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THE CURRENT STATUS OF GEOTHERMAL DIRECT USE DEVELOPMENT IN THE UNITED STATES UPDATE: 1985 - 1990

John W. Lund, Paul J. Lienau, G. Gene Culver

Geo-Heat Center
Oregon Institute of Technology
Klamath Falls, OR 97601

ABSTRACT

Information is provided on the status of geothermal direct heat utilization in the United States, with emphasis on developments from 1985 to 1990. A total of 452 sites, which include approximately 130,000 individual installations, have been identified with an annual energy use of 19.7 x 10^{12} kJ. Approximately 44% of this use is due to enhanced oil recovery in four midwestern states, and 30% is due to geothermal heat pumps. Since 1985, 25 new projects, which include approximately 200 individual installations, and representing a thermal capacity of 106.7 MWt and annual energy utilization of 1.1 x 10^{12} kJ, have become operational or are under construction. Earth-coupled and groundwater heat pumps, representing the largest growth sector during this period, add an additional 400 MWt and 1.2 x 10^{12} kJ to these figures. Geothermal heat pumps have extended geothermal direct heat use into almost every state in the nation. Slightly over 200 direct heat geothermal wells, averaging 150 m in depth, along with approximately 30,000 heat pump wells, have been drilled for these projects. Between 20 and 25 professional man-years of effort are estimated to have been allocated to geothermal direct heat projects during each of the five years.

INTRODUCTION

Geothermal energy is estimated to currently supply approximately 19.7 x 10^{12} kJ of heat energy annually through direct heat applications in the United States. This includes an estimated 8.6 x 10^{12} kJ used for enhanced oil recovery in four midwestern states. The above estimates are based on an extensive survey conducted in 1988 by the Geo-Heat Center for the U.S. Department of Energy (DOE) and updated in 1990.

A comparison between the numbers reported at the 1985 International Symposium on Geothermal Energy by Meridian Corporation (Kenkeremath, et al., 1985) and the 1988/1990 surveys by the Geo-Heat Center is presented in Figure 1. The main differences between the two sets of data results from: (1) many unknown projects were identified in the 1988 extensive survey, (2) geothermal heat pumps were included in the later survey, (3) resorts and baths were estimated with very limited technical data in 1985, and (4) there was a 24% increase in annual energy utilization from 1985 to 1990, excluding geothermal heat pumps, based on the 1988/1990 survey data.

Table 1. Comparison of Inventories of U.S. Geothermal Direct Heat Projects

Application	1985 Survey[a] No. of Sites	1985 Survey[a] Annual Energy x 10^9 kJ	1990 Survey[b] No. of Sites	1990 Survey[b] Annual Energy x 10^9 kJ
Geothermal Heat Pumps[c]	NA	NA	147	5,966
Resorts and Baths	121	126	114	1,531
Fish Farming	9	417	18	1,185
Space Heating[d]	77	460	103	842
District Heating[e]	13	240	18	715
Industrial Processes	5	124	12	425
Enhanced Oil Recovery[f]	NA	NA	4	8,597
Greenhouses	28	345	36	417
	253	1,712	452	19,678

a. Kenkeremath, et al., 1985.

b. Lienau, et al., 1988.

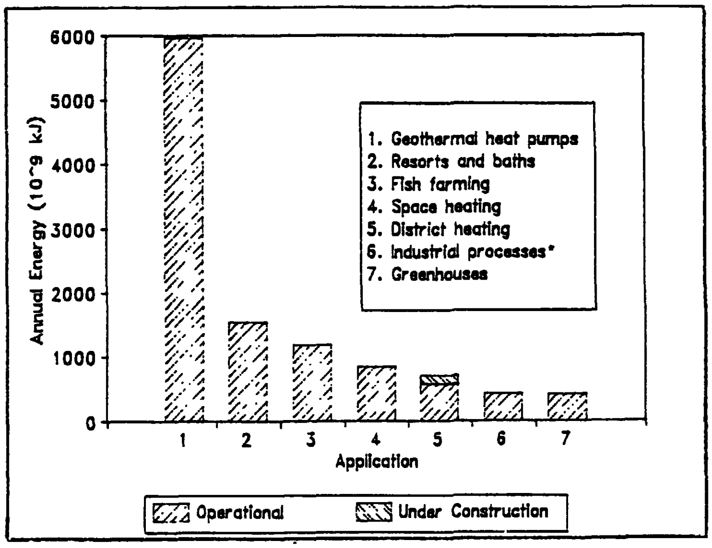
c. Includes 30 states with residential geothermal heat pumps totaling over 110,000 units.

d. Includes Klamath Falls residential downhole heat exchanger systems (550), schools (7), apartment buildings (13), churches (4), and Reno/Moana residential downhole heat exchangers (300).

e. Includes two systems reported under construction: Mammoth Lakes (124 x 10^9 kJ), and Bridgeport (15 x 10^9 kJ/y). The city of Klamath Falls system is undergoing reconstruction of the distribution piping.

f. Enhanced oil recovery located in 4 states (based on USGS data).

The relative importance of the seven major direct use applications are shown in Figure 1. The enhanced oil recovery is not shown due to its large value. It can be seen, after industrial processes, that geothermal heat pumps, and resorts and baths dominate the picture, whereas in the 1985 report, space conditioning and district heating dominated. As explained earlier, this shift in emphasis is due mainly to better documentation of actual use.



* Does not include 8,597 x 10^9 kJ used in enhanced oil recovery.

