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POTENTIAL APPLICATION OF MADISON FORMATION WATERS FOR COMMUNITY HEATING IN SOUTH DAKOTA

Prepared by: R. A. FREEMAN and R. F. MEIER
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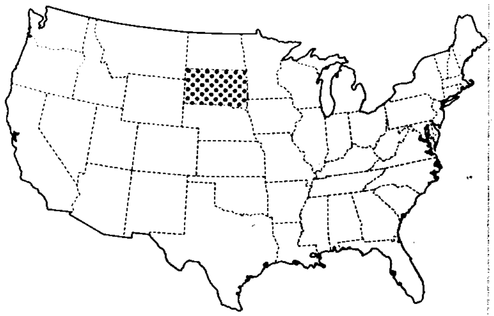
LAUREL, MD 20810

For the:
PLANNING BRANCH
DIVISION OF GEOTHERMAL ENERGY
U.S. DEPARTMENT OF ENERGY
20 MASSACHUSETTS AVENUE, N.W.
WASHINGTON, DC 20545



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Johns Hopkins Road, Laurel, Maryland 20810
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PREFACE

The Applied Physics Laboratory of the Johns Hopkins University, in its role as Regional Operations Research Contractor to the Planning Section of the Division of Geothermal Energy, Department of Energy, examined the potential for geothermal energy applications in the state of South Dakota. This report was written to bring together all of the considerations for the application of the Madison Formation waters for space heating. The report is intentionally brief. It was written primarily for the information and the use of the people in South Dakota. These data should encourage them to take the initiative, individually or collectively, to develop further their natural resource. If additional data or assistance is required, the reader is referred to the following agencies:

The South Dakota State Energy Office
Pierre, SD 57501

Fifth District Planning and Development Commission
P.O. Box 640
Pierre, SD 57501

Sixth District Council of Local Governments
P.O. Box 1586
Rapid City, SD 57709

Idaho National Engineering Laboratory
Operations Office
Box 1625
Idaho Falls, ID 83401

Department of Energy
Division of Geothermal Energy
Washington, DC 20545

We acknowledge the considerable assistance of many organizations and individuals in South Dakota, notably: Dr. Duncan McGregor of the State Geological Survey; Scott McGregor of the State Planning Bureau; Gerald Bergum of the Fifth District Planning and Development Commission; Van Linquist and Brian Shorten of the Sixth District Council of Local Governments; G. Stroppel, President of the Midland Town Council; John Iszler, Superintendent of Schools in Edgemont; Charles Maxon, Superintendent of Schools in Philip; Arthur D. Thomas, former Administrator, and William Allison, present Administrator, of St. Mary's Hospital in Pierre.

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I. PURPOSE

The primary purpose of this report is to call attention to the possibility of using natural underground hot water in South Dakota for community space heating and to assist citizens, governing bodies, and advisory groups in considering this geothermal energy as an alternative to the other forms of energy (mainly fuel oil and propane gas) widely used today for space heating.

Secondary purposes are to explain the role of the federal Department of Energy in developing the use of alternative sources of energy, to suggest possible funding assistance to communities and individuals in changing from their present energy base, and to call attention to legal and jurisdictional factors that need to be considered in making such changes.

II. INTRODUCTION

The Madison Limestone Formation (the Madison) that lies beneath the western half of South Dakota contains large amounts of hot water at temperatures between 120 and 160°F (49 and 71°C). Much of the water is potable and has been used by some communities and individuals for many years. A few isolated projects (e.g., Midland High School and St. Mary's Hospital in Pierre) exist or are under way to employ the waters for space heating. These projects, however, will use only a very small fraction of the energy resource.

The geology of the Madison is reasonably well known and this knowledge is being advanced further by state and federal studies. Thus it can be stated that the waters of the Madison represent a geothermal resource that is available today to the citizens of western South Dakota. Furthermore, no new technology is required to tap this energy source, so that it is possible to develop it in a relatively short time.

