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MASTER

MONTANA GEOTHERMAL COMMERCIALIZATION PLANNING

SEMI-ANNUAL PROGRESS REPORT

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1.0 INTRODUCTION

Geothermal energy-- heat from the earth-- seems to be an attractive energy source that may supplement the world's shrinking fuel supply. Unlike nuclear and fossil fuel energy, geothermal energy faces little public opposition and has only minor environmental impacts. In addition, geothermal energy has the potential for being economically competitive with conventional fuel sources, at least in areas where the hot water or steam is near the earth's surface.

Montana has numerous surface indicators of geothermal energy, such as hot springs and hot water wells. These have aroused interest on the part of both state and federal governments in identifying the production potential of this resource.

1.1 PURPOSE OF PROJECT

During 1978 and 1979, the U.S. Department of Energy and the Montana Department of Natural Resoures and Conservation have cooperatively sponsored a geothermal planning project. This continuing planning project is an attempt to identify systematically the development potential of Montana's geothermal resources.

The Montana geothermal planning project involves seven major tasks, enumerated below:

(1) identification of geothermal resources;
(2) construction of area development plans (ADPs);
(3) construction of site-specific development plans;
(4) construction and discussion of time-phased project plans (i.e., a description of active or planned demonstration and commercial geothermal projects within the state);
(5) aggregation of area and site-specific geothermal information to provide estimates of the total geothermal resources

available and possible development dates for them;

(6) compilation of the legal requirements and other institutional concerns that bear on timely, efficient, and environmentally compatible commercialization of geothermal resources; and

(7) development of a public outreach program.

Each of these tasks is described and discussed more fully in the following sections.

1.2 OBJECTIVES

The emphasis of this project has been on identifying geothermal resources and their potential uses. Project objectives include determining potential geothermal energy supplies, calculating present and projected energy demands, and producing development scenarios for the use of geothermal energy. The project has emphasized the direct use of geothermal heat, involving low-to-moderate temperature applications such as space heating and industrial process heating. High temperature applications (greater than 150° C) such as electrical generation were not considered, since Montana has no known high temperature geothermal reservoirs.

1.3 TECHNICAL APPROACH AND TEAM MEMBERS

1.3.1 TECHNICAL APPROACH

Area development plans and site-specific development plans were prepared using projected populations and energy supply and demand figures. The approach in preparing these development plans involved the following five steps:

(1) calculating present and projected energy consumption for a given area;

(2) calculating potential geothermal energy supplies;

(3) matching potential geothermal resources with nearby projected energy demands;

(4) estimating projected costs of both conventional and geothermal energy; and

(5) generating possible development scenarios for a given site

or area, using the data derived above.

Projected energy consumption for a given site or area was calculated from specific population (Dodge, 1977) and energy consumption data (The Montana Power Company, 1979). Present per capita energy consumption data were extrapolated through the year 2020 by multiplying these data by the projected populations of each area or site. Potential future changes in energy consumption patterns and environmental limitations were also considered in estimating energy consumption rates.

The supply of geothermal energy in a given area was calculated by two different methods. The first method, developed by Keith Brown (1978), is based upon variables of potential flow and temperature of a geothermal reservoir (see Appendix A). These variables are determined empirically from surface observations, e.g., present flow and surface temperature.

The second method of determining geothermal energy supplies was developed by the U.S. Geological Survey (Muffler, 1978; see Appendix B). This method involves estimating the geothermal reservoir volume as well as reservoir temperature.

Potential geothermal resources were matched to specific energy consumers by examining variables of distance between the resource and the potential consumer as well as the process heat requirements of the consumer. It is not likely that potential users or consumers of energy in Montana requiring temperatures in excess of 150^{o}C will be able to rely on geothermal energy.

The New Mexico Energy Institute (1979) has developed projections of energy costs for both conventional and geothermal resources. This model was used in calculating the potential costs of energy supplies for the Montana project. Knowledge of many of these variables is poor; therefore, the projected costs of both geothermal energy and conventional energy should be viewed only as reasonable expectations based on the authors' best estimates of future developments.

The economic feasibility (market penetration) of geothermal energy was estimated by comparing the cost of producing one million British thermal units (Btu) from a geothermal resource with the cost of producing the same amount from conventional sources. It was assumed that development of geothermal resources would begin whenever projections might show geothermal energy and conventional energy to be equal in cost. Development time for a geothermal resource was assumed to be five years, and new industrial applications were assumed to be cost-competitive from the start.

1.3.2 TEAM MEMBERS

Although the project was originally designed to include one full-time person to direct the project task and another to perform tasks involving public awareness, only one staff member was available from January through June, 1979. A second staff member was hired in June, and a third person will be hired in September to help fulfill the project objectives.

1.4 BENEFITS OF THE PROJECT TO MONTANA AND TO THE U.S. DEPARTMENT OF ENERGY

The efforts of the Montana geothermal team provide useful information both to the general public and to interested developers within the state. Through the outreach program, site-specific information on geothermal resources is transferred to landowners and to other interested persons. Also, information concerning possible applications of geothermal resources is provided to local government officials, developers, and landowners.

The U.S. Department of Energy(DOE) also benefits from the work of the Montana team. DOE's major interest is in stimulating the commercial development of geothermal energy and in assessing the possible market penetration rate for geothermal. The Montana project provides DOE with data on current energy consumption and projected geothermal energy supplies for use in the preparation of national plans and policies.

2.0 SUMMARY OF STATE PROJECT TASKS AND WORK ACCOMPLISHED

2.1 PREPARATION OF AREA DEVELOPMENT PLANS

The first task to be undertaken is that of preparing area development plans which describe geothermal resources and their potential use on a county or multicounty basis. The preparation of these plans has been the primary effort of the planning project during the first half of 1979. The methods used to prepare the area development plans are described in section 3.2.

Development plans for Area 1 (Jefferson, Broadwater, and Lewis and Clark counties) and Area 2 (Madison County) have been completed and are included in this report. Two more area development plans will be completed by the end of 1980. These plans assess Area 3 (Treasure, Rosebud, Custer, Fallon, Big Horn, Powder River, and Carter counties), and Area 4 (Gallatin, Park, and Meagher counties).

Cost analyses show that the proximity of the geothermal resource to the end user is the most important criterion in geothermal energy development in Montana. Therefore, commercial attractiveness, or market penetration, of geothermal development is dependent not only upon the amount of energy within an area, but also upon its accessibility.

Energy demand calculations for Area 1 show that approximately 3.9×10^{12} Btu of electricity and natural gas were consumed in 1978. Small amounts of other fuels (such as fuel oil and liquid petroleum gas) were also consumed. Area 1 might consume about 6.3×10^{12} Btu per year by 2000, and 9.8×10^{12} Btu per year by 2020. (See page 19 for an explanation of the assumptions used in making the projections of energy demand.)

The U.S. Geological Survey calculations of geothermal reservoir energy in Area 1 show a potential energy supply that might supplement a large part of the future energy demand of this region. This estimated energy supply is about 13.4×10^{12} Btu per year, which far exceeds the energy demand estimate of 9.8×10^{12} Btu per year in 2020. Even if only 15 percent of the available geothermal energy were to be used (2.0×10^{12} Btu), it would still provide over 20 percent of the total energy demand for Area 1 in 2020. Most of this geothermal energy could replace natural gas energy used for space and process heating.

Area 2, like Area 1, contains large geothermal reservoirs that might be used to supplement other fuels in meeting future energy demands. In 1978, Area2 used approximately 19.4 x 10^{10} Btu of electricity, fuel oil, and liquid petroleum gas for space and hot water heating. This present energy demand is expected to remain essentially unchanged during the next 40 years.

The total estimated potential energy contained in Area 2's ten geothermal reservoirs is 8.0 x 10^{12} Btu per year. This potential energy is about 41 times the present energy demand for space and hot water heating.

2.2 PREPARATION OF SITE-SPECIFIC DEVELOPMENT PLANS

The second task for the Montana geothermal project is that of preparing site-specific development plans for those particular communities where energy demand coincides geographically with a geothermal resource. The goals of this task are to examine the economic feasibility of geothermal development, to identify those factors that may discourage development, and to postulate target dates for the development of a given geothermal resource. In 1978, thirteen tentative site-specific development plans were produced. These plans are presently being revised, and the revisions should be completed by the end of 1979. Preliminary economic modeling indicates that Broadwater, Boulder, and Alhambra Hot Springs in Area 1 and Ennis Hot Spring in Area 2 show excellent potential for the development of geothermal energy.

2.3 ANALYSIS OF INSTITUTIONAL FACTORS AFFECTING GEOTHERMAL DEVELOPMENT

Through the institutional analysis, state and federal regulations relevant to geothermal development will be identified. Since most geothermal resources in Montana are on private and state land, only the state regulations will be examined in depth. Other state geothermal teams are analyzing federal geothermal regulations, and their analyses should be applicable to federal lands in Montana.

During the past year, data on various requirements and permits necessary for exploration, resource assessment, and development of geothermal resources on private and state land have been gathered together. This information will be published in a state geothermal handbook which will be available to potential geothermal developers. This handbook will expedite the use of geothermal resources in Montana by presenting a step-by-step procedure for obtaining permission to develop such a resource.

2.4 OUTREACH PROGRAM DEVELOPMENT

The fourth task involves promoting the use of geothermal energy by industry, utilities, agricultural interests, municipalities, and individuals. To this end, the Montana team is:

(1) contacting leaders in communities, business, industry, and government to inform them of geothermal development opportunities and programs;

(2) maintaining geothermal information files on a wide range of subjects, and providing public access to this information;

(3) coordinating regional support to assist potential users of geothermal energy;

(4) encouraging geothermal exploration, reservoir assessment, and geological research; and

(5) preparing informational brochures on various topics, such as geothermally heated greenhouses and warm water aquaculture.

Outreach efforts to date include answering inquiries about geothermal energy and personally contacting individuals who have provided data needed to complete other project tasks. The hiring of second and third staff members will increase the outreach program involvement significantly.

2.5 STATE GEOTHERMAL PLAN

The results of the first four tasks will be used to complete the fifth task --the preparation of a state plan for the development of geothermal energy. This plan will outline possible developmental pathways for Montana's geothermal resources, as well as contain Montana policies and regulations governing their development. Those people involved in the Montana Alternative Renewable Energy Sources grant program are anxious to coordinate the disbursement of their grants with a state geothermal plan. Thus the state plan will be used as a guide in directing state support of geothermal developments.

3.0 SPECIFIC TASK DESCRIPTION AND PRODUCTS

3.1 GEOTHERMAL PROSPECT IDENTIFICATION

Most of the known geothermal resource sites in Montana have been measured for observed and potential temperature and flow by the State Resource Assessment Team. In addition to these parameters, each site has been classified according to its development potential. The following definitions (Meyer and Davidson, 1978) were used in this classification:

(1) Proven sites are those which are in an advanced stage of development or commercialization by a private company or by government for specific applications and/or demonstrations; or those for which there are favorable quantitative data on measured subsurface temperature, volume, and water flow.

(2) Potential sites are those on which there is current active exploration or development, or for which some favorable quantitative subsurface data have been estimated or measured.

(3) Inferred sites or areas are those identified by surface manifestations such as wells or springs, chemical thermometry, or proximity to potential or proven sites.

Table 1 lists all of the known geothermal sites in Montana along with observed flow and surface temperature, calculated reservoir temperature, and development potential classification data. Note that none of the geothermal sites in the proven or potential categories have reservoir temperatures sufficiently high for electrical generation (150^{o} C or greater). However, commercial interest has been shown in the electrical generation potential of four geothermal sites appearing in the inferred category. These four sites are Corwin Springs (La Duke), Hunter's Hot Springs, West Yellowstone Known Geothermal Resource Area (KGRA), and Barkell's-New Biltmore Potential Geothermal Resource Area (PGRA).