Figure 1. Direct heat utilization in the United States - 1990.

DIRECT USE GROWTH

Historically, direct uses of geothermal energy in the United States were by small resorts and limited space and district heating systems. As shown on Figure 2, the oil price shocks of the 1970s revived interest in the use of geothermal resources as an alternative energy source. Beginning in 1978, the USDOE initiated numerous programs that also caused significant growth in the industry (Kenkeremath, et al., 1985). The annual compound growth rate for the industry from 1940 to 1970 was about 2%, from 1970 to 1985 about 8%, and from 1985 to 1990 it is about 11%. These figures do not include enhanced oil recovery data. The recent interest in geothermal heat pump installations, expects to generate a growth rate for that sector of about 50% in 1990.

Geothermal Localities

Tremendous potential exists in the United States for the development of geothermal energy for direct heat projects. The low- and intermediate-temperature (<90° to 150°C)

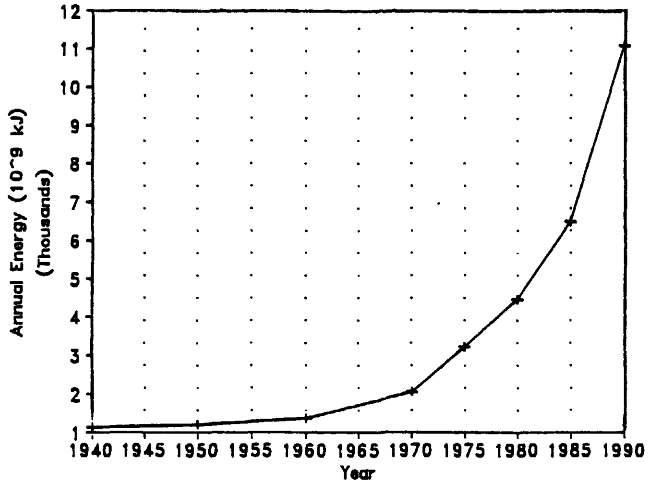


Figure 2. Geothermal direct heat growth in the United States (does not include enhanced oil recovery).

geothermal resource is used almost exclusively for these applications. This resource base, as reported in Muffler (1978) and Reed (1983), is estimated at 28,000 x 10^{15} kJ (26,500 Quads), and the wellhead thermal energy recoverable from these resources is estimated at 318 x 10^{15} kJ (302 Quads).

Table 2. Thermal Energy from Low-to-Intermediate Temperature Identified Geothermal Systems in the United States[a]

System	Resource Temperature (°C)	No. of Systems	Resource[b] Base x 10^{15} kJ	Resource[c] Recoverable x 10^{15} kJ
Hydrothermal-Convection	< 90	1,123	200	31
	90 to 150	163	700	176
Conduction-Dominated to 3 km	<90	38	27,100	111
		1,324	28,000	318

a. Reed, 1983 and Muffler, 1978.
b. Resource base - geothermal energy in the ground.
c. Recoverable Resource - energy that might be recoverable at the wellhead.