Because South Dakota lacks local fossil fuels and transportation systems for coal and gas (except in some border areas of the state) it is desirable to develop available alternative energy forms that surmount these difficulties. As early as 1974 the state suggested using the geothermal potential within its borders (cf, S. D. Geologic Survey Publication No. 110).

This report suggests that the most practical early application of the Madison waters is in community space heating using a procedure patterned after the Rural Electric Administration's pioneering efforts in electrification; that is, local hot waters should be considered as a municipal commodity. The general design of such a community system is discussed along with its cost, means of financing, and life expectancy. Legal questions and state statutes that are pertinent are cited and the life expectancy of the entire Madison resource and equipment to exploit the resource are considered.

III. BACKGROUND

A. National Approach to Developing Geothermal Resources

The Division of Geothermal Energy (DGE) was established in 1974 as part of the U.S. Energy Research and Development Administration (ERDA), now the Department of Energy. DGE's activities include geothermal research and development, feasibility demonstrations, and issuance of grants in specific areas.

Through operations research contractors, DGE identifies sources and potential uses of geothermal energy and prepares scenarios for the public and private development of the resources.

As one of the DGE operations research contractors the Applied Physics Laboratory of The Johns Hopkins University (APL) examined available information on the Madison and prepared an initial scenario for the development of the aquifer. Because of its temperature and availability an important application is commercial and residential space heating. The Idaho National Engineering Laboratory is continuing the evolution of the scenario.

B. National Geothermal Energy Goals

The goal of DGE is to establish geothermal energy as an economical, environmentally clean alternative to fossil fuel energy and thus help to satisfy the constantly increasing national energy demands. DGE anticipates that all U.S. geothermal resources will provide about 0.6×10^{15} Btu of energy per year by 1975 and 18×10^{15} Btu per year by 2020. Current total U.S. energy consumption is 70×10^{15} Btu per year (cf, DOE/DGE Program Goals). Thus it is seen that geothermal energy is not expected to contribute significantly to the total national demand within the next few years, but eventually will do so and thus reduce the need for fossil fuels.

Of the five primary types of geothermal energy (hydrothermal, geopressured, hot dry rock, magma, and normal gradient) the first is of initial interest to South Dakota.

C. The Madison Limestone Formation and Its Energy Potential

The Madison is a well known aquifer that underlies portions of South Dakota, North Dakota, Montana, and Wyoming. In South

Dakota it extends beneath the western half of the state. The entire aquifer covers an area of about 25 000 mi^2 amd stores an estimated 10^9 acre-ft of water. The water temperatures are considered moderate, ranging from about 120 to 160°F (49 to 71°C). Figure 1 is taken from the U.S. Geological Survey Water Resources Investigation 63-75, and shows temperature data points for the Madison. Note that the temperatures are given in degrees Celsius. Note, also, that the temperature tends to increase as one moves east from the Black Hills area.

Surface waters in the Black Hills, Big Horn, and Laramie Mountains are believed to recharge the Madison aquifer at the rate of about 150 000 acre-ft per year.

The average age of the Madison waters is estimated by U.S. Geologic Survey/Water Resources to be between 15 000 and 30 000 years and the waters reside in a limestone formation averaging 400 ft in thickness and at modest depths ranging from 2000 to 6000 ft in South Dakota. The porosity of the formation averages 8%; the transmissivity is estimated to be 0.013 ft^2/s and the storage coefficient is estimated to range from 0.0001 to 0.00025 (South Dakota School of Mines Report, "The Geothermal Applications on the Madison Aquifer System (Pahasapa) in South Dakota," 1976). The values of these parameters indicate to reservoir engineers that adequate flow rates can be maintained without depletion of the aquifer.

The ability of the aquifer to transmit water is quantitatively described by its transmissivity. Transmissivity is the rate at which water passes through a unit width of the aquifer under a unit hydraulic gradient (Lohman and others, 1972). The storage coefficient is a dimensionless number that is the ratio of the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the hydraulic head (pressure) (Lohman and others, 1972).

