technical and economic subsystems for each potential site. The purpose of geochemical engineering and materials technology, therefore, is to address the special character of geothermal fluids and their interaction with other materials.

Fluid chemistry programs develop monitoring and control instruments, fluid control technology, and economic fluid disposal procedures that reduce scaling and cost of use. Materials development programs tailor borehole and conversion equipment to geothermal use. As noted above, oil field equipment is poorly suited to geothermal use; this is primarily because materials are degraded by the high temperatures and fluid chemistry.

Technology Demonstration

DOE builds and tests facilities to demonstrate that the use of hydrothermal resources is technically feasible, economically sound, and environmentally acceptable. Demonstration products also foster the business infrastucture necessary for the private sector to continue Federal without initiatives.

50 MWe Flash Steam Demonstration Plant. In FY 77, Congress, authorized DOE to carry out a geothermal demonstration project using a hot water hydrothermal resource. The project entails construction and operation of a commerical-scale (50 MWe gross output) electric power plant. The plant will also serve as a "pathfinder" for the regulatory process and other legal and institutional aspects of geothermal development. A cooperative agreement between DOE, Union Geothermal of New Mexico, and Public Service Company of New Mexico was signed in August 1979. The final EIS was prepared for release in January 1980. Plant design is under way at Baca Ranch, (NM) and an order for a turbine has been placed. The plant is scheduled for start-up in 1982.

50 MWe Binary Demonstration Plant. This project entails design and construction of a power plant that uses an organic fluid (for example, isobutane) as the turbine working fluid. Because certain organic fluids vaporize at lower temperatures than does water, high efficiency use can be made of lower temperature geothermal resources in this way. To date no successful large scale geothermal binary plant has been operated for an extended period, and yet engineers believe that development of binary technology is key to economic utilization of the more abundant, lower

temperature geothermal resources (300°F to 450°F). DOE's demonstration plant will be built at Heber, CA, in the Imperial Valley, and is being cost shared with San Diego Gas and Electric and Chevron.

H G P-A Geothermal Wellhead Generator. This project will evaulate the feasibility of using a wellhead generator to produce baseload electrical power. The generator will use the geothermal fluid from geothermal well H G P-A in the rift zone of an active volcano in the Puna District of Hawaii. The major power plant components will be mounted in such a way that they can be moved to other sites at some future date. The project is expected to lead to commerical applications of wellhead generators in remote areas of the western continental United States and Hawaii. It is scheduled for operation in April 1981.

Raft River Facility. A pilot plant now being built has a 5 MWe turbine generator with a binary Rankine power cycle, and will use energy from a moderate-temperature hydrothermal resource (150°C) to generate electricity for a utility power grid.

Resource Identification, Assessment, and Exploration

The objectives of the Federal resource identification program are to

- Characterize the geological nature of each type of geothermal system and the reservoirs within these systems
- Estimate the location, distribution, and energy content of individual geothermal systems and reservoirs
- Inventory the identified portion and predict the undiscovered portion of the nation's geothermal resources

- Confirm the existence and commercial potential of high- and moderate-temperature reservoirs suitable for electric power generation
- Confirm low- and moderate-temperature prospects that show potential for direct heat applications.

To achieve these objectives, DOE and the U.S. Geological Survey (USGS) undertake national, regional, and in cooperation with individual states, site-specific assessments of the geothermal resource (with emphasis on the hydrothermal resource). In addition, exploratory drilling programs have begun in several regions where a strong interest in direct heat has been exhibited, but where appropriate resources have not yet been confirmed.

Industry Coupled Case Study Program. To accelerate confirmation of geothermal reservoirs with apparent commercial electric potential, the Industry-Coupled Case Study program was begun in FY 78. DOE shares exploration and drilling costs with industry, in exchange for public release of data; these data help in finding successful techniques for exploration, well drilling, and completion. In FY 79, nine companies participated. The program was extended to northern Nevada, where 12 candidate sites are being investigated for exploratory drilling in FY 80. Although this program has been strongly supported by industry, Congress has not appropriated further funds. The program is a needed element in DOE's efforts, and should be reinstated.