Table 1. Surface Temperature, Observed Flows, and Calculated Reservoir Temperatures of Selected Montana Geothermal Resources[1]

Resource	Observed Surface Temperature (°C)	Observed Flow (liters/min)	Calculated Reservoir Temperature (°C)[2]
A. Proven			
Ennis	33°	57	129°a
New Biltmore	53°	380	71°c,e
Camp Aqua	50°	---*	100°c,d,g
B. Potential			
Alhambra	56°	570	96°a
Boulder	76°	950	136°a
Bozeman	55°	228	80°c,e,g
Broadwater	62°	285	118°a
Camas	45°	200	100°c,d,e,g
Chico	45°	500	58°c,e,g
Elkhorn	48°	400	65°c,e,g
Granite	51°	140	80°i
Gregson	70°	1,000	118°a
Hunter's	59°	5,000	78°c,e,g
Jackson	58°	1,000	125°c,e,g
La Duke	65°	500	73°c,e
Lolo	44°	100	83°c,e,g
Norris	52°	334	107°a
Pipestone 1, 2	57°	300	88°c,e

Hot Spring	Observed Surface Temperature (°C)	Observed Flow (liters/min)	Calculated Reservoir Temperature (°C)[2]
Potosi 1, 2, 3	50°	2,300	60°c,e
Silver Star	72°	228	131°a
Sleeping Child	45°	437	125°c,d,g
Warm Springs	77°	600	79°c,e
White Sulphur Springs	46°	1,500	125°c,d,e,g
Wolf Creek	68°	1,189	77°c,e
Marysville KGRA	103°[3]	---	122°a
C. Inferred Resources			
Anaconda	22°	---	75°a,b,c,d,g
Anderson's	25°	---	30°c,d,e,g
Anderson's Pasture	26°	340	45°c,d,e,g
Apex	25°	---	76°b
Avon	26°	---	---
Bear Creek	24°	114	---
Bearmouth 1	20°	---	35°c,e,g
Bearmouth 2	20°	---	35°c,e,g
Beaverhead Rock	27°	380	---
Bedford	24°	5,700	30°h
Blue Joint 1	29°	1,020	45°c,e,g
Blue Joint 2	29°	850	45°c,e,g
Bridger Canyon	20°	---	25°h
Brook's	20°	304,000	25°h
Brown's	24°	12,914	30°h

Hot Spring	Observed Surface Temperature (°C)	Observed Flow (liters/min)	Calculated Reservoir Temperature (°C)[2]
Carter Bridge	28°	---	40°
Deer Lodge	26°	---	40°c,e,g
Durfee Creek	21°	57,000	30°h
Gallogly	49°	456	56°c,e,g
Garrison	25°	---	35°c,e,g
Green Springs	26°	---	---
Greyson	18°	---	25°h
Landusky 1	21°	2,280	35°c,e,g
Landusky 2	---	---	---
Landusky Plunge	24°	11,400	30°c,e,g
Little Warm Springs 1	---	---	---
Little Warm Springs 2	22°	4,560	35°c,e,g
Little Warm Springs 3	23°	---	35°c,e,g
Lodgepole 1, 2, 3	30°	10,260	35°c,e,g
Lowell's	19°	4,275	30°h
McMenomey Ranch	19°	---	---
Nimrod	20°	760	30°h
Plunkett's	17°	15,200	20°h
Puller's	44°	570	90°b,c,d,e,g
Quinn's	43°	76	99°c,e
Renova	50°	---	---
Sloan Cow Camp	30°	---	85°c,d,e,g
Staudermeyer Ranch	28°	6,796	45°c,d,e,g

Hot Spring	Observed Surface Temperature (°C)	Observed Flow (liters/min)	Calculated Reservoir Temperature (°C)[2]
Sun River	30°	1,900	35°h
Toston	16°	33,984	20°h
Trudeau	23°	---	23°e
Vigilante	24°	1,900	35°h
Warner	18°	---	23°e
West Fork Swimming Hole	26°	1,869	30°c,d,e,g
Lucas'	42°	---	60°h
Ringling	48°	---	60°h
Symes'	40°	---	102°c,d,e,g

SOURCE:

[1]Sonderegger 1979, Montana Bureau of Mines and Technology, Butte, Montana. Unpublished data, July 10, 1979.

[2]Reservoir temperature estimation methods:

a. Determined by U.S. Geological Survey Methodology (Muffler 1978).

b. Na-K-Ca temperature modified by magnesium correction.

c. Na-K-Ca temperature.

d. Quartz temperature.

e. Chalcedony temperature.

f. Mixing with shallow ground water is known to be occuring.

g. Temperature listed is an estimate based upon items indicated by the preceding footnotes.

h. Temperature was estimated by analogy with other carbonate aquifer systems. Independent temperatures could not be calculated, due either to a lack of chemical analyses or to calculated temperature values lower than the observed surface temperature.

i. Temperature was estimated from nearby spring with similar geologic setting.

[3]The Marysville KGRA surface temperature is the temperature of the bottom of the test well - approximately 1700 meters deep.

3.2 AREA DEVELOPMENT PLANS

Of all of the hot springs and hot water wells in Montana, approximately ten have known or potential flows and temperatures suitable for large-scale applications. Only two of these ten sites, Broadwater Hot Springs and Ennis Hot Springs, are located near larger population centers.

3.2.1 STATE GEOTHERMAL PLANNING AREAS

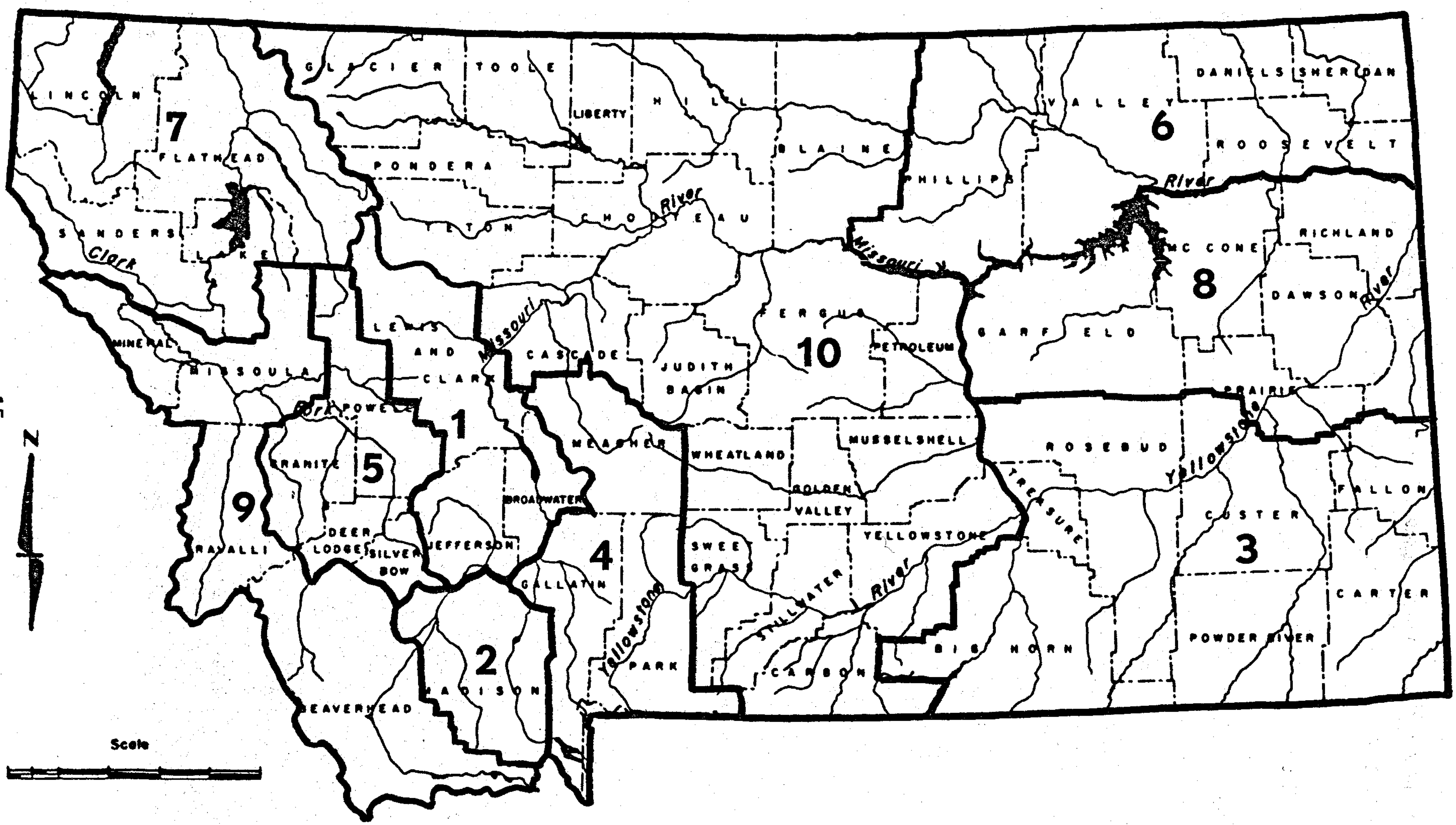
For purposes of geothermal planning,the state was divided into ten areas, observing county boundaries and the boundaries of multicounty planning districts. The ten areas are shown on Figure 1. A majority of Montana's geothermal resource sites are located in the first seven planning areas.

Past or present geothermal development has occurred in areas 1,2,4, and 5. Several organizations in areas 1, 4, and 5 are presently constructing large geothermal space heating units, while the Sioux and Assiniboine tribes in Area 6 recently received a federal grant to study the feasibility of installing a large space heating district using a geothermal source on the Fort Peck Indian Reservation.

Five of the ten geothermal planning areas are of particular interest, based on the potential that these areas appear to have for geothermal space heating projects within the next twenty years. The five planning areas and their most promising sites are the following:

(1)	Area 1	Alhambra Hot Springs Boulder Hot Springs Broadwater Hot Springs
(2)	Area 2	Ennis Hot Springs
(3)	Area 4	Bozeman Hot Springs
(4)	Area 5	Warm Springs
(5)	Area 6	Saco (Madison Formation) Glasgow (Madison Formation)

Figure 1: Geothermal Development Areas in Montana



Other planning areas also have potential for space heating using geothermal resources, but such development is not expected in the near future.

3.2.2.1 Area 1 Development Plan.

Area 1 consists of Lewis and Clark, Jefferson, and Broadwater counties. These counties were grouped together to reflect the common dependence of their inhabitants upon Helena for jobs and consumer goods, and due to the number of geothermal resources in the area.

Industry and Economy. The dominant industry of Jefferson and Broadwater counties is agriculture. Cattle ranching accounts for the largest portion of the agricultural income, but wheat, barley, oats, rye, and potatoes are also grown. Agriculture will probably not expand in Area 1, due mainly to the growth of towns and subdivisions occupying ever more land. Forest products also add to the economy of the area, particularly in Jefferson County. A potential 17.8 million board feet of timber could be harvested annually in Jefferson County, although only about a third of this figure is presently being harvested. The major industries in Area 1 are located in East Helena (Lewis and Clark County), which are a lead smelter and zinc plant.

Population. In 1977, Area 1 contained approximately 51,000 persons. Eighty percent of them lived in or near Helena, one of the six major population centers in Montana. Helena is the major commercial and population center for at least an 80 kilometer radius. Jefferson County contains approximately 7,300 people, while Broadwater has about 3,000, over half of which live in Townsend, the county's only major population center.

Projections for population growth in Area 1 are shown in Table 2. It should be noted that the population projections are in all probability subject to inaccuracies, because population changes depend upon unpredictable social and economic changes. Thus, the projections to 2020 are used solely to show one of many possible future situations for the purpose of developing scenarios for community energy supplies and demands. These projections should not be interpreted as predictions of likely population trends.

Table 2. Projected Population of Area I.

	1980	1985	1990	1995	2000	2020
A) Lewis and Clark County						
East Helena	2,030	2,327	2,612	2,967	3,319	5,223
Helena	27,507	33,541	35,412	40,218	44,980	70,777
Canyon Creek	40	46	51	59	66	104
Marysville	102	117	131	150	168	264
Canyon Ferry	435	500	560	639	715	1,125
Lincoln	1,005	1,156	1,294	1,496	1,653	2,595
Augusta	500	575	644	734	822	1,291
County total[1]	40,930	46,931	52,691	59,843	66,929	104,647
Percentage change from previous projection		15%	12%	14%	12%	57%
B) Broadwater County						
Townsend	1,643	1,870	2,086	2,365	2,643	4,159
Toston	100	114	127	143	160	252
Winston	32	36	40	46	51	80
County total	3,011	3,428	3,822	4,334	4,844	7,622
Percentage change from previous projection		14%	11%	13%	12%	57%
C) Jefferson County						
Boulder	1,552	1,744	1,910	2,102	2,356	3,707
Whitehall	1,277	1,436	1,572	1,730	1,939	3,051
Clancy	230	258	281	309	346	544
Alhambra	65	73	79	87	98	154
Jefferson City	100	112	122	134	150	236

Jefferson County (cont'd.)	1980	1985	1990	1995	2000	2020
Basin	96	108	117	129	144	227
Cardwell	35	39	43	47	53	83
Gruber Estates	110*	123	134	148	165	260
Lump Gulch	125*	140	153	168	188	296
Corbin-Wickes	70*	78	85	94	105	165
County total	7,269	8,169	8,945	9,847	11,035	17,364
Percentage change from previous projections		12%	9%	10%	12%	57%
Area I Total Population	51,210	58,528	65,458	74,024	82,808	130,300
Percentage change from previous projections		14%	12%	13%	12%	57%

1. County totals include rural areas as well as the listed communities.

* Unincorporated city population figures from United States Department of Agriculture Committee for Rural Development, Eggen, James et al, "Lewis and Clark County Situation Statement-1972." 1972. Lewis and Clark County, Montana.

NOTE: See page 16 for derivation and accuracy of these projections.

Area 1 Energy Consumption. Natural gas, electricity, wood, coal, fuel oil, and solar energy are all used within Area 1. Natural gas probably accounts for most of the consumption, especially for heating purposes. In communities where natural gas is unavailable, liquid petroleum gas and fuel oil replace it.

Easily obtainable energy consumption information is available only for electricity and natural gas. These being the preponderant energy sources, it seems safe to estimate total demand based on these alone.

Natural gas and electricity consumption figures were provided by the Montana Power Company (1979). These figures represent annual consumption totals for many of the communities in Area 1, broken down into subtotals reflecting residential, commercial, and municipal/industrial use. Current energy demands for most of the communities were estimated by multiplying the average annual energy consumption per customer by the total number of customers within an individual community. Community consumption figures were then added together to arrive at an estimate of total current energy demand.

The resulting estimates, along with energy demand projections through the year 2020, are presented in the following sections. It is important to note that the accuracy of these projections of energy demand is based on the accuracy of the population projections (see discussion, page 16), and on the assumption that the average annual energy consumption per customer remains constant through the year 2020. Thus the calculated energy demands represent reasonable developmental pathways for planning purposes, but not firm predictions. Consumption data for 1978 were used for the 1980 starting date.