The southern region of the Madison contains water that is generally potable with dissolved solids of 1000 to 2000 ppm. To the north the water becomes more saline and less potable. Dissolved solids are as high as 6000 ppm near the North Dakota border; this presents problems in direct use of the water.

Detailed discussions of the Madison's geology and its geothermal potential are available in a series of publications by the South Dakota Geologic Survey (of particular interest is the Report of Investigations No. 110). The report by the South Dakota School of Mines and Technology "Geothermal Applications on the Madison Aquifer System (Pahasapa) in South Dakota," 1976 is also important.

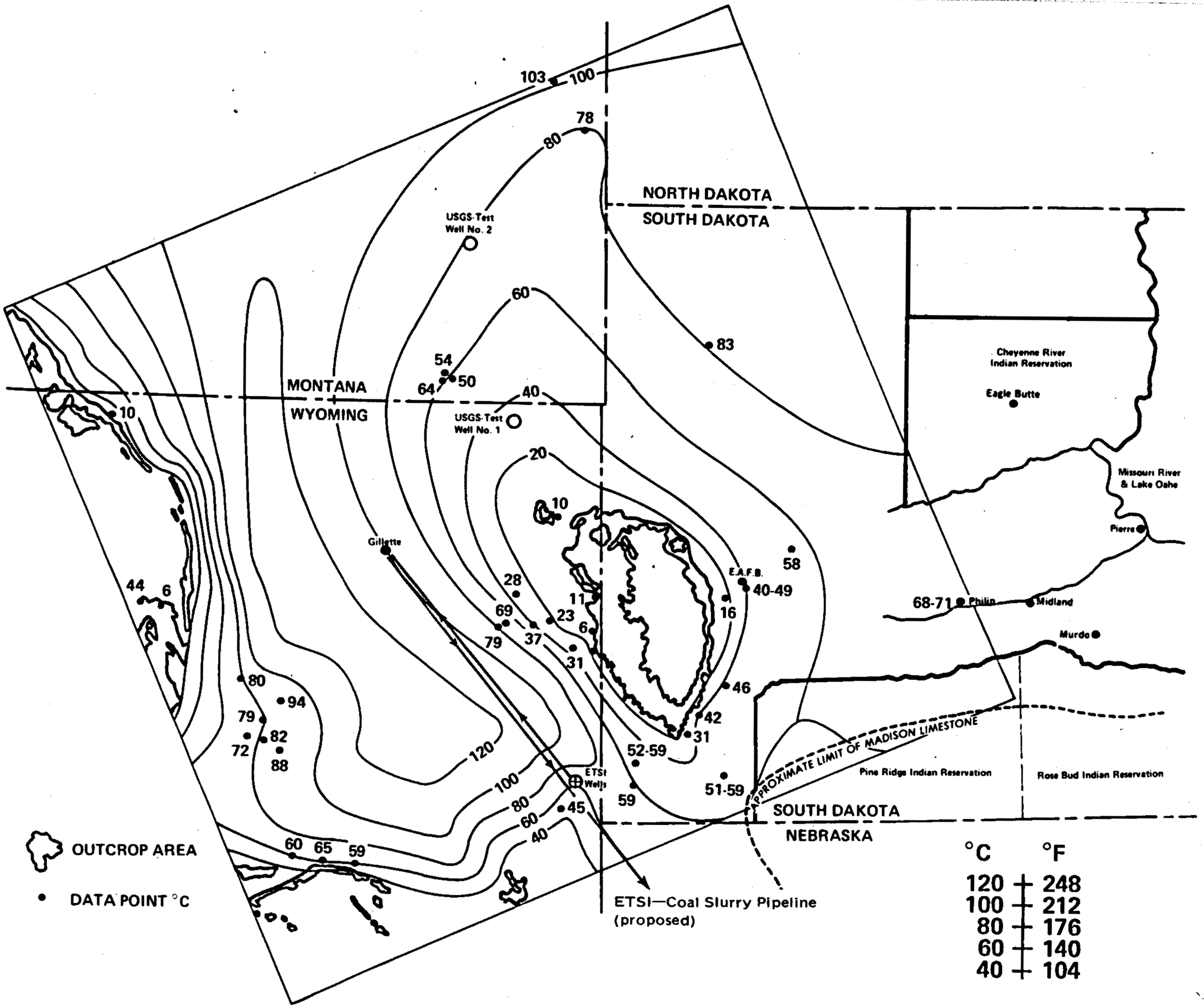


Fig. 1 Region of interest to USGS/WR and temperatures in the Madison.