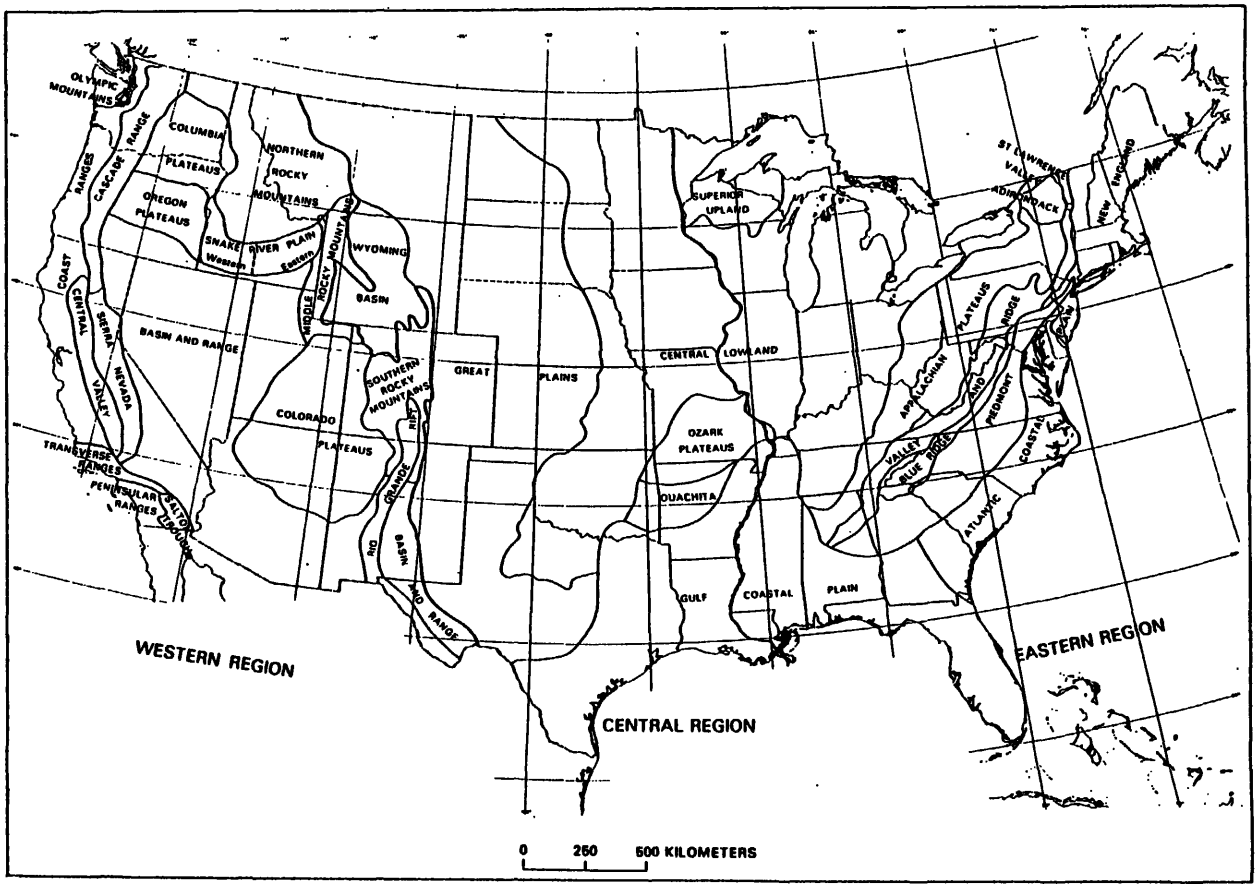


Figure 3a. Geologic provinces of the United States (Reed, 1983).

Low- and intermediate-temperature geothermal resources occur in two types of geothermal systems: (1) hydrothermal-convection, and (2) conduction-dominated, which are quantified in Table 2.

In hydrothermal-convection systems, upward circulation of water transports thermal energy to reservoirs at shallow depth or to the surface. These systems commonly occur in regions of active tectonism and above-normal heat flow, such as much of the western United States. In conduction-dominated systems, there exists high vertical temperature gradients in rocks that include aquifers of significant lateral extent. These conditions occur beneath many deep sedimentary basins throughout the United States (Reed, 1983).

Table 3 provides information about geothermal localities in the United States according to geologic provinces (Reed, 1983). The geologic provinces are identified on Figure 3. The information in Table 3 relies heavily on Mariner and Sorey's methodology presented in Reed (1983).

Developments from 1985 to 1990

Direct heat projects that became operational or were under construction from January 1, 1985 to January 1, 1990, are listed in Table 4. There were 27 projects identified in eight states, including space heating for approximately 100 new homes in the Reno area and 20 in Klamath Falls using downhole heat exchangers. During this period, the thermal capacity of direct heat projects increased by 107 MWt, representing an annual energy utilization of 1,133 x 10^9 kJ (not including heat pumps).

Projects under construction include two geothermal district heating systems in eastern California: the Mammoth Lakes system which recently issued an RFP (request for proposal), and Bridgeport. The San Bernardino district heating system has 30 buildings connected since 1985 and five more are expected to be connected by the end of 1990 (Fisher, 1990). The majority of the Klamath Falls district heating system has been shut down since 1985 due to leaking pipe connections in the FRP secondary loop (Rafferty, 1989).