Area 1 Natural Gas Consumption (Residential and Commercial). Estimates of total natural gas consumption in Area 1 are shown in Table 3. Currently amounting to about 245.8×10^{10} Btu per year. About 30 percent of the total is consumed by the residential segment, and about 20 percent by the commercial sector. Industrial and municipal consumption accounts for the remaining 50 percent.

Table 3. Total Natural Gas Consumption Projections for Area I

Community Segment	1980	1985	1990	1995	2000	2020
Residential	161.9×10^{4} MCF 74.9×10^{10} Btu	185.1×10^{4} MCF 85.3×10^{10} Btu	207.2×10^{4} MCF 95.5×10^{10} Btu	234.1×10^{4} MCF 107.9×10^{10} Btu	262.4×10^{4} MCF 120.9×10^{10} Btu	411.9×10^{4} MCF 189.8×10^{10} Btu
Commercial	106.2×10^{4} MCF 48.2×10^{10} Btu	120.9×10^{4} MCF 55.7×10^{10} Btu	135.4×10^{4} MCF 62.4×10^{10} Btu	153.2×10^{4} MCF 70.6×10^{10} Btu	171.4×10^{4} MCF 79.0×10^{10} Btu	269.2×10^{4} MCF 124.1×10^{10} Btu
All Others	264.8×10^{4} MCF 122.0×10^{10} Btu	301.8×10^{4} MCF 139.1×10^{10} Btu	338.1×10^{4} MCF 155.8×10^{10} Btu	381.9×10^{4} MCF 176.0×10^{10} Btu	427.7×10^{4} MCF 197.1×10^{10} Btu	671.6×10^{4} MCF 309.5×10^{10} Btu
TOTALS	533.4×10^{4} MCF 245.7×10^{10} Btu	607.8×10^{4} MCF 280.1×10^{10} Btu	680.7×10^{4} MCF 313.7×10^{10} Btu	769.3×10^{4} MCF 354.5×10^{10} Btu	861.5×10^{4} MCF 397.0×10^{10} Btu	1352.7×10^{4} MCF 623.4×10^{10} Btu

SOURCE: The Montana Power Company, unpublished data, March 29, 1979, and projections from those data by the authors, using projected population from Dodge 1977.

NOTE: See pages 16 and 19 for the derivation and accuracy of these projections.

Natural gas consumption projections for specific communities are shown in Table 4. Residential and commercial consumers in the Helena and East Helena area account for 93 percent of the present consumption of natural gas in the residential and commercial sectors. The remaining consumption in these two community segments is divided among the smaller communities as shown in the table. The total consumption figures for the residential and commercial segments in the table are slightly lower than the Area 1 total figures shown in Table 3, due to the inclusion of a few rural areas not appearing in Table 4.

Most of the natural gas is used in low temperature (less than 100°C) applications such as space heating. However, some East Helena industries use it to produce temperatures in the 500-1000°C range.

Projections for natural gas consumption in Table 3 suggest that Area 1 may increase its consumption by approximately 60 percent by the year 2000. Natural gas reserves in Canada could supply this increased demand, but are subject to price increase and may become unavailable should the Canadians decide to retain their resources.

Area 1 Electrical Consumption (Residential and Commercial). Total electrical consumption estimates for Area 1 are shown in Table 5. The present electrical consumption is about 141.8×10^{10} Btu per year. Approximately 40 percent of this energy is consumed by residences, while the commercial segment consumes about 25 percent. Approximately 40 percent of the electrical demand comes from industrial consumers.

Electrical consumption projections for specific communities are shown in Table 6. As shown, approximately 80 percent of all electricity used in the residential and commercial segments goes to Helena and East Helena. Only a small amount is used to produce temperatures less than 100°C. As with the gas consumption tables, the electrical tables show different totals for the residential and commercial segments due to the inclusion of certain rural areas that are not shown in the community data in Table 6.

Table 4. Projected Annual Natural Gas Consumption for Specific Communities in Area I. (in 10^{10} Btu)

Community	Community Segment	1980	1985	1990	1995	2000	2020
Helena	Residential	64.2	73.8	82.7	94.3	105.6	165.8
	Commercial	42.1	48.5	54.3	61.9	69.3	108.8
Boulder	Residential	2.7	3.0	3.3	3.6	4.1	6.4
	Commercial	2.4	2.7	3.0	3.2	3.6	5.7
Clancy-Alhambra	Residential	1.9	2.1	2.3	2.5	2.8	4.4
	Commercial	0.4	0.4	0.5	0.5	0.6	0.9
Corbin-Jefferson City	Residential	0.3	0.3	0.3	0.4	0.6	1.4
	Commercial	0.1	0.1	0.1	0.1	0.1	0.6
East Helena	Residential	5.4	6.3	7.0	8.0	8.9	14.0
	Commercial	3.2	3.6	4.1	4.7	5.2	5.9
Marysville	Residential	0.1	0.1	0.1	0.1	0.1	0.2
	Commercial	0.0	0.0	0.0	0.0	0.0	0.0
Wolf Creek	Residential	0.2	0.3	0.3	0.4	0.4	0.6
	Commercial	0.7	0.8	0.9	1.1	1.2	1.9
AREA I TOTAL NATURAL GAS CONSUMPTION	Residential	74.9	85.9	96.0	109.3	122.5	192.8
	Commercial	48.9	56.1	62.9	71.5	80.0	123.8

SOURCE: The Montana Power Company, 1979, Dodge 1977.

Note: See pages 16 and 19 for the derivation and accuracy of these projections.

Table 5. Total Electricity Consumption Projections for Area 1.

Community Segment	1980	1985	1990	1995	2000	2020
Residential	149.1×10^6Kwh 50.9×10^{10}Btu	170.2×10^6Kwh 58.1×10^{10}Btu	190.6×10^6Kwh 65.1×10^{10}Btu	215.4×10^6Kwh 73.5×10^{10}Btu	241.4×10^6Kwh 83.4×10^{10}Btu	378.7×10^6Kwh 129.3×10^{10}Btu
Commercial	103.2×10^6Kwh 35.2×10^{10}Btu	107.7×10^6Kwh 36.8×10^{10}Btu	133.0×10^6Kwh 45.4×10^{10}Btu	150.3×10^6Kwh 51.3×10^{10}Btu	168.3×10^6Kwh 57.4×10^{10}Btu	264.2×10^{10}Btu 90.2×10^{10}Btu
All Others	163.2×10^6Kwh 55.7×10^{10}Btu	186.6×10^6Kwh 63.7×10^{10}Btu	208.2×10^6Kwh 71.1×10^{10}Btu	235.2×10^6Kwh 80.3×10^{10}Btu	264.0×10^6Kwh 90.1×10^{10}Btu	414.5×10^6Kwh 141.5×10^{10}Btu
TOTALS	415.5×10^6Kwh 141.8×10^{10}Btu	464.5×10^6Kwh 158.5×10^{10}Btu	531.8×10^6Kwh 181.5×10^{10}Btu	600.9×10^6Kwh 205.1×10^{10}Btu	673.7×10^6Kwh 229.9×10^{10}Btu	1057.4×10^6Kwh 360.9×10^{10}Btu

SOURCE: The Motnana Power Company, 1979, and calculations from those data by the authors, using projected population figures from Dodge, 1972

NOTE: See pages 16 and 19 for the derivation and accuracy of these projections.

Table 6. SNAP. Projected Annual Electric Consumption for Selected Communities in Area I (in 10^{10} Btu)

Town	Community Segment	1980	1985	1990	1995	2000	2020
Helena	Residential	35.6	40.8	45.7	52.1	58.4	91.6
	Commercial	24.1	27.7	31.0	35.4	38.2	62.2
Basin	Residential	0.4	0.4	0.5	0.5	0.6	0.9
	Commercial	0.5	0.5	0.6	0.6	0.7	1.1
Boulder	Residential	1.6	1.8	1.9	2.2	2.4	3.8
	Commercial	1.6	1.8	2.0	2.2	2.5	3.9
Clancy-Alhambra	Residential	1.6	1.8	2.0	2.2	2.5	3.9
	Commercial	0.8	0.9	0.9	1.1	1.2	1.9
Corbin-Jefferson City	Residential	0.3	0.3	0.3	0.3	0.4	0.6
	Commercial	0.1	0.1	0.1	0.1	0.1	0.2
East Helena	Residential	5.5	6.3	7.0	8.0	9.0	14.1
	Commercial	2.7	3.1	3.5	4.0	4.5	7.1
Marysville	Residential	0.8	1.0	1.2	1.3	1.5	2.3
	Commercial	0.5	0.6	0.7	0.8	0.9	1.3
Radersburg	Residential	0.3	0.3	0.4	0.4	0.5	0.8
	Commercial	0.7	0.8	0.8	0.9	1.1	1.6
Townsend	Residential	1.9	2.2	2.4	2.8	3.1	4.8
	Commercial	2.2	2.5	2.7	3.1	3.4	5.4
Wickes	Residential	0.1	0.1	0.1	0.1	0.1	0.1
	Commercial	0.0	0.0	0.0	0.0	0.0	0.0
Winston	Residential	0.1	0.2	0.2	0.2	0.2	0.4
	Commercial	0.1	0.1	0.1	0.1	0.1	0.2

Town	Community Segment	1980	1985	1990	1995	2000	2020
Wolf Creek	Residential	0.9	1.0	1.2	1.3	1.5	2.3
	Commercial	0.8	1.0	1.1	1.2	1.4	2.2
Lincoln	Residential	1.9	2.2	2.5	2.8	3.1	4.9
	Commercial	1.1	1.3	1.5	1.7	1.8	2.9
Total Community Electric Consumption (Area 1)	Residential	50.1	58.4	65.4	74.2	83.3	130.5
	Commercial	35.2	40.4	45.0	51.2	55.9	90.0

SOURCE: The Montana Power Company 1979.

NOTE: See pages 16 and 19 for the derivation and accuracy of these projections.

The total electrical demand projections through the year 2020 are also shown in Table 5. Electrical demand is projected to increase by 62 percent through 2000. This demand projection, as well as the projections in Table 6, reflect recent energy conservation programs that indicate per capita decreases in electrical demand. The availability of electricity will probably not affect energy consumption rates, since the major fuel consumed for heating purposes is natural gas.

Area 1 Industrial Consumption. In addition to the residential and commercial energy demands in Area 1, industry is an important energy consumer. Most of the existing industrial energy consumption was inventoried, although consumption data for some of the smaller industries could not be obtained. Existing industrial energy consumption is presented in Table 7.

The major industrial energy consumers in Area 1 are cement products industry and a primary lead smelter. These industries account for approximately 83 percent of the total industrial energy consumption. Industrial energy consumption in Table 7 totals 261.9×10^{10} Btu per year. This total is 95 percent of the Montana Power Company's estimate of industrial energy consumption within the area. Thus the great majority of industrial energy consumption is accounted for.

Rough projections in industrial energy demand in Area 1 are shown in Table 8 and suggest that Area 1 may increase its industrial energy consumption by more than 40 percent by the year 2000. By 2020, industrial energy consumption may increase by 96 percent from the present demand. (The methodology and limitations of these projections are explained on page 19.)

A list of present and potential manufacturers in Area 1 that have process heat requirements compatible with geothermal applications (i.e., temperatures less than 150° C) is shown in Table 9. Such industries now account for approximately 10 percent of the total industrial energy demand, but if industries grow as projected, there should be steadily increasing demands for this low temperature energy.

Table 7. Estimated Energy Consumption of Area 1 Manufacturers

Industry	SIC Number[1]	Number of Employees[2]	County	Minimun Required Temperature (°C)[3]	Total Annual (Btu/year)[3]
American Chemet Corporation	2816	L	Lewis & CLark	N/A*	5.8×10^{10}
Asarco Incorporated	3332,2816	L	Lewis & Clark	1315	55×10^{10}
Big Sky Redi Mix	3273	S	Lewis & CLark	48	0.1×10^{10}
Blackfoot Treating Plant	2411	M	Lewis & Clark	N/A	N/A
Champion Building Products	2421	U	Lewis & Clark	N/A	1.1×10^{10}
Chemetron Corporation	2813	S	Lewis & Clark	148	3.6×10^{10}
Cloverleaf Dairy	2023,2026	M	Lewis & Clark	71	9.8×10^{10}
Dairyland Wholesale	2024	S	Lewis & CLark	132	0.5×10^{10}
Darigold Products	2021	S	Jefferson	77	3.4×10^{10}
Elk River Concrete	3272	S	Lewis & Clark	116	0.5×10^{10}
Hi Country Beef Jerky	2013	U	Lewis & Clark	N/A	N/A
The Independent Record	2711	L	Lewis & Clark	148	0.2×10^{10}
Kaiser Cement & Gypsum Corporation	3241	L	Jefferson	1482	169.0×10^{10}
Lehrkind Helena Coca-Cola	2086	S	Lewis & Clark	77	1.0×10^{10}
Lincoln Log Cabins	2452	U	Lewis & Clark	N/A	N/A

Industry	SIC Number[1]	Number of Employees	County	Minimum Required Temperature (°C)[3]	Total Annual Energy Use (Btu/year)[3]
McGrew Machine & Fabric	3433,3443	S	Jefferson	N/A	3.3×10^{10}
Mountain Bell Dial Exc.	4811	U	Lewis & Clark	N/A	1.3×10^{10}
Mountain Bell State Headquarters	4811	U	Lewis & Clark	N/A	1.0×10^{10}
Robbins Posts	2411	S	Jefferson	N/A	N/A
State Nursery	0181	U	Lewis & Clark	66	2.4×10^{10}
Structural Components Inc.	3439	S	Jefferson	N/A	2.8×10^{10}
Townsend Lumber Company	2421	L	Broadwater	N/A	0.9×10^{10}
Townsend Star	2711	U	Broadwater	148	0.2×10^{10}

Total Industrial Energy Consumption in Area 1. 261.9×10^{10} Btu

*N/A = Not Available

1. SIC (Standard Industrial Codes), Directory of Montana Manufacturers, 1976-7.

2. (S = 1-10 employees, M = 11-50 employees, L = over 50 employees, U = Unknown.