To estimate the geothermal potential of the Madison for community space heating (or other purposes where the assumptions apply) in western South Dakota the following assumptions are considered: the average water temperature is 140°F, water is withdrawn at the natural recharge rate of 150 000 acre-ft per year, and the load rejection temperature (water temperature at the end of the process) is 100°F. On this basis, the quantity of energy available is 16×10^{12} Btu — the equivalent of 2.7 million barrels of oil per year.

D. Geologic Prerequisites to Extensive Geothermal Development

Although the Madison can be used for space heating and other applications much more widely than it is today, several important factors must be better known before extensive geothermal development can be shown economically practicable. These factors, listed below, require the collection of basic and definitive engineering data relating to the Madison itself and to other aquifers that may interact with the Madison.

1. The heat source and its life expectancy

South Dakota is a stable tectonic region and thus it is considered probable that the thermal properties of the Madison waters will remain essentially constant for a long time. However, the exact nature of the heat source that raises the water temperature above that found at equal depths in most other regions of the United States is not yet known. In Goguel's book Geothermics, the source is suggested to be a concentration of trace radioactive elements in the Precambrian granite that covers the Madison formation. If this is true then the natural diminution of water temperatures is expected to be very slow, measured in tens of thousands of years. The USGS/WR Madison Study (in progress) should resolve the question of heat source and better predict the expected life of the Madison as a geothermal resource.

2. Madison parameters

Factors that affect drilling and withdrawal of water are well known in various regions but not for all parts of the Madison that are of interest. These factors include the aquifer thickness, porosity, permeability, potentiometric head (artesian pressure), temperature, and depth below ground level. USGS/WR work and planned work of the School of Mines will help to develop these data. Additional assistance may be available through the resource engineering program of the Division of Geothermal Energy of the Department of Energy.

3. Effects of substantial withdrawal

Broad use of the water can affect the aquifer thermal properties, quality of water, and artesian pressure. In turn, such changes would affect the annual cost of a heating system by demanding higher flows, more rapid cleaning or replacement of components, and possible installation of pumps.

Currently USGS/WR is developing (as outlined in Report 75-631) a detailed and quantitative model of the hydrology in the Madison aquifer and other aquifers that can affect its flow. Although postponed by recent congressional action, the Wyoming proposal to use Madison water to move coal via a slurry pipeline from the Powder River Basin is of particular interest. DGE is negotiating to have the study extended so that proposed Madison usage in South Dakota would be included. A letter of intent has been written and proposes a joint effort by DOE/DGE, the state of South Dakota, and USGS to collect the additional data needed to properly represent South Dakota use of the Madison waters (letter from U.S. Department of Interior Geologic Survey, April 1977).

4. Thermodynamic model of aquifer

A model of the aquifer that includes the western South Dakota region of the aquifer needs to be developed so that various rates of withdrawal and locations of withdrawal can be examined with respect to cooling the aquifer, well-to-well artesian effects, or the need to reinject water after use. The USGS model should be carefully examined to see if it would be adequate or could be modified for South Dakota's purposes.

IV. DEMOGRAPHY AND ENERGY USE IN THE MADISON AREA

A. Demography

In western South Dakota, where the Madison aquifer is relatively shallow and its geothermal waters are readily available, 117 000 persons occupy 45 000 residences (excluding Rapid City). Of this population within the boundaries of the Madison, about 74 700 live in rural areas with an average density of 2 persons per square mile. The remaining 42 300 live in communities of varying size: 18 with 10 to 100 persons, 44 with 100 to 1000 persons, 6 with 1000 to 2000 persons and 2 with 2000 to 10 000 persons.