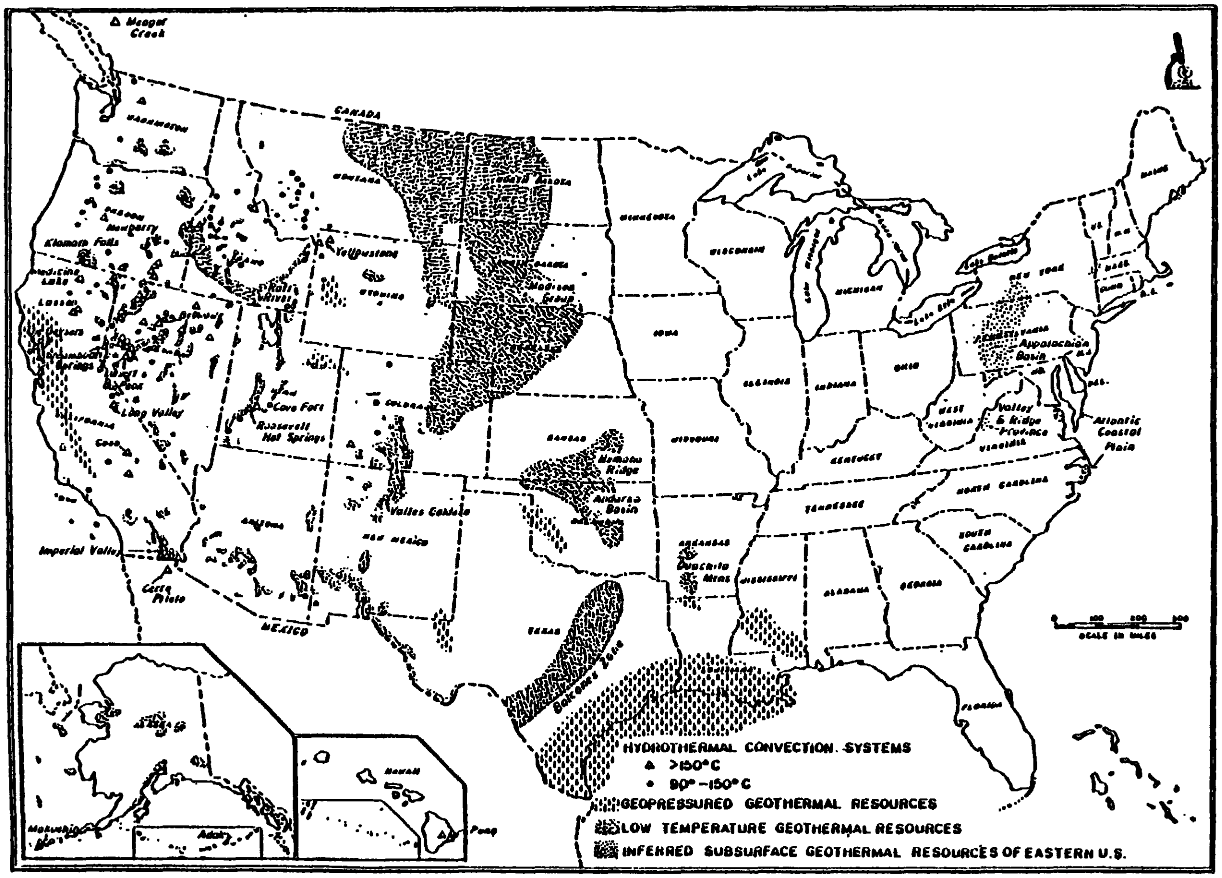


Figure 3b. Geothermal resources in the United States (Wright, 1989).

After a lengthy negotiated settlement between the contractor, engineer and city, the FRP pipe will be replaced with steel pipe, and the system put back in operation by the 1990/91 heating season.

There were significant developments in the industrial sector with the establishment of heap leaching of gold in Nevada at Round Mountain and Florida Canyon (Trexler, et al., 1987). Over 5.3 ha of geothermally heated greenhouses were built in Montana and New Mexico. The largest was Burgett Floral, Animas, New Mexico, with 4.05 ha. Four aquaculture projects were started in Arizona, primarily at Hyder Valley, where tilapia, catfish and bass are raised (Fitzsimmons, 1988).

At the present time, earth-coupled and groundwater heat pump systems are being installed in great numbers. Groundwater aquifers in the range of 5° to 30°C are being used in these systems in just about every state in the nation (mainly in the midwest and east). Geothermal heat pumps utilize groundwater in wells or by direct earth coupling with vertical heat exchangers. It is estimated that almost 50,000 groundwater systems and over 30,000 closed-loop, earth-coupled systems (2/3 of these are vertical installations and 1/3 horizontal) are being used. Last year, there were over 10,000 earth-coupled and 8,000 groundwater systems installed in the United States, and this year, the total is estimated to reach 25,000 (Lund, 1988 and 1989). The estimated capacity of the heat pumps installed from 1985 to 1990 is 400 MWt and the annual energy utilization is 12 x 10^{12} kJ. The popularity of these systems is due to the recent promotion by electric utility companies and the availability of low-temperature resources throughout the country. A summary of geothermal heat pump installations is listed in Table 5.

METHODOLOGY

The thermal capacity of a direct heat site (Tables 1 and 4) was computed using actual fluid temperature drops and flow rates as defined by:

$$\dot{q} = C_f \dot{m} (T_i - T_o)$$

TABLE 3 - INFORMATION ABOUT GEOTHERMAL LOCALITIES

Rock[1] = Main type of reservoir rock.

Water[2] = Total dissolved solids, in mg/kg, before flashing.
Categories: (1) <1,000 mg/l, (2) 1,000 to 10,000 mg/l, and (3) >10,000 mg/l.

Status[3]
- N = Identified geothermal locality, but no assessment information available
- R = Regional Assessment.
- P = Pre-feasibility studies.
- F = Feasibility studies (reservoir evaluation and engineering studies).
- U = Commercial utilization.

Reservoir Temp[4] = Low (L) <90°C, Intermediate (I) 90 to 150°C, and High (H) >150°C.

Locality Geologic Province	Accessible Resource Base 10^{15} kJ L	I & H	Reservoir Rock[1]	Water[2]	Status[3] in January 1990	Reservoir Temp.[4] and No. Systems
Central Alaska	2.60	11	Granitic plutons	--	R,U	L(25), I & H(15)
SE Alaska	0.58	10		--	R,U	L(5), I(5), H(1)
Aleutian Islands	0.35	10	Volcanic	--	R	L(3), I(15)
Hawaii	0.70	9	Basaltic dikes	L(2)	R,F,U	L(1)
Olympic Mountains	0.29	--	Sedimentary and Volcanic rock	L(2)	R,U	L(2)
Cascade Range	3.5	57	Basalt flows and andesitic to dacite stratovolcanoes	L(1)	R,U	L(36), I & H(13)
Coast Range	3.7	165	Sedimentary rocks	L(2)	R	L(46), H(1)
Central Valley	0.094	--	Geopressured sediment	L(3)	N	L(2)
Sierra Nevada	3.6	120	Granitic rocks	L(1)	R,P	L(20)
Transverse Ranges	2.7		Granitic and metamorphic basement	L(1,2)	R,U	L(26)
Peninsular Ranges	5.7		Granitic and metamorphic terraces	L(1,2)	R,U	L(29)
Salton Trough	2.9	240	Active tectonism and recent volcanism	L(1,2), H(3)	R,U	L(18), I & H(10)
Basin & Range	107	280	Range front faults and sedimentary filled basin	L(1), I(2)	R,F,U	L & I(471)
Oregon Plateaus	6.1	.80	Marine strata and intrusive	L(1)	R,U	L(40)

(continued)

Table 3. (continued)