3. Brown, 1978, and EG & G 1979

Table 8. Projected Energy Demands of Existing Industries in Area 1. (in 10^{10} Btu)

SIC Number	Annual Growth Rate	1980	1990	2000	2020
0181	2.5%	2.4	3.1	3.9	6.4
2021	2.0	3.4	4.1	5.0	7.5
2023	2.5	8.5	10.8	13.9	22.7
2024	2.0	0.5	0.6	0.7	1.1
2026	0.3	1.3	1.4	1.4	1.4
2086	3.0	1.0	1.3	1.8	3.2
2421	1.0	2.0	2.2	2.4	3.0
2439	2.5	2.8	3.6	4.6	7.5
2711	2.5	0.4	0.5	0.6	1.0
2813	1.5	3.6	4.2	4.9	6.5
2816	2.0	5.8	7.0	8.6	12.7
3241	1.5	169.0	196.1	227.6	306.6
3272	3.4	0.5	0.7	0.9	1.8
3273	3.4	0.1	0.1	0.2	0.4
3332	2.0	55.0	67.0	81.7	121.4
3433	1.5	1.8	2.1	2.5	3.3
3443	1.5	1.5	1.7	2.0	2.6
4811	2.5	2.3	2.8	3.6	5.9
Total Projected Industrial Consumption		261.9	309.3	366.3	515.0

Source: DOE, 1979, Dodge, 1977, and estimates based upon the authors' knowledge of the characteristics of local industries.

Table 9. Estimated Current and Projected Area 1 Industrial Energy Demands That Are Replaceable by Geothermal Energy

S ategory	SIC Number	Minimum Process Temperature[2,3] (°C)	Industry Growth Rate (per year)	Estimated annual energy consumption (in Btu/yr) 1980	1990	2000	2020
O ental Floriculture	0181	65	2.5	$2.4x10^{10}$	$3.1x10^{10}$	$3.9x10^{10}$	$6.4x10^{10}$
C ery Butter	2021	77	2.0	$3.4x10^{10}$	$4.1x10^{10}$	$5.0x10^{10}$	$7.5x10^{10}$
C nsed and Evaporate ilk	2023	71	2.5	$8.5x10^{10}$	$10.8x10^{10}$	$13.9x10^{10}$	$22.7x10^{10}$
I ream and Frozen Des t	2024	77	2.0	$0.5x10^{10}$	$0.6x10^{10}$	$0.7x10^{10}$	$1.1x10^{10}$
F d Milk	2026	77	2.3	$0.8x10^{10}$	$0.9x10^{10}$	$0.9x10^{10}$	$0.9x10^{10}$
B led and Canned Soft inks	2086	77	3.0	$1.0x10^{10}$	$1.3x10^{10}$	$1.8x10^{10}$	$3.2x10^{10}$
I ganic Pigments	2816	93	2.0	$3.5x10^{10}$	$4.3x10^{10}$	$5.3x10^{10}$	$6.4x10^{10}$
C crete Products	3272	116	3.4	$0.5x10^{10}$	$0.7x10^{10}$	$0.9x10^{10}$	$1.8x10^{10}$
R dy Mix Cement	3273	66	3.4	$0.1x10^{10}$	$0.1x10^{10}$	$0.2x10^{10}$	$0.4x10^{10}$
M t Packing Plants	2011	176	1.4	$0.0x10^{10}$	$7.4x10^{10}$	$8.5x10^{10}$	$11.2x10^{10}$
S mills and Planing Mills	2421	93	1.0	$0.0x10^{10}$	$0.0x10^{10}$	$2.0x10^{10}$	$2.2x10^{10}$
C crete Block and Brick	3271	less than 150	2.5	$0.0x10^{10}$	$0.0x10^{10}$	$16.0x10^{10}$	$20.5x10^{10}$
		Replaceable Industrial Energy Demand TOTALS		$20.7x10^{10}$	$33.3x10^{10}$	$59.1x10^{10}$	$84.3x10^{10}$

1 placeable industrial e ergy is that requiring process heat at less than 150°C
2 own, Ken, Solar Energy Research Institute, Denver, Colorado
3 urce: DOE, 1979, Dodg , 1977, and estimates based upon authors' knowledge of the characteristics of local industries

Residential, commercial, and industrial consumers could all make use of significant amounts of geothermal energy. The following sections discuss the expected geothermal production potential for Area 1, including estimates of energy supplies replaceable by geothermal for existing and projected industries and residences.

Area 1 Geothermal Resources. Geothermal resources are found in all three counties in Area 1. Most of the known sites have been investigated by the Montana Resource Assessment Team, and some heat flow, shallow resistivity, and geothermometry measurements have been taken. The measurements indicate favorable development potential for direct application in the cases of five hot springs with observed temperatures above 50°C and flow rates greater than 285 liters per minute, and one hot water well. These six sites are:

(1) Broadwater Hot Springs
(2) Boulder Hot Springs
(3) Alhambra Hot Springs
(4) Renova Hot Springs
(5) Pipestone Hot Springs
(6) Marysville KGRA (well)

Later geological or geophysical exploration may show that other sites also have favorable geothermal resources.

Broadwater County has no known high temperature springs, but does have one spring that produces a large volume of water at 24°C. This water issues from Tertiary sediments near the Missouri River and has a flow rate of 5,700 liters per minute. Also, near the Canyon Ferry Reservoir is an area of high heat flow rate, and one energy production company has expressed interest in exploring it.

Jefferson County contains four hot springs with temperatures ranging from 50°C to 74°C and flow rates from 150 to 2,300 liters per minute. The spring with the highest temperature and fastest flow lies within the Boulder KGRA near the center of Jefferson County. Renova, Pipestone, and Alhambra hot springs also lie within Jefferson County.

Lewis and Clark County has two known geothermal sources. Broadwater Hot Springs, which has a surface tempeeature of 62°C and a flow rate of 285 liters per minute, is located near Helena. The other source is the Marysville KGRA located north of Helena. A well drilled to a depth of 2000 meters in this area has recorded a temperature of over 100°C. This well has not been test pumped, but flow rates exceeding 2000 liters per minute might be obtained from it. The Marysville KGRA is noted for a much higher than normal heat flow.

Of the six most favorable reservoirs of geothermal energy in Area 1, four are located near population centers. The other two hot springs, Renova and Pipestone, are remote from populated areas and are therefore not considered in the following economic analyses. The distances from the four economically analyzed reservoirs to the nearest population centers are presented below:

(1)	Alhambra Hot Springs	--	2 km to a small population center 0.4 km to another
(2)	Boulder Hot Springs	--	4.5 km to a potential user in Boulder
(3)	Broadwater Kot Springs	--	Immediately adjacent to a housing area 6.5 km to downtown Helena
(4)	Marysville KGRA	--	2.4 km to north Helena Valley 1.6 km to Little Prickly Pear Valley

Only a few people are presently using the geothermal energy in Area 1. Water from hot springs is being used in some swimming pools near Helena and Boulder. In addition, Alhambra Hot Springs heats a nursing home near Helena and Broadwater Hot Springs heats a health club and two homes. However, interest in geothermal energy is increasing.

Reservoir Energy Calculations. Two different methods of resource evaluation were employed to project potential geothermal energy supply. The DNRC method (Appendix A), developed by Keith Brown, is based upon known surface flow and temperature. It was assumed that flow and temperature increase with depth, as described in Appendix A. Estimates of these temperature and flow increases also incorporate characteristics of local geological features. A second method of estimation was developed by the U.S. Geological Survey (Muffler, 1978). This approach involves estimating potential reservoir volume and temperature. Reservoir temperature is estimated from chemical analysis of surface geothermal water.

Table 10 shows the geothermal reservoir energy for Area 1 as calculated by the U.S. Geological Survey methodology, some of the results of which have been revised to reflect local geological conditions more closely. Most of these reservoirs are fault controlled and therefore may have relatively small volumes. Table 11 shows the geothermal reservoir energy as calculated using DNRC's method. Generally it will be noted that results of the two reservoir calculation methods differ by a factor of 10 to 100. This disparity reflects the fact that there is great uncertainty about the geology and hydrology of most Montana geothermal reservoirs. Brown's estimates should not be considered necessarily conservative, nor should those of the U.S. Geological Survey be considered overly optimistic. Rather, their separate results represent two of many possible estimates dependent upon presently inaccessible measures. Thus it is not yet possible to say which estimate, if either, comes closer to the actual energy content of a given reservoir.

For example, the Marysville KGRA has the potential for providing large amounts of heat energy to Helena. But how much? The USGS calculations suggest that about 39×10^8 Btu per hour might be extracted from this reservoir over a thirty-year period, while the DNRC method suggests a potential production rate of about 1×10^8 Btu per hour.

The Boulder reservoir also should be capable of providing substantial energy to help fill local demands. USGS calculations suggest that the Boulder reservoir might produce about 10×10^8 Btu per hour for thirty years, while DNRC empirical calculations suggest a potential production rate of about 1×10^8 Btu per hour. So here again, the disparity of figures stands out.

Table 10. Area 1 Geothermal Resource Base Calculated from USGA Methodology[1]

Location	Mean Estimates of Reservoir Temperature[2] (t_o)	Mean Estimates of Reservoir Volume[3] (v)	Reservoir Thermal Energy (gr)	Available Wellhead Energy (gwh)	Usable Recoverable Energy Per Year (B)	Energy Supply Rate (R)
Alhambra Hot Springs	96^oC	3.3 km^3	$7.22 \times 10^{17}J$	$1.80 \times 10^{17}J$	$14.43 \times 10^{14}J/yr$	$68.70 \times 10^{10}J/hr$
	(205^oF)		($6.85 \times 10^{14}Btu$)	($1.71 \times 10^{14}Btu$)	($13.77 \times 10^{11}Btu/yr$)	(6.51×10^8 Btu/hr)
Boulder Hot Springs	136^oC	3.3 km^3	$10.80 \times 10^{17}J$	$2.70 \times 10^{17}J$	$21.61 \times 10^{14}J/yr$	$103.00 \times 10^{10}Btu/hr$
	(277^oF)		($10.21 \times 10^{14}Btu$)	($2.56 \times 10^{14}Btu$)	($20.51 \times 10^{11}Btu/yr$)	(9.73×10^8 Btu/hr)
Broadwater Hot Springs	118^oC	3.3 km^3	$9.18 \times 10^{17}J$	$2.29 \times 10^{14}J/yr$	$18.43 \times 10^{14}J/yr$	$87.30 \times 10^{10}J/hr$
	(224^oF)		($8.71 \times 10^{14}Btu$)	($2.18 \times 10^{14}Btu$)	($17.41 \times 10^{11}Btu/yr$)	($8.28 \times 10^8Btu/hr$)
Marysville KGRA	122^oC	15 km^3	$43.35 \times 10^{17}J$	$10.80 \times 10^{17}J$	$86.72 \times 10^{14}J/yr$	$412.07 \times 10^{10}J/hr$
	(252^oF)		($41.03 \times 10^{14}Btu$)	($10.31 \times 10^{14}Btu$)	$82.20 \times 10^{11}Btu/yr$)	($39.11 \times 10^8Btu/hr$
Area 1			$70.55 \times 10^{17}J$	$17.59 \times 10^{17}J$	141.19 J/yr	$671.01 \times 10^{10}J/hr$
TOTALS			($66.80 \times 10^{14}Btu$)	($16.76 \times 10^{14}Btu$)	(133.89 Btu/yr)	($63.63 \times 10^8Btu/hr$)

[1] See Appendix B for explanations of table headings and reservoir energy equations

[2] Sonderegger, 1979b.

[3] Muffler, 1978.