B. Energy Use

The total commercial and residential (non-electric) energy consumption in South Dakota during 1973 was 54.2×10^{12} Btu (equivalent to 9.4 million barrels of oil). In decreasing order of importance this energy was supplied by natural gas, oil, LPG, electricity, and coal. In the Madison region the resources were oil, LPG, electricity, and coal.

Assuming that energy consumed per capita was uniform throughout the state, the 17% of the population living in the Madison region consumed 2×10^8 Btu per residence for a total of 8.3×10^{12} Btu (the equivalent of 1.6 million barrels of oil). For those living in towns with populations greater than 10 the consumption was 3.2×10^{12} Btu.

V. POTENTIAL GEOTHERMAL APPLICATION OF THE MADISON AQUIFER

The preceeding sections have defined the Madison aquifer as a geothermal resource that is being used for a few space heating projects. This application has much broader uses.

In addition, geothermal energy is a clean source with few environmental disadvantages and, since it is indigenous to the state, its use could reduce the problems that accompany the almost complete dependence on imported fuels: shortages, distribution, and increasing prices.

Therefore, it is suggested that communities consider developing local systems that tap the Madison and use the energy of the hot waters primarily for heating homes, but including other buildings as would best meet a community's needs.

The key question in considering this conversion is whether or not the community (ultimately its citizens) can afford the costs. Unless the monthly costs (capital amortization, maintenance, etc.) to a subscriber can be less than current and projected costs of conventional fuel systems the subscriber cannot be expected to be interested in converting to geothermal energy use.

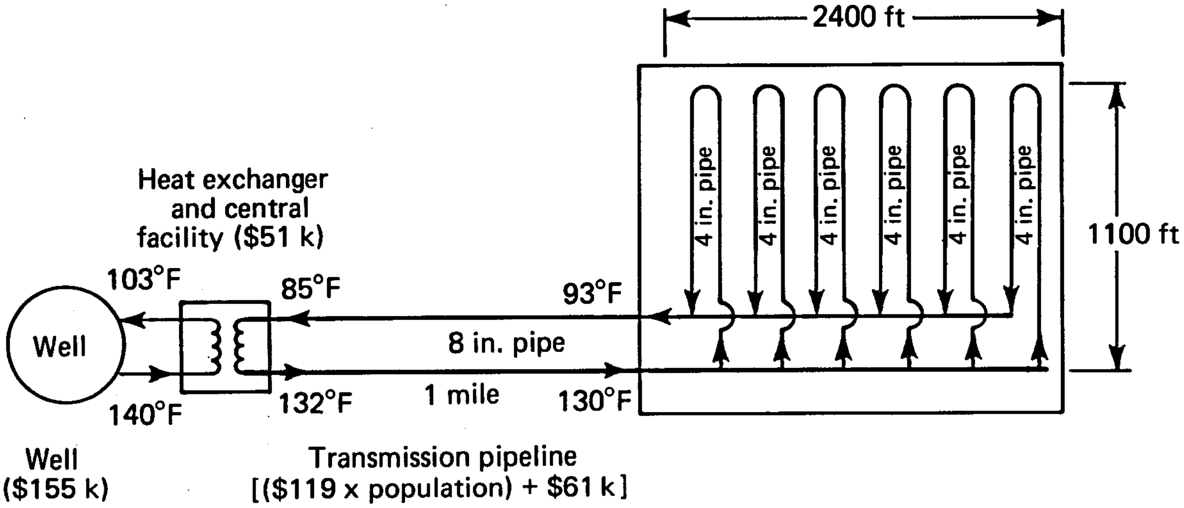
To answer this question a cost model for a community geothermal space heating system shown in Fig. 2 was developed (see Appendix A) and is used to show, in terms of town population, where the system may be cost competitive with fossil fuels.