Locality Geologic Province	Accessible Resource Base 10^{15} kJ L	I & H	Reservoir Rock[1]	Water[2]	Status[3] in January 1990	Reservoir Temp.[4] and No. Systems
Columbia Plateaus	78	0	Flood basalts	L(1)	R,U	L(15)
Western Snake River Basin	28	491	Silicic Volcanic and clastic sedimentary	L(1)	R,U	L(32)
Eastern Snake River Plain	5.7	21	Basalt flows	L(1)	R,U	L(20)
Northern Rocky Mountains	5.4	11	Crystalline rocks	L(1)	R,U	L(135)
Middle Rocky Mountains	1.8	2		L(1)	R,U	L(25)
Southern Rocky Mountains	3.1	5	Crystalline basement and volcanic rocks	L(1)	R,U	L(34)
Colorado Plateaus	1.56	1	Sedimentary	L(2)	R	L(30)
Rio Grande Rift	5.4	93	Interconnected partly filled structural basins	L(1)	R	L(48)
Wyoming Basin			Sedimentary	L(2)	R,U	
Great Plains			Sandstones and limestones		R,U	

TABLE 4 - UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT IN THE UNITED STATES
New Projects from January 1, 1985 to January 1, 1990

* Type of Use

I = Industrial process heat | D = District heating
C = Air conditioning | B = Bathing and swimming
A = Agricultural drying | G = Greenhouses
F = Fish and other animal farming | O = Other (please specify by footnote)

Locality (Footnote for comments)	Type*	Maximum Utilization Flow Rate kg/s	Temperature °C Inlet	Temperature °C Outlet	Thermal Capacity MWt	Average Annual Utilization Flow Rate kg/s	Energy x 10^9 kJ	Load Factor
AZ, Hyder Valley	F	252	41	27	11.7	101	148	0.40
Safford	F	63	41	27	2.9	25	37	0.40
Tucson	F	51	27		2.3	21	30	0.41
Hyder Valley	F	54	41	27	2.1	21	26	0.37
CA, Mammoth Lakes (under const.)	D	109	166	NA	15.1	28	124	0.26
San Bernardino (expansion)	D	233	59	46	12.8	35	61	0.15
Litchfield (expansion)	D	76	77	58	6.2	19	49	0.25
Bridgeport (under constr.)	D	41	93	NA	1.9	10	15	0.25
Cedarville Elem. & High School	S	7	52	41	0.4	3	5	0.40
Modoc H.S.	S	41	73	44	0.6	11	5	0.26
Indian Valley Hospital	S	6	43	35	0.2	1	1	0.16
Lake Ag Park	G	3	60	46	0.1	0.6	0.6	0.19
HI, Geothermal Technology Program	I	0.2	99-188			0.2		
ID, Fort Boise VA Caldwell	S	19	72	23	1.8	4	13	0.23
J. E. Simplot	F	50	39	29	2.5	40	63	0.80

(continued)

Table 4. (continued)

Locality (Footnote for comments)	Type*	Maximum Utilization Flow Rate kg/s	Temperature °C Inlet	Outlet	Thermal Capacity MWt	Average Annual Utilization Flow Rate kg/s	Energy x 10^9 kJ	Load Factor
MT, High Country Roses	G	13	66	20	2.5	6	35	0.44
Montana Rose and Floral	G	29	92	80	1.4	10	15	0.34
NV, Round Mountain Gold Corp.	I	189	86	35	14.1	88	208	0.47
Florida Canyon	I	25	114	62	1.4	23	42	0.95
Reno - Res. (Tot. of 100 new)	S	NA	50-83	NA	4.4	NA	42	--
Hobo H.S.	F	6	45	26	0.6	5	16	0.85
Elko County School Dist.	D	19	88	38	2.1	5	17	0.26
NM, Burgett Floral	G	16	118	82	5.5	6	69	0.40
OR, Klamath Falls Res. (20 new)	S	NA	82	NA	12.8	NA	101	--
Henley H.S. (u.c.)	S	25	53	44	0.9	6	7	0.25
Hot Lake RV Park	S,B	52	88		0.3	11	2	0.21
Klamath Res.	D	5	82		0.3	2	0.7	0.25
				Subtotal	107.0		1,133.0	
All of U.S. - Heat Pumps					400.0		1,200.0	
				TOTAL	507.0		2,333.0	