State-Coupled Program. Low- and moderate-temperature resources are being defined in cooperation with nearly all 37 states that have identified resource

potential. The effort consists of two phases. Phase 1 analyzes existing geological and geophysical data to establish the size and distribution of hydrothermal resources. Phase 2 assesses target areas in detail and may drill heat flow measurement holes to confirm the existence and nature of the resource.

User Coupled Drilling Program for low- and moderate-temperature resources. Competitively selected teams composed of a developer and a user share the cost of surface exploration and drilling to locate and confirm reservoirs that could be commercially developed for direct heat applications as identified by the user.

USGS Assessment. A comprehensive, multi-year study of the Cascade Mountains of Washington, Oregon, and northern California is under way to determine the character and extent of geothermal resources of the region. It is being conducted by the USGS, state agencies, several universities, and several private firms. Reconnaissance studies have been initiated and will be followed by selection of a few areas for concentrated studies. In a related effort, DOE and USGS are jointly evaluating the resource potential of Mount Hood, Oregon.

Ice-Breaker Plants

A new initiative that DOE/DGE is considering is the cost-sharing with industry of "ice-breaker" plants on certain geothermal reservoirs. These plants would be 10 to 20 MWe in size and would enable the developer and utility to gather data on resource temperature and producibility in a production setting without commitment to the cost of a large-scale plant.

Industry favors this approach and indeed is proceeding in just this way with development of the high-temperature resource at Roosevelt Hot Springs, Utah.

Commercialization

The hydrothermal commercialization program of DOE seeks to accelerate commercial utilization of hydrothermal resources for electric power and for direct heat applications, thereby displacing fossil fuels. This program formulates geothermal commercial development plans, develops a national progress monitoring system, assesses the market penetration potential for hydrothermal resources, and identifies direct heat markets suitable for early penetration. Further activities encompass development planning in cooperation with local and state officials and potential users, support for economic and engineering feasibility studies, continuing interagency coordination and policy development, and outreach programs to acquaint potential users with the availability and competitive cost of hydrothermal energy and with the availability of financial assistance through various Federal programs. The program also seeks to make States a principal partner in implementing the Federal program by funding State commercialization and planning teams.

Outreach. Except for a small group of technical specialists, few people understand the range of possible applications of geothermal energy. DOE/DGE has an outreach program to mitigate this barrier. One phase aims to inform potential users and developers and their support groups of geothermal energy's costs, benefits, safety, reliability, and environmental effects. A second phase reaches out to the general public, trade, industrial, and professional associations, and other large groups capable of making primary financial

commitments to geothermal development.

Direct Heat Applications. The principal goal of the direct heat applications program in DOE is to build a direct-use infrastructure by funding selected direct heat applications. The first solicitation for direct use field experiments was issued in 1977; 22 proposals were received. Eight of these proposals were selected for contracts, with the Federal share of the cost varying from 46 percent to 80 percent. A second solicitation was issued in FY 78, resulting in 40 proposals, of which 15 were selected for initial FY 79 funding.

Of the 23 contracts underway in FY 79, the majority are for space and district heating, while three are directed at agriculture, and three involve industrial processing. The equivalent of 900,000 barrels of oil per year would be displaced if each of these projects succeeds.

Feasibility Studies. This program funds studies to determine the technical and economic feasibility of proposed hydrothermal applications. These are done in conjunction with potential users. Since the geothermal program began, 23 such studies have been completed--7 of space and district heating, 10 of industrial processing, and 6 of agribusiness or aquaculture. Results from 17 completed studies were analyzed for factors influencing decisions to invest in direct use processes. The cost of energy from geothermal sources was shown to be competitive with fuel-oil-based energy if at least 20 percent of the energy from the wells is used.

Environment

The Federal environmental program includes acquisition of baseline data, monitoring, and research related to air and water quality, ecology, noise, ground subsidence and induced seismicity, health effects and socioeconomic problems; regional and site specific assessments of the environmental, health, and socioeconomic impacts of the development of geothermal resources; development and assessment of environmental control technologies; and the promulgation of regulations to protect the environment from the adverse effects of exploiting geothermal resources.

The DOE, EPA, and DOI have been the principal supporters of the environmental program, with DOE sponsoring most of the research activities. DOE and EPA have increased their funding for cooperative projects over the past few years.