DESCRIPTION OF COMMUNITY HEATING SYSTEM

A. Cost Analysis

The geothermal space heating system is divided, for cost modeling puposes, into four main components (cf, Fig. 2);

1. Geothermal well,
2. Heat exchanger and central facility,
3. Two-way transmission from production well to community, and



Town distribution system per capita

Hookup	$115
Conversion	$192
Distribution pipe	$438
Total	$745

Total cost = $155 k + $51 k + [($119 x population) + 61 k] x miles + ($745 x population)
(for population = 312)

Fig. 2 South Dakota Madison geothermal space heating system.

4. Community distribution system (two-way pipe line, residence hook-up, and conversion of home heating system).

The Supply well (and reinjection if required)

Based on current prices (cf, Appendix A) the cost of drilling, casing, and enclosing a 7 in. diameter well drilled 3800 ft into the Madison formation was estimated by Francis-Meador-Gellhaus, Inc., to be about $155 000. This figure is used to calculate total community costs in an illustrative example below. Such a well is assumed to be artesian and have a flow rate of 1300 gal/min.

The central heat exchanger

A central heat exchanger is used to transfer heat from the well water to a secondary closed-loop system containing treated water and to increase the overall system reliability. A stainless steel, plate-type heat exchanger with removable covers (to permit ready access for periodic inspection and cleaning) was selected. This type is considered to be extremely reliable and so a back-up exchanger should not be required.

The cost of the heat exchanger is directly proportional to the plate (surface) area, which, in turn, is proportional to the heating demand. Thus, given the population and heating demand, the per capita cost of the heat exchanger is readily determined.

To allow for growth it is assumed that the central exchanger for a community is designed with 35% excess capacity.

Town distribution system

The required cross-sectional area of the transmission pipeline is directly proportional to the population it serves. Similarly, the cost per unit length of installed pipeline is approximately a linear function of the cross-sectional area of the pipe. It follows that pipeline costs are directly proportional to the population served and, thus, per capita cost can be determined. Similarly, average cost per residence can be determined using the average of 2.6 occupants per residence.

Figure 3 shows installed costs per mile for the closed-loop, two-way distribution line. Costs include those for cement-asbestos pipe, trenching to bury the pipe 5 ft deep, on-site application of 1 in. foam insulation on the feedline, refilling the trench and compacting the refill soil only where the line intersects roads. Compacting was assumed to be required over 15% of the line. Specific costs are shown for installation of production size pipes as well