TABLE 5 - HEAT PUMP LOADS

State	Site	(oC)	(MWt)	(10^9 kJ)
FL	All of State	24	369.6	1188.1
MI	All of State	8	62.4	601.7
IN	All of State	12	86.5	556.3
OH	All of State	12	59.9	385.0
WI	All of State	8	332.6	320.9
IL	All of State	12	46.6	299.5
KY	All of State	15	40.7	262.0
TX	All of State	19	68.3	219.8
DA	All of State	10	31.6	203.2
MN	All of State	7	16.6	160.4
MD	All of State	14	21.6	139.1
NC	All of State	17	42.4	136.4
LA	All of State	20	41.6	133.6
AR	All of State	17	34.9	112.3
VA	All of State	15	16.6	107.0
SC	All of State	19	28.3	90.9
ND	All of State	6	8.3	80.2
MD	All of State	14	24.9	80.2
NB	Northern Part of State	11	10.8	69.5
NJ	All of State	13	10.8	69.5
IA	All of State	11	10.8	69.5
DE	All of State	14	9.5	60.9
SD	All of State	8	6.2	60.2
NY	All of State	8	5.2	49.7
GA	All of State	19	11.3	36.3
TN	All of State	16	8.1	26.1
KS	All of State	14	3.7	23.7
CO	All of State	11	3.3	21.4
AL	All of State	19	3.8	12.4
MS	All of State	19	1.8	5.9
AZ	All of State	17	1.7	5.4
OK	Central Part of State	17	0.4	1.0
FL	Patrick Air Force Base	22	11.6	146.3
OR	Portland Office Buildings		8.8	55.3
UT	LDS Office Building	16	7.9	49.8
SD	St. Joseph Indian School	23	2.2	21.7
ID	College of Southern Idaho	39	2.4	19.0
WA	Clark College	13	2.0	14.5
NY	Sagamore Resort	8	1.2	11.6
WA	Grant County Courthouse	29	1.1	8.8
IN	Corporate Square	13	1.2	7.8
WA	Yakima County Jail	24	1.1	7.7
WA	Chinoth Tower	16	0.9	6.9
WA	Cowlite County Courthouse	13	0.9	6.3
WA	Sundown M. Ranch	21	0.5	3.9
KS	Elementary Schools (3)	15	1.4	3.5
ND	Buxton School	6	0.4	3.4
7 States	10 Other	11-30	2.4	11.4
			1466.8	5966.0

ABLE 6 - WELLS DRILLED FOR DIRECT HEAT UTILIZATION OF GEOTHERMAL RESOURCES FROM JANUARY 1, 1985 TO JANUARY 1, 199

(Do not include thermal gradient wells less than 100 m deep)

* Type or purpose of well and manner of production
(Use one symbol from column (1) and one from column (2)

(1) T = Thermal gradient or other scientific purpose
E = Exploration
P = Production
I = Injection
C = Combined electrical and direct use

(2) A = Artesian
P = Pumped
F = Flashing

** For wellhead temperatures less than 100°C, multiply the temperature in °C by 4.1868 to obtain the enthalpy.

Locality (Footnote for comments)		Year Drilled	Type of Well (1)	(2)	Total Depth (meters)	Maximum Temp. °C	Flow Rate kg/s
AZ	Hyder Valley	1985	P	P	152	32.0	76.0
	Hyder Valley	1985	P	P	152	32.0	51.0
	Hyder Valley	1986	P	P	100	40.0	38.0
	Hyder Valley	1987	P	P	305	32.0	126.0
	Hyder Valley	1987	P	P	305	40.0	63.0
CA	Calistoga High School	1986	I	NA	80	82.0	
	Calistoga Mineral Water	1985	P	P	97	121.0	18.9
	Sierra Valley	1989	P	A&P	398	38.0	25.0
	Modoc High School, Alturas	1988	P	A&P	736	73.0	5.0
	Bieber School	1987	E	NA	647	55.0	
	Near White Sulphur Springs	1989	E	NA	457	35.0	
	Mammoth Lakes	1988	T	NA	468	71.5	
	Mammoth Lakes	1988	T	NA	490	73.1	
	Susanville	1988	I	NA	200	40.0	
	Lake Co. Ag Park, Kelsyville	1986	I	NA	492	61.1	
	Lake Co. Ag Park, Kelsyville	1987	P	P	170	62.7	9.5
	Lake Co. Ag Park, Kelsyville	1987	P	P	152	67.2	9.5
	Kelsyville School	1988	E	NA	213	33.0	
	San Luis Bay	1988	P	P	183	41.0	3.8
	Paso Robles	1988	E	NA	335	43.0	31.5
	Fort Bidwell	1985	P	A	884	98.8	25.2
	Clear Lake (4 - T)	1987	T	NA	152	41.0	
	Napa Valley Springs, Calistoga	1988	P	P	91	104.0	0.8
	Private Pool, Calistoga	1986	P	P	73	60.0	1.6
	Niland	1989	P	A	198	49.0	4.4
	Niland	1986	P	A	146	61.0	32.2
	Niland	1989	P	A	146	61.0	37.9
CO	Ouray	1988	E		97		
	Ouray	1988	E		105		
	Ouray	1988	E		91		
	Ouray	1988	E		91		
	Ouray	1988	P	A	29	69.0	11.4
	Ouray	1988	P	A	29	69.0	38.0

(continued)

Table 6. (continued)

	Locality (Footnote for comments)	Year Drilled	Type of Well (1)	Type of Well (2)	Total Depth (meters)	Maximum Temp. °C	Flow Rate kg/s
ID	Boise	1989	P		605		
	Gooding	1989				68.3	94.7
	Challis	1989	P		116		32.0
	Hagerman	1989	P	A	310		
	Stanley	1989	P	P			
	Buhl	1990			137	48.9	32.0
	Buhl	1987	P				
	Caldwell, Simplot Fish Prop.	1987	P	A	333	38.9	31.6
	Lava Hot Springs	1988					
	Caldwell, Simplot Fish Prop.	1988	P	A	645	40.0	6.3
NM	Radium Springs	1986	I		73		
	Radium Springs	1986	I		110		
	Radium Springs	1986	P		85	23.3	
	Radium Springs	1986	P	P	37	23.3	21.5
	Radium Springs	1987	P	P	46	23.3	21.5
	Radium Springs	1986	T	P	91	11.1	
	Gila Hot Springs	1986	T	P	75	15.6	
	Gila Hot Springs	1986	P	A	73	23.3	2.4
	Gila Hot Springs	1985	T	A	139	22.8	1.0
NV	Elko Schools	1986	I		122		
	Elko Schools	1985	P	A	600	88.0	19.0
	Carlin Schools	1987	P	P		30.0	3.8
	Wells Schools	1986	P	P		30.0	3.2
	Wells Elementary	1987	P	P		30.0	1.6
	Salem Plaza, Reno	1988	I		510	71.0	
	Peppermill, Reno	1989	I		1220		
	Residential, Reno	1985-89	100P	DHE	100-300	50-83.0	
	Virginia Lake, Reno	1986	I				
	Round Mountain Gold Corp.	1988	P	P	262-300	86.0	190.0
	Round Mountain Gold Corp.	1987	I		183		
	Florida Canyon Mining - Pegasus Gold	1986	P	P	177	114.0	25.0
	Jackpot Y3 Ranch	1988	P	P		42.0	107.0
OR	Klamath Falls Residential	1986-89	20P	DHE	63-216	36.0-103	
	Klamath Co. Detention Center	1988	P	P	427	66.0	38.0
	Oregon Institute of Technology	1989	I		611	37.0	
	Henley School	1989	P	P	459	54.0	63.0
SD	Chamberlain	1988	P	A	290	23.0	15.7