Table 11. Area 1 Geothermal Resource Base Calcualted from Local Surface Data[1]

Location	Present Known Temperature	Potential Temperature (t_{pot})	Present Flow[2] (F)	Potential Flow (F_{pot})	Available Wellhead Energy (g_{wh})	Usable Recoverable Energy (Q)	Energy Supply Rate (R)
Alhambra Hot Springs	55° C (131° F)	75°C (167° F)	31.7 l/s (500 gpm)	63.3 l/s (1000 gpm)	4.99×10^{14} J/yr (4.73×10^{11} Btu/yr)	1.55×10^{14} J/yr (1.47×10^{11} Btu/yr)	3.53×10^{10} J/hr (0.34×10^{8} Btu/hr)
Boulder Hot Springs	76° C (169° F)	96° C (205° F)	37.4 l/s (590 gpm)	114.0 l/s (1800 gpm)	12.10×10^{14} J/yr (11.50×10^{11} Btu/yr)	4.36×10^{14} J/yr (4.14×10^{11} Btu/yr)	10.00×10^{10} J/hr) (0.95×10^{8} Btu/hr)
Broadwater Hot Springs	66° C (152° F)	86° C (188° F)	13.1 l/s (207 gpm)	54.0 l/s (850 gpm)[3]	5.06×10^{14} J/yr (4.80×10^{11} Btu/yr)	1.73×10^{14} J/yr (1.64×10^{11} Btu/yr)	3.90×10^{10} J/hr (0.37×10^{8} Btu/hr)
Marysville KGRA	97° C (206° F)	117° C (242° F)	0 l/s (0 gpm)	95.0 l/s (1500 gpm)[4]	12.70×10^{14} J/yr (12.01×10^{11} Btu/yr)	4.92×10^{14} J/yr (4.67×10^{11} Btu/hr)	11.20×10^{10} J/hr (1.07×10^{8} Btu/hr)
Area I Totals					34.85×10^{14} J/yr (33.04×10^{11} Btu/yr)	12.56×10^{14} J/yr (11.92×10^{11} Btu/yr)	28.63×10^{10} J/hr (2.73×10^{8} Btu/hr)

[1]See Appendix A for table heading explanations and reservoir energy equations

[2]Known temperatures and flows from Sonderegger 1979 b.

[3]Estimated from well data

[4]Estimated from pump data

Table 12. Total and Replaceable Energy Demands for the Residential and Commercial Segments of Area 1 Communities[1]

	Current Residential Consumption (in 10^{10}Btu/yr)		Current Commercial Consumption (in 10^{10}Btu/yr)	
A) Potential Class[4]	Total Demand	Replaceable Demand	Total Demand	Replaceable Demand
East Helena	10.9	8.7	5.9	4.2
Helena	99.8	79.8	66.2	47.7
Marysville	0.9	0.7	0.5	0.4
Clancy/Alhambra	3.5	2.8	1.2	0.9
Boulder	4.3	3.4	4.0	2.9
TOTALS	119.4	95.4	77.8	56.1
B) Inferred Class[5]				
Townsend	1.9	1.5	2.2	1.6
Winston	0.1	0.1	0.1	0.7
Basin	0.4	0.3	0.5	0.4
Corbin-Jefferson City	0.6	0.5	0.2	0.1
TOTALS	3.0	2.4	3.0	2.8

C) Total Replaceable energy:

Potential Class - 151.5×10^{10}Btu/yr

Inferred Class - 5.2×10^{10}Btu/yr

[1]The Montana Power Company, 1979.

[2]"Potential Class" refers to those communities that are located near potential geothermal resources.

[3]Replaceable Demand in the residential sector is assumed to be 80% of the total demand (process temperatures is less 100°C).

[4]Replaceable Demand in the commercial sector is assumed to be 72% of the total demand (process temperatures is less 150°C).

[5]"Inferred Class" refers to those communities that are located near inferred geothermal resources.

NOTE: See pages 16 and 19 for the derivation and accuracy of these projections.

Projected Geothermal Energy Replacement (Residential and Commercial Segments). The current heat energy demand that conceivably could be replaced by geothermal energy was estimated from data provided by the Solar Energy Research Institute and the Montana Power Company. Calculations suggest that geothermal energy, if available, could replace up to 80 percent of the total Area 1 residential energy consumption. Residential energy generally requires temperatures of less than 100°C. Similarly, 72 percent of the total commercial energy consumption in Area 1 could be replaced by geothermal energy at temperatures less than 150°C, if available. The total energy demand and replaceable energy demand figures for residential and commercial segments are given in Table 12.

Area 1 Economic Analysis. Given that considerable fractions of residential and commercial consumption could be replaced by geothermal energy (if available), the question then arises whether such a replacement would be economically feasible. Therefore, the cost per million Btu of geothermal energy was estimated in cooperation with the New Mexico Energy Institute at Las Cruces. The analysis compared projected community development with local estimated reservoir potential. Results of the comparison are shown in Table 13.

As the table clearly shows, the cost of producing one million Btu of geothermal energy differs markedly from community to community. For example, development costs for geothermal energy ($1.20 per million Btu) of a new community at Broadwater Hot Springs near Helena would be very competitive with present conventional fuel costs. On the other hand, retrofitting Helena for geothermal energy seems unlikely at the present time due to a prohibitive cost ($7.84 per million Btu). However, moderate inflation rates in the price of conventional fuels could make geothermal energy competitive for the Helena area in perhaps five years.

Development scenarios for each of the geothermal resource/community pairings were also prepared (see Table 13). The scenario for a new 825-person development in Helena suggest that a 325-unit subdivision could be operating by 1985, and further, that five new 100-unit subdivisions could be added every four years between 1985 and 2005, for a total of 825 additional housing units.

The second economic analysis assumes a retrofit of existing buildings in Helena, using Broadwater Hot Springs as the energy source. According to this, a 1000-person heating district could be converted to use geothermal energy between 1984 and 1989. Two additional units of equal size could be established by 2010.

Table 13. Hypothetical Development Economics for Selected Geothermal Resource-Community Pairings

Area 1

1) Community: Installation of new heating district for 825 people, beginning in 1980, near Helena.

Resource: Broadwater Hot Springs

Assumptions:
Resource temperature of 67°C
Existing wells used
23,400 additional people added to the area by 2020
Transmission line distance of 6.4 km

	Private Development	Municipal Development
Price of Geothermal Energy (per 10^6 Btu)	$1.20	$0.50

2) Community: Retrofit of existing buildings in Helena

Resource: Broadwater Hot Springs

Assumptions:
District size of 1000-3500 people
6.4 km transmission distance
Residential and commercial segments only

	Price of Geothermal Energy (per 10^6 Btu)	
Assumed Size of Heating district	Private Development	Municipal Development
1000 person	$7.84	$3.52
1500 person	7.02	3.14
2000 person	6.65	2.97
2500 person	6.51	2.90
3000 person	6.40	2.86
3500 person	6.27	2.80

3) Community: Marysville

Resource: Marysville Known Geothermal Resource Area (KGRA)

Assumptions:
- Reservoir temperature of 102^{o}C
- Resource depth of 915 meters
- Population of Marysville is 100
- Transmission line distance is 0.4 km
- 8400 degree days
- 1900 liters/minute well production rate
- 2.5% conventional fuel inflation rate

Price of Geothermal Energy (per 10^6 Btu)	Private Development	Municipal Development
	$13.88	$5.17

4) Community: Prickly Pear Valley

Resource: Marysville Known Geothermal Resource Area (KGRA)

Assumptions:
- Resource temperature of 103^{o}C.
- Resource depth of 915 meters
- Increase in population of 200 people
- Transmission line distance is 8 km
- One new industry, using 1 X 10^{10} Btu/year

Price of Geothermal Energy (per 10^6 Btu)	Private Development	Municipal Development
	$3.05	$1.28

5) Community: Alhambra - Geothermal heating district

Resource: Alhambra Hot Springs

Assumptions:
- Resource temperature of 75^{o}C
- Resource depth of 400 meters
- 5% conventional fuel inflation rate
- 3% population growth rate
- Transmission line distance of 2 km
- Present population of 65

Price of Geothermal Energy (per 10^6 Btu)	Private Development	Municipal Development
	$15.80	$6.44

6) Community: Clancy - Geothermal heating district

Resource: Alhambra Hot Springs

Assumptions: Resource temperature of 75°C
Resource depth of 400 meters
5% conventional fuel inflation rate
3% population growth rate
Transmission line distance of 0.4 km

	Private Development	Municipal Development
Price of Geothermal Energy (per 10^6 Btu)	\$5.23	\$2.12

7) Community: Boulder - Geothermal heating district

Resource: Boulder Hot springs Known Geothermal Resource Area (KGRA)

Assumptions: Resource temperature of 76°C
Depth to resource is 400 meters
Transmission line distance of 4.5 km
5% conventional fuel inflation rate
2.5% population growth rate

	Private Development	Municipal Development
Price of Geothermal Energy (per 10^6 Btu)	\$4.08	\$1.73

NOTE: See pages 16 and 19 for the derivation and accuracy of these projections.

The third analysis, that of the Marysville KGRA, exemplifies a resource of great potential but at such depth that its development would be prohibitively expensive, at least in the foreseeable future. It appears to be economically unfeasible to drill a deep well to heat even Marysville, let alone to transport the energy about 24 km to Helena. This rather pessimistic evaluation could be subject to revision, e.g., if experimental drilling should tap into shallower reservoirs of energy.

Potentially, both Clancy and Alhambra could use Alhambra Hot Springs for heating purposes. The U.S. Geological Survey estimate of the available geothermal reservoir energy is about 138×10^{11} Btu per year, while the current energy demand for the two communities combined is only about 5×10^{10} Btu per year. Limiting factors other than the availability of geothermal energy will therefore determine the rate of geothermal development. Economic analysis shows that Clancy could have geothermal heat at prices comparable to conventional fuels at the present time; therefore development of geothermal district heating could begin somewhat before 1990. A ten year lag time prior to development would allow for incorporation of the community and the development of demonstration projects. By 1990, many people in Clancy might well be anxious to turn to geothermal energy if conventional fuels continue to increase in cost.

Boulder also potentially has more geothermal energy than it has energy demand. As with Clancy, the cost is presently competitive with conventional energy supplies. Here, too, construction of a geothermal heating destrict might begin following a successful demonstration project. Development of this area could therefore begin by 1987 and be completed by 1995.

Table 14 compares projected geothermal energy supplies with total energy demands of Area 1. The percentage of the total energy demand that might be supplied by geothermal energy stands at about 1 percent for 1985 and increases to about 9 percent by 2020. These projections are presented graphically in Figure 2.

Table 14. Percentage of Energy Demand That Could Be Supplied by Geothermal Energy

Area 1

1) Area I Energy Demand (in 1×10^{10} Btu/yr)

	1980	1985	1990	1995	2000	2020
Residential/Commercial	209.8	235.9	268.4	303.3	340.7	533.4
Industrial	261.9	284.9	309.3	308.7	366.3	515.0
Area 1 TOTAL	471.7	520.8	577.7	612.0	707.0	1048.4

2) Area I Projected On-Line Geothermal Supply (in 1×10^{10} Btu/yr)

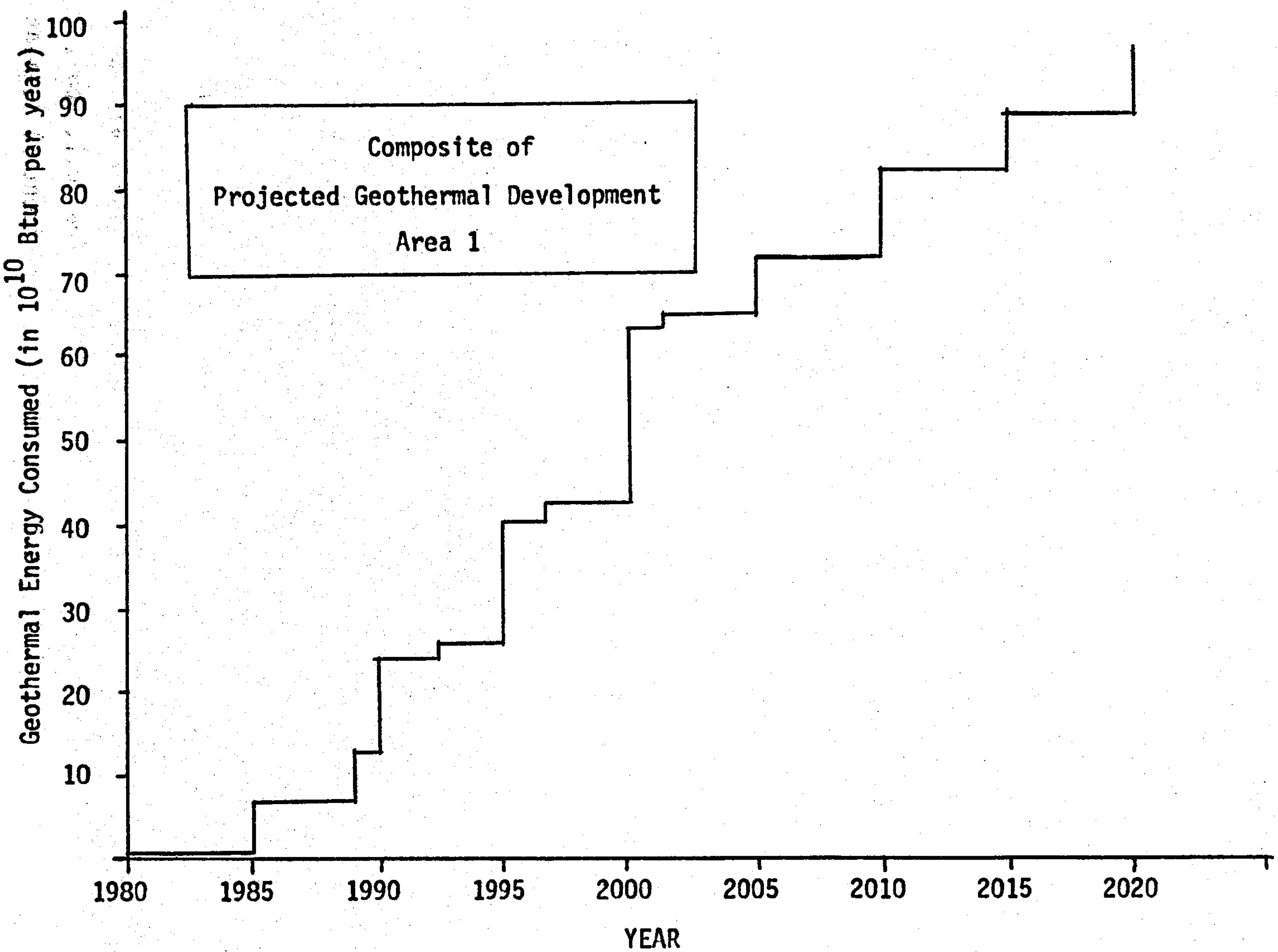
	1980	1985	1990	1995	2000	2020
Residential/Commercial	0.0	3.8	9.1	21.7	27.9	35.8
Industrial	0.0	2.7	10.4	16.2	35.4	60.2
Area 1 TOTAL	0.0	6.5	19.5	37.9	63.3	96.0

3) Percentage of Total Energy Demand That Could Be Supplied By Geothermal Energy (Geothermal Energy Supply/Total Demand)

	1980	1985	1990	1995	2000	2020
% Replaceable by Geothermal	0%	1%	3%	6%	9%	9%

Note: See pages 16 and 19 for the derivation and accuracy of these projections.