Geothermal Loan Guaranty Program (GLGP)

On January 5, 1979, DOE published its proposed regulations for GLGP for comment from interested parties (44FR 1568). The proposed regulations incorporated GLGP amendments in P.L. 95-238, which in summary:

- Pledge the full faith and credit of the United States to the payment of these guarantees
- Allow DOE to borrow funds from the Department of the Treasury, if balances in the Geothermal Resources Development Fund are insufficient to carry out guaranty and other responsibilities
- Authorize DOE to help the borrower pay the loan principal
- Allow DOE to complete and operate a plant acquired through

default

- Provide for loan guarantees up to 75% of estimated project cost for up to 30 years.
- Limit loans to $100 million per project and to $200 million per qualified borrower
- Limit to 1 percent the guaranty fee to be imposed annually on the outstanding guaranteed debt, and permit fee collection to be deposited in the Geothermal Resources Development Fund
- Authorize DOE to reimburse qualified public agencies and Indian tribes for a portion of the interest when a holder of the debt guaranteed under this regulation is required to include that income under Chapter 1 of the Internal Revenue Code
- Authorize certain forms of community impact for loans over $50 million.

To date 16 applications for loan guaranty have been received and 6 have been granted for a total of $136 million.

THE PROMISE OF GEOTHERMAL ENERGY

Inventories by the U.S. Geological Survey (Muffler, 1978) show that the geothermal resource base in the U.S. is large indeed. In the identified hydrothermal areas, excluding the national parks, it is estimated that 23,000 MWe of electrical energy and 42 Quads of beneficial heat could be developed if these areas were fully exploited. In addition, USGS scientists believe that there is a large undiscovered resource base that could contribute an additional 72,00 to 127,000 MWe and 184-310 Quads of beneficial heat (Table 11, Muffler, 1978). These figures give probable upper bounds for the hydrothermal energy resource base as presently understood. Of course not all of this resource base could be economically developed, even by the end of this century.

In a sophisticated study done over the past year, DOE has assessed the share of the electric market likely to be captured by hydrothermal power by the year 2000 (Anon., 1980). The study was performed in such a way that the effect of DOE's present and proposed programs, and of hypothetical changes in programs, could be determined. Tables 5, 6 and Figure 7 show the results of this study. If Federal program elements are continued it is more than 50% likely that by the year 2005, 12,800 MWe of electrical power generation will be developed from hydrothermal resources. By this time the estimated contribution from geopressured resources is 2,700 MWe (from the thermal energy) and from hot dry rock resources is 1,300 MWe.

A companion study is presently being performed to estimate the contribution of direct heat geothermal resources to our energy needs.

Preliminary analysis shows that at least 0.5 Quads will be on line by 2000, where 1 Quad = 10^{15} BTU. For comparison the current energy consumption for all forms including transportation is about 80 quads/year.

Geothermal energy is indeed a promising and viable energy alternative.

TABLE 5

NATIONAL ELECTRIC POWER ESTIMATE
(With Federal Program)

YEARS	PROJECTED NUMBER OF GIGAWATTS WITH A LIKELIHOOD			
	> 0%	> 10%	> 50%	> 90%
1980	1.0	1.0	1.0	1.0
1985	1.8	1.8	1.7	1.7
1990	3.8	3.8	3.7	3.6
1995	9.1	8.9	7.9	7.1
2000	17.0	16.8	12.8	10.8

TABLE 6

COMPARISON OF HYDROTHERMAL ESTIMATES FOR POWER ON LINE (MW_e) THROUGH 1987

REGION	MARKET SHARES TASK ESTIMATE		EPRI - UTILITY SURVEY (1980)		DOE TELEPHONE SURVEY
	>90% LIKELIHOOD	>50% LIKELIHOOD	ANNOUNCED	PROBABLE	ANNOUNCED PLANS (1980)
NORTHERN CALIF.	1780	1780	1113	1424	2418
SOUTHERN CALIF.	540	660	689	854	308
OREGON & WASHINGTON	0	0	10	45	0
NEVADA	40	40	17	75	60
UTAH	220	260	0	130	20
ARIZONA	0	0	17	25	0
IDAHO, MONTANA, WYOMING	0	20	10	20	0
COLORADO	0	0	0	0	0
NEW MEXICO	40	40	18	80	45
TOTAL	2620	2800	1873	2643	2851