(continued)

Table 6. (continued)

Locality (Footnote for comments)		Year Drilled	Type of Well (1) (2)	Total Depth (meters)	Maximum Temp. °C	Flow Rate kg/s
UT	Washakai	1988	P P	450		
	Newcastle	1989	DHE	400		
WA	Walla Walla	1985	P P	255	22.0	38.0
	Vancouver, Clark College	1985	2PH P	60	11.0	126.0
	Vancouver, Clark College	1985	2I	60		
	Long View	1985	HP P	50	11.0	38.0
	Yakima area	1985	7HP P	60	22.0	

Table 7 - ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to Personnel With A University Degree)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

Year	(Professional Man Years of Effort)					
	(1)	(2)	(3)	(4)	(5)	(6)
1985	7.8	2.5	8.4	0	0	2.9
1986	7.8	2.5	9.4	0	0	3.6
1987	7.8	2.5	9.9	0	0	4.4
1988	7.5	2.5	9.9	0	0	4.1
1989	7.6	2.5	9.4	0	0	4.5

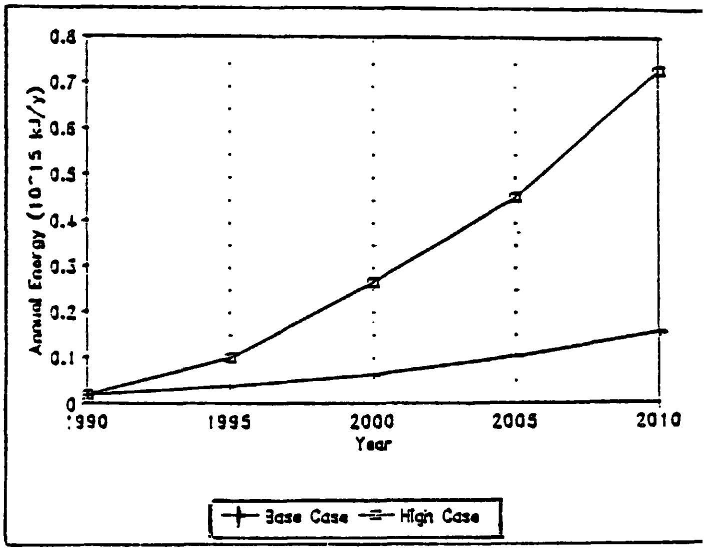


Figure 4. Projected growth for direct heat projects excluding enhanced oil recovery.

where: $\dot{q}$ = thermal capacity
C_f = specific heat of the fluid
$\dot{m}$ = mass flow rate
T_i = inlet fluid temperature
T_o = outlet fluid temperature

Data usually available for a direct heat site are the wellhead temperature and the maximum flow rate. If the outlet temperature is unknown, the thermal capacity is estimated using an assumed outlet temperature or an estimated value of the thermal capacity per unit area (kW/m^2), if the heated structure's floor area was known.

Average annual energy was estimated using a site specific load factor. The load factor of a direct heat system is the ratio of the average annual load to the peak load. The load factor ranges from 9% in southern California to 25% in the northern states, and as high as 50% in Alaska.

In the case of geothermal heat pump wells, it was assumed that an average residence would require a temperature drop of 5.6°C at 0.50 kg/s to meet the thermal capacity of a typical 167 m^2 home. When calculating energy use, load factors are considered for the heating mode only (Table 5), since this extracts heat from the earth; whereas, the cooling mode returns heat to the earth and is thus not considered a geothermal use.

The thermal capacity of aquaculture projects and swimming pools, where possible, were calculated from flows and temperature differences. Often, the entire output of a thermal spring simply flows continuously through the pool; thus, in the case of swimming pools, the annual energy was adjusted by a utilization factor of: 0.8 in northern states and 0.4 in southern states, to give a more realistic value of the beneficial heat. In addition, if the pool was only used a portion of the year, this value was further adjusted.

Much of the information on heat pumps in Table 5 was based on information provided by the International Ground Source Heat Pump Association (Ellis, 1988 and 1989) and from various state organizations. The average load factor is 12.5%.