Figure 2. Projected Geothermal Development in Area 1.



3.2.2.2 Area 2 Development Plan. Madison County alone comprises Area 2, and is notable for its low population and relative abundance of easily accessible geothermal resources. Given the nature of the terrain and the rather restricted economic base of Madison County, sizable increases in population seem remote. However, the very abundance of geothermal energy potential conceivably could render some future development attractive. Whether such development will occur is problematic; but in the present, many Area 2 residents have expressed a keen interest in developing their geothermal potential.

Industry and Economy. Although recreation and tourism are important to the economy of Area 2, agriculture, especially cattle production, is by far the area's most important economic base. Cattle grazing occupies a large proportion of the area's private and public land, while irrigated bottomlands are used for hay production. A small amount of wheat and barley is grown on unirrigated land. There are presently no major industrial consumers in Area 2.

Population. Most of the approximately 6000 people in Area 2 live in river valleys. There are no towns that contain over 700 people; three towns have between 500 and 700 people; four towns have between 100 and 200 people; and several smaller communities have less than 100 people. Projected population for Area 2 and its largest communities is shown in Table 15

Indications are that the population will decline until about 1995, after which it may show a slight increase.

Area 2 Energy Consumption. Specific information about energy consumption rates for Area 2 was not available at the time of this report; therefore it was estimated from information provided by the Montana Department of Community Affairs (Dodge, 1977). The methodology and limitations of these projections are explained on pages 16 and 19.

Natural gas is supplied to some areas along the Jefferson River, but the majority of Area 2 relies upon liquid petroleum gas, fuel oil, coal, solar energy, and electricity. Estimates are that the residential segment

Table 15. Projected Population of Area 2

	1980	1985	1990	1995	2000	2020
<u>Madison County</u>						
Alder	125	124	122	119	121	148
Ennis	674	668	656	643	654	799
Harrison	175	174	170	167	170	208
Jeffers	45	45	44	43	44	54
Jefferson Island	30	30	29	29	29	35
Laurin	60	60	58	57	58	71
McAllister	40	40	39	38	39	48
Norris	30	30	29	29	29	35
Pony	100	99	97	95	97	118
Twin Bridges	569	564	554	542	551	673
Silver Star	75	74	73	72	73	89
Sheridan	727	721	708	693	705	861
Virginia City	174	173	169	166	169	206
Waterloo	60	60	58	57	58	71
Area 2. Total Population*	5602	5556	5455	5342	5433	6634
Percentage Change from Previous Projection		-1%	-2%	-2%	2%	22%

Source: Dodge, 1977, Brown, Keith, 1979

Area 2 total includes rural areas as well as the listed communities.

of Area 2 consumes about 18.6 x 10^{10} Btu per year for space and water heating, while the commercial segment consumes only about 1 x 10^{10} Btu per year. Industry consumes insignificant amounts of energy for space and water heating. The three major communities in Area 2 are Ennis, Sheridan, and Twin Bridges. Table 16 shows the energy consumption of these three communities. About 30 percent of all energy used in the residential sector is consumed by these three communities, as is about 30 percent of all commercially consumed energy.

Table 16. Estimated Energy Consumption in Ennis, Twin Bridges, and Sheridan

Community	Current Annual Energy Consumption Residential	Current Annual Energy Consumption Commercial
Ennis	2.24×10^{10} Btu	0.10×10^{10} Btu
Twin Bridges	1.89×10^{10} Btu	0.08×10^{10} Btu
Sheridan	2.41×10^{10} Btu	0.10×10^{10} Btu
Total Energy Use	6.54×10^{10} Btu	0.28×10^{10} Btu

Because population is not expected to increase significantly in the next 20 years, and because both the high cost of conventional fuels and state policies encourage energy conservation measures, it is not expected that current energy consumption figures will increase. Therefore, it is assumed that geothermal resources would be developed if industry were to move into the area specifically to make use of inexpensive geothermal energy.

Area 2 Geothermal Resources. Area 2 has numerous indicators of geothermal activity. The eleven known hot springs in the area are listed in Table 17, along with potential reservoir energy estimates calculated

Table 17. Area 2 Resource Base (Calculated from Local Surface Data)[1]

Hot Springs	Present Known Temperature (t)[2]	Potential Temperature (t_{pot})	Present Flow[2] (F)	Potential Flow (F_{pot})	Available Wellhead Energy (q_{wh})	Usable Recoverable Reservoir Energy (Q)	Energy Supply Rate (R)
Beaverhead Rock	27° C (81° F)	47° C (117° F)	6.3 l/s (100 gpm)	25.3 l/s (400 gpm)	1.07×10^{14} J/yr (1.02×10^{11} Btu/yr)	0.16×10^{14} J/yr (0.15×10^{11} Btu/yr)	0.36×10^{10} J/hr (0.03×10^{8} Btu/hr)
Ennis	83° C (182° F)	103° C (218° F)	1.3 l/s (20 gpm)	63.4 l/s (1000 gpm)	7.34×10^{14} J/yr 6.96×10^{11} Btu/yr)	2.72×10^{14} J/yr (2.58×10^{11} Btu/yr)	6.20×10^{10} J/hr (0.59×10^{8} Btu/hr)
New Biltmore	54° C (130° F)	74°C (166° F)	6.3 l/s (100 gpm)	31.7 l/s (500 gpm)	2.47×10^{14} J/yr (2.34×10^{11} Btu/yr)	0.76×10^{14} J/yr (0.72×10^{11} Btu/yr)	1.7×10^{10} J/hr (0.17×10^{8} Btu/hr)
Norris	52° C (126°F)	72° C (162° F)	6.7 l/s (106 gpm)	13.4 l/s (212 gpm)	1.01×10^{14} J/yr (0.96×10^{11} Btu/yr)	0.30×10^{14} J/yr (0.29×10^{11} Btu/yr)	0.69×10^{10} J/hr (0.07×10^{8} Btu/hr)
Puller's	44° C (112° F)	64° C (148° F)	3.2 l/s (50 gpm)	6.3 l/s (100 gpm)	4.11×10^{14} J/yr (3.90×10^{11} Btu/yr)	0.11×10^{14} J/yr (0.11×10^{11} Btu/yr)	0.25×10^{10} J/hr (0.02×10^{8} Btu/hr)
Barkell's	71° C (161° F)	92° C (197° F)	9.5 l/s (150 gpm)	19.0 l/s (300 gpm)	1.91×10^{14} J/yr (1.81×10^{11} Btu/yr)	0.67×10^{14} J/yr 0.64×10^{11} Btu/yr)	1.53×10^{10} J/hr (0.15×10^{8} Btu/yr)
Sloan Cow Camp	30° C (86° F)	50° C (112°F)	22.2 l/s (350 gpm)	44.3 l/s (700 gpm)	2.04×10^{14} J/yr (1.93×10^{11} Btu/yr)	0.36×10^{14} J/yr (0.34×10^{11} Btu/yr)	0.81×10^{10} J/hr (0.08×10^{8} Btu/hr)
Trudau	22° C (73° F)	43° C (109° F)	11.1 l/s (175 gpm)	22.2 l/s (350 gpm)	0.81×10^{14} J/yr (0.77×10^{11} Btu/yr)	0.07×10^{14} J/yr (0.07×10^{11} Btu/yr	0.17×10^{10} J/hr (0.02×10^{8} Btu/hr)
Vigilante	23° C (74°F)	43° C (110°F)	139.3 l/s (2200 gpm)	139.3 l/s (2200 gpm)	5.18×10^{14} J/yr (4.91×10^{11} Btu/yr)	0.51×10^{14} J/yr (0.48×10^{11} Btu/yr)	1.16×10^{10} J/hr (0.11×10^{8} Btu/hr)
West Fork Swimming Hole	28° C (82° F)	48° C (118°F)	31.7 l/s (500 gpm)	63.3 l/s (1000 gpm)	2.72×10^{14} J/yr (2.58×10^{11} Btu/yr)	0.42×10^{14} J/yr (0.39×10^{11} Btu/yr)	0.94×10^{10} J/hr (0.09×10^{8} Btu/hr)

Hot Springs	Present Known Temperature (t)[2]	Potential Temperature (t_{pot})	Present Flow[2] (F)	Potential Flow (F_{pot})	Available Wellhead Energy (g_{wh})	Usable Recoverable Resevoir Energy (Q)	Energy Supply Rate (R)
Wolf Creek	66^{o} C (151^{o} F)	86^{o} C (187^{o}F)	19.6 l/s (310 gpm)	39.3 l/s (620 gpm)	3.66×10^{14} J/yr (3.48×10^{11} Btu/yr)	1.25×10^{14} J/yr (1.18×10^{11} Btu/yr	2.84×10^{10} J/hr (0.27×10^{8} Btu/hr)
Area II Totals					3.32×10^{14} J/yr (30.66×10^{11} Btu/yr)	7.33×10^{14} J/yr (6.95×10^{11} Btu/yr)	16.65×10^{10} J/hr (1.58×10^{8} Btu/hr)

[1]See Appendix A for explanation of table headings and reservoir energy equations

[2]Known emperatures and flows from Sonderegger, 1979b.

NOTE: See pages 16 and 19 for the derivation and accuracy of these projections.

Table 18. Area 2 Resource Base (Calculated from USGS Methodology)[1]

Resource	Mean Estimates of Reservoir Temperature[2] (t_o)	Mean Estimates of Reservoir Volume[3] (v)	Reservoir Thermal Energy (q_r)	Available Wellhead Energy (q_{wh})	Usable Recoverable Energy (B)	Energy Supply Rate (R)
Beaverhead Rock	---UNABLE TO OBTAIN SUITABLE GEOTHERMOMETRY---					
Ennis	129^oC	3.3 km^3	10.20 x 10^{17}J	2.54 x 10^{17}J	20.30 x 10^{14}J/yr	96.65 x 10^{10}J/hr
	(264^oF)		9.68 x 10^{14}Btu	2.41 x 10^{14}Btu	19.31 x 10^{11}Btu/yr	9.17 x 10^{8} Btu/hr
New Biltmore	105^oC	3.3 km^3	8.02 x 10^{17}J	2.01 x 10^{17}J	16.03 x 10^{14} J/yr	76.31 x 10^{10}J/hr
	(221^oF)		7.61 x 10^{14}Btu	1.90 x 10^{14}Btu	15.27 x 10^{11}Btu/yr	7.24 x 10^{8}Btu/hr
Norris	124^oC	1.0 km^3	2.94 x 10^{17}J	0.74 x 10^{17}J	5.89 x 10^{14}J/yr	28.04 x 10^{10}J/hr
	(255^oF)		2.79 x 10^{14}Btu	0.70 x 10^{14}Btu	5.58 x 10^{11}Btu/yr	2.66 x 10^{8} Btu/hr
Pullers	52^oC	1.0 km^3	1.00 x 10^{17} J	2.58 x 10^{17}J	20.69 x 10^{14}J/yr	9.50 x 10^{10}J/hr
	(126^oF)		0.95 x 10^{14} Btu	0.24 x 10^{14}Btu	1.90 x 10^{11}Btu/yr	0.90 x 10^{8}Btu/hr
Barkell's	131^o	3.3 km^3	10.30 x 10^{17}J	2.58 x 10^{17}J	20.69 x 10^{14}J/yr	98.33 x 10^{10}J/hr
	(268^oF)		9.77 x 10^{14}Btu	2.45 x 10^{14}Btu	19.63 x 10^{11}Btu/yr	9.33 x 10^{8}Btu/yr
Sloan Cow Camp	93^oC	1.0 km^3	2.11 x 10^{17}J	0.53 x 10^{17}J	4.21 x 10^{14}J/yr	20.00 x 10^{10}J/hr
	(199^oF)		2.00 x 10^{14}Btu	0.50 x 10^{14}Btu	4.00 x 10^{11}Btu/yr	1.90 x 10^{8}Btu/hr

Trudau	$65^{o}C$ (149°F)	1.0 km^3	1.35×10^{17}J 1.28×10^{14}Btu	0.34×10^{17}J 0.32×10^{14}Btu	2.70×10^{14}J/yr 2.56×10^{11}Btu/yr	12.86×10^{10}J/hr 1.22×10^{8}Btu/hr
Vigilante	$25^{o}C$ (77°F)	1.0 km^3	0.27×10^{17}J 0.26×10^{14}Btu	0.07×10^{17}J/yr 0.06×10^{14}	0.54×10^{14}J/yr 0.51×10^{11}Btu/yr	2.57×10^{10}J/hr 0.24×10^{8}Btu/hr
West Fork Swimming Hole	$35^{o}C$ (95°F)	1.0 km^3	0.54×10^{17}J 0.51×10^{14}Btu	0.14×10^{17}J 0.13×10^{14}Btu	1.08×10^{14}J/yr 1.03×10^{11}Btu/yr	5.14×10^{10}J/hr 0.49×10^{8}Btu/hr
Wolf Creek	$78^{o}C$ (172°F)	3.3 km^3	5.61×10^{17}J 5.32×10^{14}Btu	1.40×10^{17}J 1.33×10^{14}Btu	11.28×10^{14}J/yr 10.70×10^{11}Btu/yr	53.44×10^{10}J/hr 5.07×10^{8}Btu/hr
Total Area II			4.34×10^{17}J 40.17×10^{14}Btu	10.6×10^{17}J 10.04×10^{14}Btu	84.72×10^{14}J/yr 80.49×10^{11}Btu/yr	402.84×10^{10}J/hr 38.22×10^{8}Btu/hr

[1] See Appendix B for explanation of table headings and reservoir energy equations

[2] Sonderegger, 1979b.