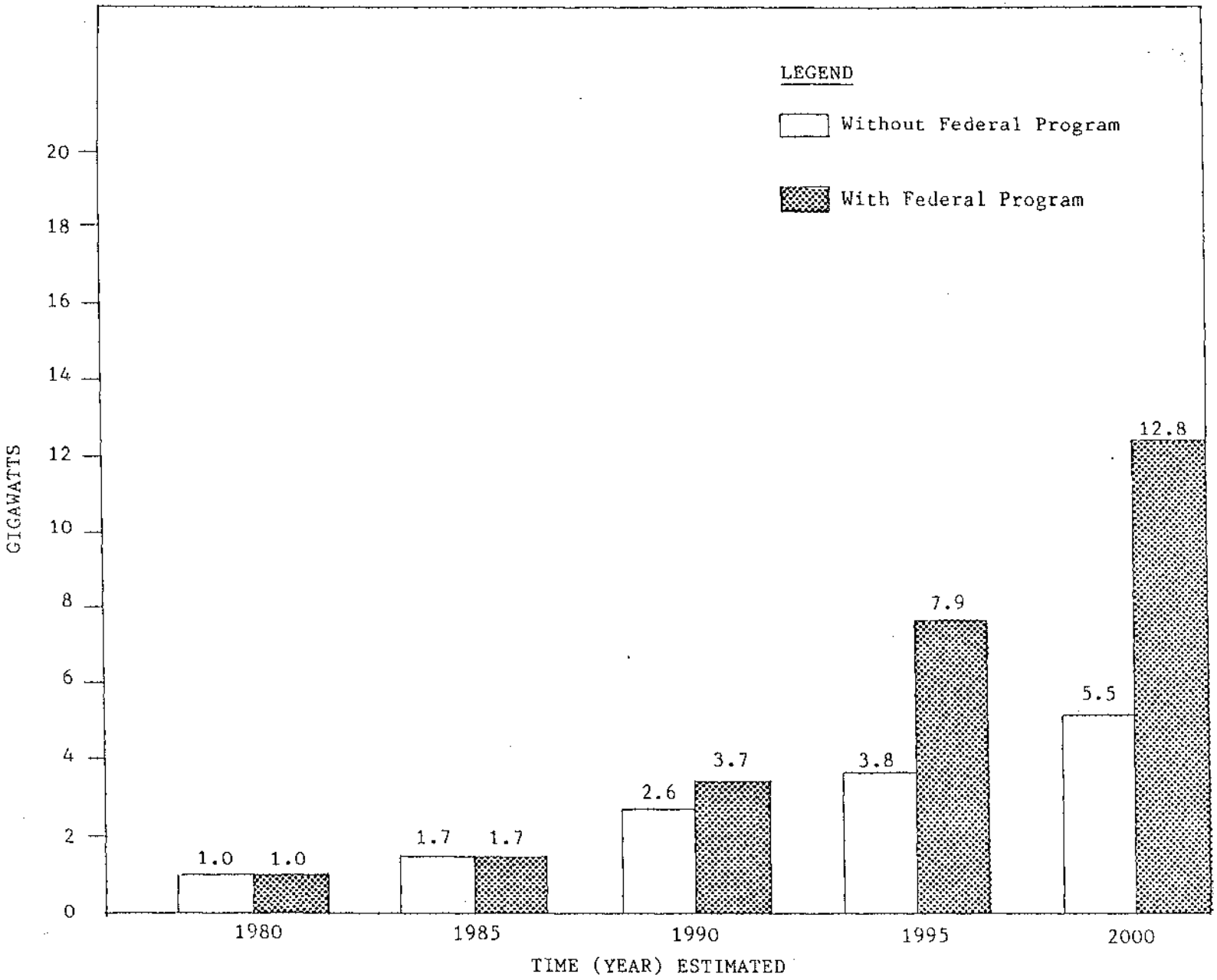

FIGURE 3

COMPARISON BETWEEN ESTIMATED POWER-ON-LINE WITH FEDERAL/DOE PROGRAM AND POWER-ON-LINE WITHOUT FEDERAL/DOE PROGRAM AT >50% LIKELIHOOD