WELLS DRILLED

Slightly over 200 direct heat geothermal wells have been drilled during the period from 1985 to 1990, as summarized in Table 6. In addition to the heat pump wells identified in the state of Washington, there have been an estimated additional 30,000 heat pump wells drilled throughout the United States that are undocumented, since they are classified as normal water wells. The majority of the wells are for production; but, we are seeing an increase in the number of injection wells, due to environmental concerns about minimizing the impact on the resource and chemical and thermal pollution of surface waters. The average depth of wells is around 150 m, with the deepest at the Peppermill Casino and Hotel in Reno of over 1,200 m. Most of the temperatures are below boiling, with the hottest slightly over 120°C. The greatest number of wells drilled in one area, is in the Moana area of Reno, Nevada, where downhole heat exchangers are used for space heating. California has a large number of new wells, primarily due to the assistance of the California Energy Commission.

Table 6 was developed by contacting state departments of water resources and other organizations for lists of geothermal wells drilled since 1985. This listing is incomplete because several states make no distinction between low-temperature geothermal and non-geothermal wells.

PROFESSIONAL PERSONNEL

The allocation of professional personnel to geothermal activities is shown in Table 7. This table is based on data gathered from the California Energy Commission and extrapolated for the rest of the United States. California Energy Commission project costs are broken out into personnel, overhead, equipment, travel, etc. These data, thought to be highly reliable, were then expanded in proportion to the activity (generally on a project basis) in other states as compared to California. The summary is estimated to be within 25% of the actual numbers.

OUTLOOK

The potential is large for the growth of the direct heat industry in the United States. Based on historical data, presented in this paper, projected growth of each direct heat technology was constructed for a base case ("business as usual") and a high case. The high case assumes extensive resource evaluation takes place, federal incentives are instituted and economic conditions change due to conventional fuel prices increases. The cumulative growth of the eight direct heat technologies are illustrated on Figure 4.

Geothermal heat pumps providing space heating and cooling will have the largest growth because the technology has applications nationwide and they reduce energy consumption by 30% when compared to air-source heat pumps. It is estimated that by the year 2010 vertical closed-loop units will have captured 15% of the air-source heat pump market--presently estimated at 800,000 units installed per year. This amounts to a 24-fold increase or 17.2% growth per year over 20 years for the high case. The base case amounts to approximately a 4-fold increase or 7.5% per year over 20 years.

Space and district heating using resources greater than 50°C are estimated to have a potential annual energy use of 14.3×10^{12} kJ per year by 2010, assuming a 33% market penetration. This represents a high case growth of 12% per year. The base case growth is estimated at 2% per year, corresponding to the population growth rate.

Greenhouses can utilize geothermal temperatures as low as 38°C. There are many such resources, but limited information is known about them. Assuming federal programs are re-instituted to provide location and confirmation, technical assistance, etc., it is estimated that the high case growth would be about 10% per year or 2.5×10^{12} kJ by 2010, a 6-fold increase.

Aquaculture is one of the fastest growing industries. Catfish processing increased 21% in 1989. Only a very small part of that is geothermal; although, it is well known that growth rate and food conversion are greatly enhanced with geothermal aquaculture where water temperatures can be maintained relatively constant. It is estimated the high case growth will be about 11% per year and the base case of about 8% per year.

Excluding enhanced oil recovery, the major industrial uses of geothermal are gold heap leaching, food dehydration and mushroom growing. Of these, gold processing seems to have the most promise of substantial increased use. It is estimated the high case growth will be about 11% and the base case about 5%.

As oil prices rise, enhanced oil recovery use would increase and, perhaps, expand to other fields that co-produce hot water and oil. Geopressured-geothermal resources and oil producing business in the Gulf Coast, Los Angeles basin, San Joaquin Valley and other basins, identified in Lunis (1989), are possible fields.

CONCLUSIONS

The results of the federal programs of the early 1980s are encouraging. For many projects, commercial exploitation is now a reality and results of resource exploration are still being utilized. Much more work in the low- and moderate-temperature resource areas is needed. The economic conditions and competitiveness of direct-heat geothermal energy development have declined in recent years, and the cost and risk of resource evaluation and confirmation is constraining accelerated growth.

As a case in point, Table 4 and 6 show significantly more direct use wells and projects in California than other states. The California Energy Commission has a grant and loan program for local governments designed to reduce the risk of developing geothermal resources. This successful program, which began in 1981, has resulted in 14 operational projects saving approximately 5,000 TOE/yr and planned activities in the coming year could result in increasing this to 12,000 TOE/yr.

Also, the large increase in geothermal heat pump use is due in large part to incentives from electric utility companies. These incentives benefit both the user by reducing installation and heating costs, and the utility because of the load leveling effects of groundwater heat pumps.

As dependence on the import of crude oil increases, there is a need for a serious program to develop alternative energy resources and encourage energy conservation. There is an enormous potential of using geothermal resources for district heating. However, there is a need for federal support (cost share) of the drilling phase for the exploitation of new geothermal reservoirs, thus mainly covering the drilling risk. This approach has proven to be very efficient in the European community (CEC, 1988) and California in triggering geothermal activity.

In the coming years, the exploitation of geothermal energy could take a major step forward, especially if conventional fuel prices escalate, given the appropriate encouragement at the national and state level, and progress in a number of areas. In particular:

* exploratory drilling in new and little known areas to overcome the initial risk,

* evaluation and confirmation of low- and moderate-temperature resources near hundreds of population centers that have potential for district heating,

- * encourage cascading from geothermal power plants to industrial processes (such as heating and drying), greenhouse and aquaculture projects,

- * technical advances to improve the economics of piping systems and reduce drilling costs.

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