[3] Muffler, 1978.

using the U.S. Geological Survey methodology. Table 18 shows the reservoir energy estimates using the DNRC calculations (Appendix B). As with Area 1, the two different methods of energy computation differ by a factor of somewhere between 10 and 100 (see pages 34-5). The usable potential geothermal energy of all known sites is about 80 x 10^{11} Btu per year, according to the U.S. Geological calculations, and about 7 x 10^{11} Btu per year using the DNRC method.

The distance from some of the largest communities to their nearest geothermal resource is shown in Table 19. Of the ten community-resource pairings, only the Ennis/Ennis Hot Springs pairing seems to be economically feasible at this time. The rest of the communities are presently either too small or too far from suitable geothermal reservoirs to be considered economical. However, if a postulated site near Twin Bridges is found, geothermal development for that community might prove feasible.

<u>Economic Analyses of Area 2 Geothermal Development</u>. As with the Area 1 projections, Area 2 economic analyses were prepared in cooperation with the New Mexico Energy Institute, Las Cruces. These analyses produced some estimates of the cost of geothermal energy per million Btu for Ennis and Twin Bridges, the two largest communites. Present (1979) costs for the lowest priced conventional fuel in the area is $6.88 per million Btu. The three economic analyses shown on Table 20 suggest that both a development at Ennis and a greenhouse operation at Twin Bridges are currently feasible economically, as estimated costs for geothermal energy are significantly lower than for conventional fuel.

Industrial use of geothermal energy would depend upon new industry moving into the area, since there are no major ones there presently. Development scenarios assume that greenhouses, aquaculture operations, sawmills, and animal feed facilities could adapt their heat demands to geothermal energy. A possible time frame for the development of these industries is presented in Table 21. Both DNRC's method (Appendix A) and the U.S. Geological Survey method (Appendix B) of estimating reservoir energy show that geothermal supplies could easily fill the energy demands of these new industries.

Table 19. Potential Community-Geothermal Resource Pairings

Community	1978 Population[1]	Geothermal Resoruce	Distance From Resource[2] to Community
1) Ennis	674	Ennis Hot Springs	2 km
2) Sheridan	727	Postulated*	21 km
3) Twin Bridges	569	Postulated*	6 km
4) Harrison	175	Norris Hot Springs	16 km
5) Pony	100	Potosi Hot Springs	10 km
6) Waterloo	60	Barkell's Hot Springs	10 km
7) Silver Star	75	Barkell's Hot Springs	2 km
8) Laurin	60	Postulated*	35 km

SOURCE: Dodge 1977, Montana State Highway commission 1978.

*Geothermal resource postulated for the purpose of making tentatiive development scenarios. There is little or no geological evidence for the existence of the resource.

Table 20. Hypothetical Development Economics for Selected Geothermal Resource - Community Pairings

Area 2

1) Community: Installation of a heating district in Ennis.

Resource: Ennis Hot Springs.

Assumptions:
Resource Temperature of 86°C
Flow Rate of 1900 liters/minute
Population of 674 people
8,300 degree days
Well depths of 91 meters
Transmission distance of 2.4 km
5% conventional fuel inflation rate
No new industry

Assumed Annual Growth Rate	Price of Geothermal Energy (per 10^6 Btu) Private Development	Municipal Development
0%	\$6.41	\$2.85
0.15%	5.13	2.22

2) Community: Installation of a heating district in Twin Bridges.

Resource: Postulated Site

Assumptions:
Resource temperature of 80°C
Population of 569
Population growth rate of 0.15%
Conventional energy inflation rate of 5%
Well depth of 400 meters

Assumed Transmission Distance	Price of Geothermal Energy (per 10^6 Btu) Private Development	Municipal Development
4.8 km	\$7.25	\$3.12
6.4 km	8.00	3.48
8 km	8.85	3.83
9.6 km	9.65	4.19

3) Community: Space heating of a proposed greenhouse near Twin Bridges.

Resource: Postulated Site

Assumptions: Resource temperature of $80^{o}C$
Population growth rate of 0.15%
Conventional energy inflation rate of 5% per year
Well depth of 400 meters
Transmission distance of 1.6 km
Annual energy consumption of greenhouse is $3 X 10^{10}$ Btu

Price of Geothermal Energy (per 10^{6} Btu) - $3.58

Table 21. Possible Scenarios of Industrial Development

Area 2

Projected Industry	Minimum Required Temperature	Development Schedule	Annual Energy Consumption[1] (Btu/yr)
1) Greenhouses	65°C	1 acre by 1980	0.7×10^{10}
		3 acres by 1990	2.0×10^{10}
		8 acres by 2000	5.2×10^{10}
		13 acres by 2010	8.5×10^{10}
		18 acres by 2020	11.7×10^{10}
2) Aquaculture	50°C	1 unit by 1985	35×10^{6}
		3 units by 1990	105×10^{6}
		5 units by 2000	175×10^{6}
3) Sawmills	82°-204°C	Small unit by 1990	0.5×10^{10}
4) Animal Feed Processing	93°C	Small unit by 1995	9.5×10^{10}

NOTE: See pages 16 and 19 for the derivation and accuracy of these projections.

Figure 3 presents graphically the composite on-line projections for geothermal energy development in Area 2. Development scenarios for Ennis assume that construction of a heating district would begin in 1982, that it would be 25 percent complete by 1985, 75 percent complete by 1987, and 100 percent complete by 1989. In addition, for planning purposes, it was assumed that two large buildings would be constructed and be part of the geothermal heating district, with one building on-line by 1990 and the other by 2000. A health resort and spa are also projected for Ennis. The projected consumption of this development is in Table 22.

Table 22. Projected Energy Use in Ennis

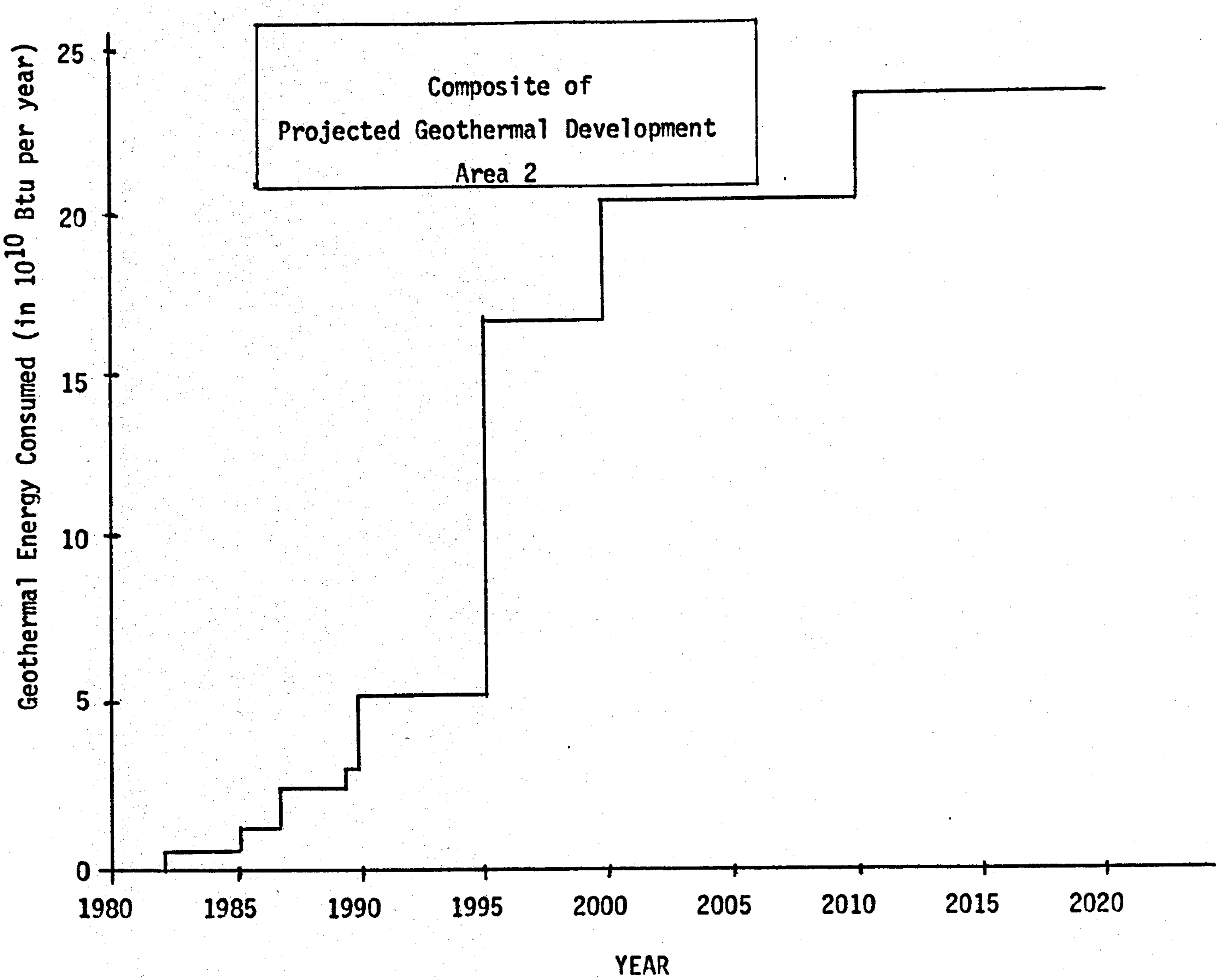
Type of Use	Annual Consumption
Residential	2.24×10^{10} Btu
Commercial	0.09×10^{10} Btu
State buildings and health spa	1.10×10^{10} Btu
TOTAL	3.34×10^{10} Btu

The U.S. Geological Survey estimate of geothermal energy available at Ennis Hot Springs is about 20×10^{11} Btu per year, which is still more than 20 times the estimated energy demand of all projected developments for Ennis.

The Twin Bridges economic analysis shows that, given geothermal reserves as postulated, the cost of a municipal heating district is already comparable to the cheapest fuel available. Therefore it is assumed that development of this heating district might begin by 1990, if a geothermal reservoir is discovered. It is assumed that the entire community of Twin Bridges would hook up to geothermal energy and consume about 2×10^{10} Btu annually.

3.2.2.3 Area 3 Development Plan. Southeastern Montana (Area 3) was chosen for study in 1979 to examine the geothermal potential of the Madison Formation, a Paleozoic limestone aquifer exhibiting high local permeability

Figure 3 Projected Geothermal Development in Area 2.



and high water temperature. The Madison Formation ranges far and wide through eastern Montana and other states; geothermal success in one area might also reasonably be expected in others as well.

Area 3 population is so sparse that the economic feasibility of any geothermal project will hinge upon drilling costs. Therefore, the analysis of this area has been limited to studying the cost of drilling into the Madison Formation. The following is a brief description of alternatives for developing this area.

Petroleum Well Utilization for Geothermal Energy. Oil wells are expensive to drill, and wells drilled into the Madison Formation can be particularly expensive because of depth. While the formation lies within a few hundred meters of the ground surface in some places, most areas of geothermal interest in the Madison Formation lie from 1500 to 3000 meters below the surface. This great depth is necessary for two reasons, those of temperature and flow rate. Shallower penetrations would be likely to prove insufficient on one or both counts.

The requirement for deep wells dictates a large end-user if the capital costs of drilling are to be justified. Deep wells may be feasible economically in the case of animal feed processing or barley malting facilities which use large amounts of energy, but development will progress at a faster pace if small-scale uses can be developed, since investment capital for high risk projects is easier to get for small-scale applications. Therefore, some way to provide access to Madison Formation water at a reasonable cost is needed.

Table 23 shows a breakdown of the costs associated with drilling deep wells in the Madison Formation. The costs for casing include surface casing to 600 feet and production casing to the bottom of the well. Normally a 7-inch diameter casing is sufficient for geothermal purposes. However, if pumping is necessary, a 12-inch diameter well is required, so the cost for wells of both diameters is given. Figures from this table indicate that a usable well in the Madison Formation can be expected to cost from one-half to one million dollars.

Table 23. Costs of Drilling Wells 5,000 and 10,000 Feet Deep

	5,000-foot well		10,000-foot well	
	7-inch diameter	12-inch diameter	7-inch diameter	12-inch diameter
1) Drilling and Logging	$125,000-150,000	-	$250,000-300,000	-
2) Casing:				
Surface 12" diameter	15,000	-	15,000	-
Production 7" diameter	90,000	-	180,000	-
3) Setting casing	5,000	-	7,000	-
4) Cement	10,000	-	20,000	-
5) Perforation	10,000	-	12,000	-
Total Costs	$255,000-280,000	$615,000	$484,000-534,000	$1,206,000
Cost Per Foot	51-56/foot	$123/foot	$49-54/foot	$121/foot

SOURCE: Griffith 1979, Sonderegger 1979a.

There are, however, several ways to acquire a deep well without having to pay the full drilling costs, i.e. :

(1) reactivating old petroleum exploration holes;

(2) arranging with an oil company to complete an exploration hole as a geothermal well, should no oil be found; or

(3) rehabilitating producing petroleum wells for geothermal production.

These three alternatives are discussed below.

Investigation showed that revamping abandoned and plugged petroleum exploration wells would be very expensive, comparable to drilling a new well. A well driller does not set casing if insufficient oil production is expected. This may result in caving and plugging of the well. Wells are usually not drilled for water production purposes and the Madison Formation need not be penetrated if a petroleum layer lies above it. Although there are a number of flowing water wells in Montana that have resulted from faulty plugging of oil exploration wells, the flow of these artesian wells is generally slow and temperatures of 49^{o}C are the usual maximum. So, while these incorrectly plugged wells could be used for some geothermal purposes, adapting correctly plugged holes to geothermal use is not economically feasible in the general case.

A second alternative is to arrange with petroleum exploration outfits to complete an oil well as a geothermal production hole. This arrangement would involve changing the normal exploration contract to reduce the royalty by perhaps 50 percent if oil were found, but to require completion of the hole as a geothermal well if oil were not found. This approach raises numerous institutional questions. For instance: 1) Who is responsible for plugging the well should it be abandoned? 2) Who will pay for site restoration? 3) How does the Oil and Gas Commission transfer its responsibility? If the drilling were to take place on state land, modification of state laws would also be necessary. However, these problems do not seem insurmountable.

The economics involved in changing an exploratory well to geothermal production were also investigated. An oil company normally puts in surface casing (normally beween 5 and about 8-1/2 inches), drills to depth, and logs.

If oil is not found, a cement plug is installed and the surface casing pulled if possible. The cost of the surface casing is generally considered to cover the plugging cost.

If the well is to be completed for hot water production, the surface casing must be left in and the main hole casing set to depth. The hole must be cemented and then perforated at the proper depth. Minor wellhead equipment would be required. Bonds might be required for plugging and surface reclamation.

Table 24 analyzes these costs. While costs are lower than for a new well, they are still high for a small facility when site location (which may not be optimum) and low production rates (800-2400 liters per minute) are considered.

Choosing this second alternative may provide a cheaper geothermal well than the first alternative, but would probably yield only a low production of hot water and at the location of drilling, not necessarily where the potential geothermal user wants it. Also, the lessor would have to be very interested in developing geothermal energy to give up part of the royalty he would receive if the driller should find oil. These problems may convince investors that this option is too expensive.

A third alternative for developing oil wells for geothermal use would involve locating and exploiting existing producing petroleum wells that are due for abandonment. These wells must be plugged before company liability to the government is released. The extra costs involved in converting them to geothermal production would be limited to 1) identifying the hot water production zones, 2) plugging the oil zone with cement, and 3) perforating the casing above the plug if the hot water zone is located there, or drilling out the plug and perforating the casing below the oil production layer, if the hot water aquifer is located beneath the plug.

There are several areas where the Madison Formation is located above the oil production zone, eliminating the need for any further drilling. Examples of these areas include parts of the Williston Basin and the Poplar area. These are commonly called Devonian targets. Some of them (such as

Table 24. Estimated Costs of Converting Exploration Wells 5,000 and 10,000 Feet Deep to Geothermal Production

	5,000-foot well*	10,000-foot well*
Casing	$90,000	$180,000
Setting casing	5,000	7,000
Cement	10,000	20,000
Perforation	10,000	12,000
Well head equipment	2,000	2,000
Bond	10,000	20,000
Total	$127,000	$ 239,000
Cost Per Foot	$26 per foot	$24 per foot

SOURCE: Griffith 1979, Sonderegger 1979a.

the Montana high line at Cutbank) also have gas production zones above the Madison Formation. Expenses for this alternative are presented in Table 25.

Normally an oil company has to pay for a rig-on-site and for cement, less the salvage value of the casing, if recoverable. Some casing may be left in the well, which would cancel out its salvage value. Therefore, to encourage the company to cooperate in well rehabilitation, a part of the standby and mobilization time of the rig may have to be paid for by the geothermal user. These costs could amount to $5000 to $6000 per day.

The total cost of converting an oil well to geothermal production is very low via this third alternative, affordable by even relatively small direct use projects. The major problems are the obvious ones of well location and flow rate. Oil and gas regulatory concerns seem to be minimal since the oil-bearing layers are to be cemented, thus reducing concern about abandonment procedures.

An area of concern not studied in depth in this report is the disposal of brine, which is often very concentrated, and which would be produced by a geothermal well. This brine may be a problem when only one drill hole is available, since reinjection would be impossible.

In conclusion, this third method of geothermal development in the Madison Formation may be the only economically feasible method available in the near future for smaller projects. However, access to drilling logs and tests that show accurately the location, character, and temperature of the resource would lessen the economic risk even further than the low cost. With careful investigation the chances of success with this third alternative are very good.

Table 25. Costs of Converting Producing Oil Wells to Geothermal Production

Expense	5,000-foot well*		10,000-foot well*	
	with additional drilling	without additional drilling	with additional drilling	without additional drilling
Field work	$1,000	$1,000	$1,000	$1,000
Cement	10,000	10,000	20,000	20,000
Perforation	10,000	10,000	12,000	12,000
Drilling 300 Additional Feet**	7,500	0	7,500	0
Total	$28,500	$21,000	$40,500	$33,000
Cost Per Foot	$5.70/foot	$4.20/foot	$4.10/foot	$3.30/foot

*7-inch diameter.

**Drilling is assumed to cost $25 per foot.

SOURCE: Griffith 1979, Sonderegger 1979.

3.3 SITE SPECIFIC DEVELOPMENT PLANS

Site specific development plans for six to ten sites are underway. Sites were chosen for their development potential and are based on geothermal resources in the potential or proven class. These site specific development are being integrated with area development plans already described.

Work to date on these site plans has involved preliminary site selection and data collection. Preliminary development plans for twelve sites were produced during the 1978 planning project (Brown, 1979). They are listed below.

(1) Barkell's Hot Springs
(2) Boulder Hot Springs
(3) Bozeman Hot Springs
(4) Broadwater Hot Springs
(5) Corwin Hot Springs
(6) Deer Lodge Warm Springs
(7) Ennis Hot Springs
(8) Marysville KGRA
(9) New Biltmore Hot Springs
(10) Warm Springs
(11) West Yellowstone KGRA
(12) White Sulphur Springs

Site specific studies in 1979 include some of the above sites, as well as some additional ones, listed below.

(1) Boulder Hot Springs
(2) Bozeman Hot Springs
(3) Broadwater Hot Springs
(4) Ennis Hot Springs
(5) Warm Springs
(6) White Sulphur Springs
(7) Alhambra Hot Springs
(8) Camp Aqua Hot Springs
(9) Saco (Madison Formation)
(10) Glasgow (Madison Formation)

All of these sites will be analyzed using the economic analysis provided by the New Mexico Energy Institute. Additional analyses will be carried out as time allows. All of the twelve original sites will be periodically reviewed and the data for each will be updated. As the study progresses, new development projections for selected sites will be produced.

3.4 TIME PHASED PROJECT PLANS

3.4.1 ACTIVE DEMONSTRATION

The Warm Springs State Hospital was awarded a grant under the Program Opportunity Notice from the U.S. Department of Energy for $600,000 to develop a local geothermal resource. The energy, used for space heating of the facility, will come from a grothermal well that should be drilled by the fall of 1979. The Montana team is not making a time phased project plan for this endeavor, but is providing advice to the project team and monitoring the general progress of the work.

3.5 STATE AGGREGATION OF PROSPECTIVE GEOTHERMAL UTILIZATION

Efforts to aggregate data on state geothermal resources will be restricted to the results of the computer modeling being conducted in cooperation with the New Mexico Energy Institute. These results, not yet available, will be presented in the final 1979 report.

3.6 INSTITUTIONAL ANALYSIS

The laws and regulations that would affect geothermal development are being compiled and analyzed and will be presented in this year's final report. This material will also be published in a state geothermal handbook for use by potential geothermal developers and for those who make and administer state laws.

3.7 OUTREACH PROGRAM

The purpose of this part of the 1979 geothermal planning project is to promote the use of geothermal energy by industrial, commercial, agricultural, and domestic consumers, by: 1) interacting with community, business, industrial, and governmental leaders concerning geothermal development opportunities and programs; 2) disseminating geothermal information and maintaining information files, and 3) encouraging geothermal exploration and reservoir assessment.

Agricultural extension agents in many eastern Montana counties have been contacted, and have offered to print news items concerning geothermal energy in their newsletter, which is circulated to the rural population. The Crow and Northern Cheyenne tribes have also been contacted concerning the presence and use of geothermal energy on their reservations, and the Sioux and Assiniboine tribes of the Fort Peck Reservation were assisted in applying for the grant they received from the U.S. Department of Energy's Program Research and Development Announcement.

In addition to the above activities, many requests for information about geothermal energy beve been filled in connection with many projects, including:

(1) heating a lumber yard near Ennis;
(2) determining whether a particular geothermal resource could heat a commercial dursery;
(3) combining geothermal energy and heat pumps to heat another commercial nursery; and,
(4) providing infomation and contacts for applying for federal and state grants.

Contacts involving community leaders and industry have not been initiated so far. The second half of the study should see greater allocation of time to this form of outreach. It is hoped that increasing civic interest will promote individual and commercial interest as well as initiating action on community district heating using geothermal energy.

Appendix A

GEOTHERMAL RESOURCE BASE: DNRC CALCULATION METHOD #1
(Using surface discharge and geologic factors)

I. <u>Resource Characteristics</u>:

1) t = hot springs surface temperature (^{o}F)

2) t_{pot} = Potential temperature of subsurface geothermal fluids
= ($t+36^{o}F$)

3) t_{ref} = Mean annual Montana air temperature
= $59^{o}F$

4) t_{dis} = Theoretical discharge temperature of geothermal fluids after use
= $100^{o}F$

5) F = Known flow of hot springs in gallons/minute

6) F_{pot} = Potential flow of hot springs in gallons/minute

7) A_u = Annual geothermal energy use factor (Percentage of available Montana geothermal energy which can be used throughout the year)
= .50 (assumed)

II. <u>Calculations</u>

A) <u>Total Available Wellhead Energy (in Btu/year) = gwh</u>

$$gwh = (F_{pot})(t_{pot} - t_{ref})(4.38 \times 10^{6})$$

B) <u>Usable Thermal Energy (in Btu/year) = Q</u>

$$Q = (F_{pot})(t_{pot}) - t_{dis})(A_u)(4.38 \times 10^{6})$$

C) <u>Energy Supply Rate (in Btu/hour) = R</u>

$$R = (F_{pot})(t_{pot} - t_{dis})(500)$$

SOURCE: Brown, 1978

APPENDIX B

GEOTHERMAL RESOURCE BASE: USGS CALCULATION METHOD #2

(USGS Circular #790 Reservoir Size Methodology)

I. Resource Characteristics:

1) v = reservoir volume in cubic kilometers (estimated)

2) t_{res} = estimated reservoir temperature

3) t_{ref} = mean annual Montana air temperature
 = 15°C

4) P_c = volumetric specific heat of rock plus water
 = 2.7 J/cm^3/°C

5) a = reservoir area (in km^2)

6) d = reservoir thickness (in km)

7) U_b = beneficial heat utilization factor (the fraction of thermal energy obtained when 150°C water undergoes a 32°C drop)
 = 0.24

8) m_{wh} = mass of steam produced at the wellhead

9) h_{wh} = enthalpy (or heat content) per unit mass of steam at the wellhead

10) h_{ref} = enthalpy per unit mass of saturated water at the reference temperature of 15^{o}C.

II. Calculations

A) Reservoir Thermal Energy (in Joules) = gr

$$gr = (P_c)(a)(d)(t_{res} - t_{ref})$$

B) Available Wellhead Energy (in joules per year) = g_{wh}

$$g_{wh} = m_{wh} \cdot (h_{wh} - h_{ref})$$

C) Recoverable Reservoir Energy (in joules) = R_g

$R_g = g_{wh}$ / gr = .25 (assumed)

D) Usable Recoverable Energy (in joules per year) = B

(The amount of thermal energy that could be directly applied to non-electric use, assuming a reservoir lifespan of thirty years)

$B = (gr)(R_g)(U_b)(1/30)$

E) Energy Supply Rate (in houles/hr) = R

(The available wellhead energy per hour, assuming a reservoir lifespan of thirty years)

$R = (gr)(R_g)(1/262,800)$

SOURCE: Muffler, 1978.

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