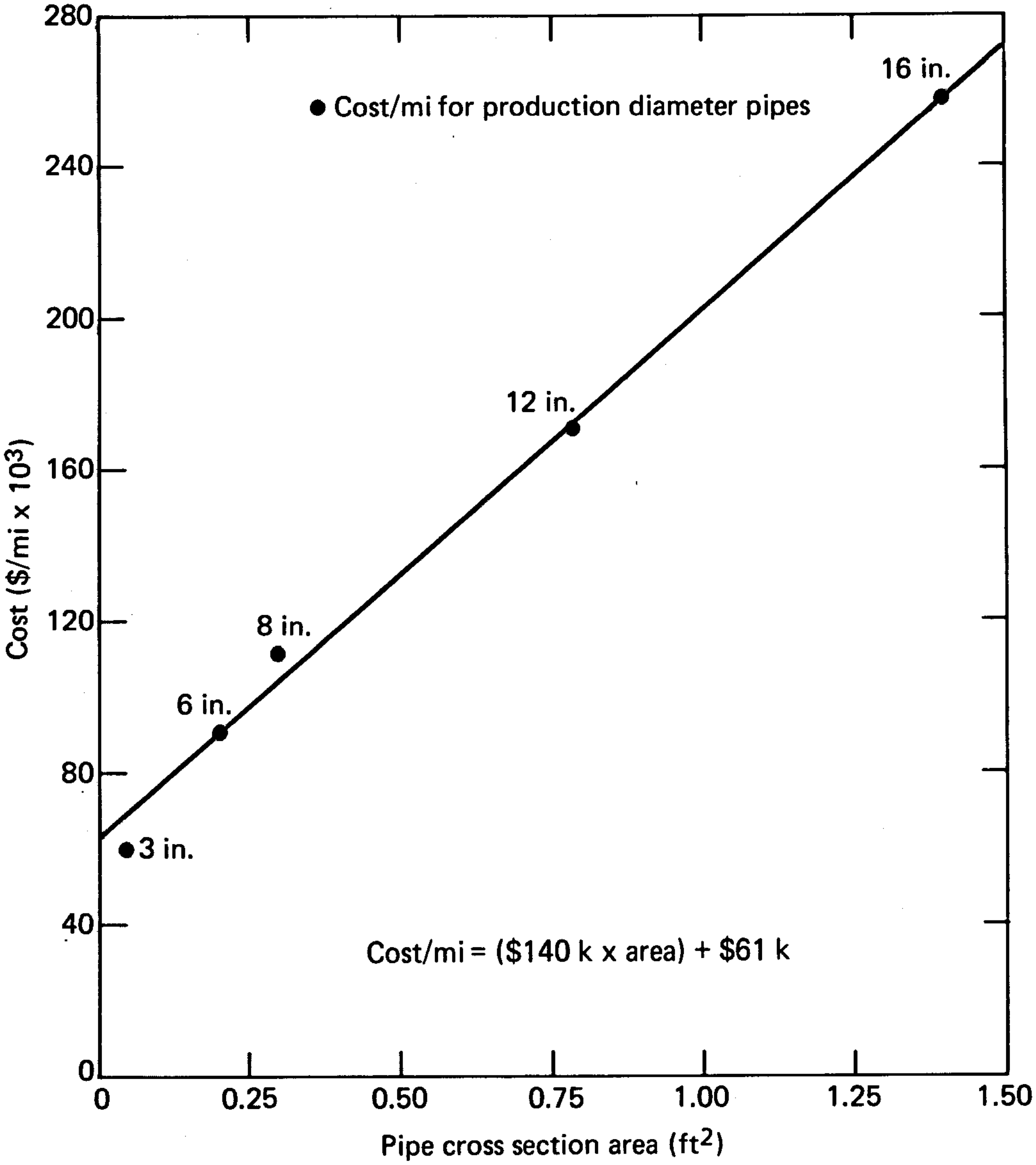


Fig. 3 Double pipeline transmission system in western South Dakota; insulation only on feedline.

as the straight line approximation used in this paper for estimating system costs.

Figure 4 shows the installed costs per mile for a one-way line, uninsulated, to a reinjection well which might be required.

Individual connections to municipal system

Residential hook-up charges and conversion, including the local heat-exchanger using the closed-loop heating fluid, are fixed costs per household and thus can be put on a per capita basis.

B. Illustrative Example

Figure 2 illustrates the total costs for a particular town (Midland, SD, with a population of 312) with the production well 1 mi from town and no reinjection well.

ENERGY DEMANDS

The design requirements, both peak heating and average seasonal demands, were determined for weather conditions existing in western South Dakota and the type of housing in Midland. The peak heating demand for 120 residences was estimated to be 9.9×10^6 Btu/h, including 10% losses and 10% margin for growth. The distribution system consists of an 8 in. main pipe and 4 in. feeder lines. Houses were assumed to be uniformly distributed through the town area for estimating the required pipe lengths. All homes were considered to be converted from a conventional forced-air system by installation of a heat exchanger.

C. Cost Model Assumptions

Using the estimated component costs and scaling above and below the population in the Midland example, monthly per capita costs for conversion were calculated.

The general form of the cost model is shown in Fig. 5 and the specific values for a town with a population of 1000 are shown in Fig. 6.

In these calculations it is assumed that all homes initially had forced-air systems. This is true in general, but can be far from correct in some communities where newer homes may be using electricity for all domestic purposes. Conversion from all-electric to geothermal is not considered in the model because the cost to the homeowner would be prohibitively high. Conversion from oil- or

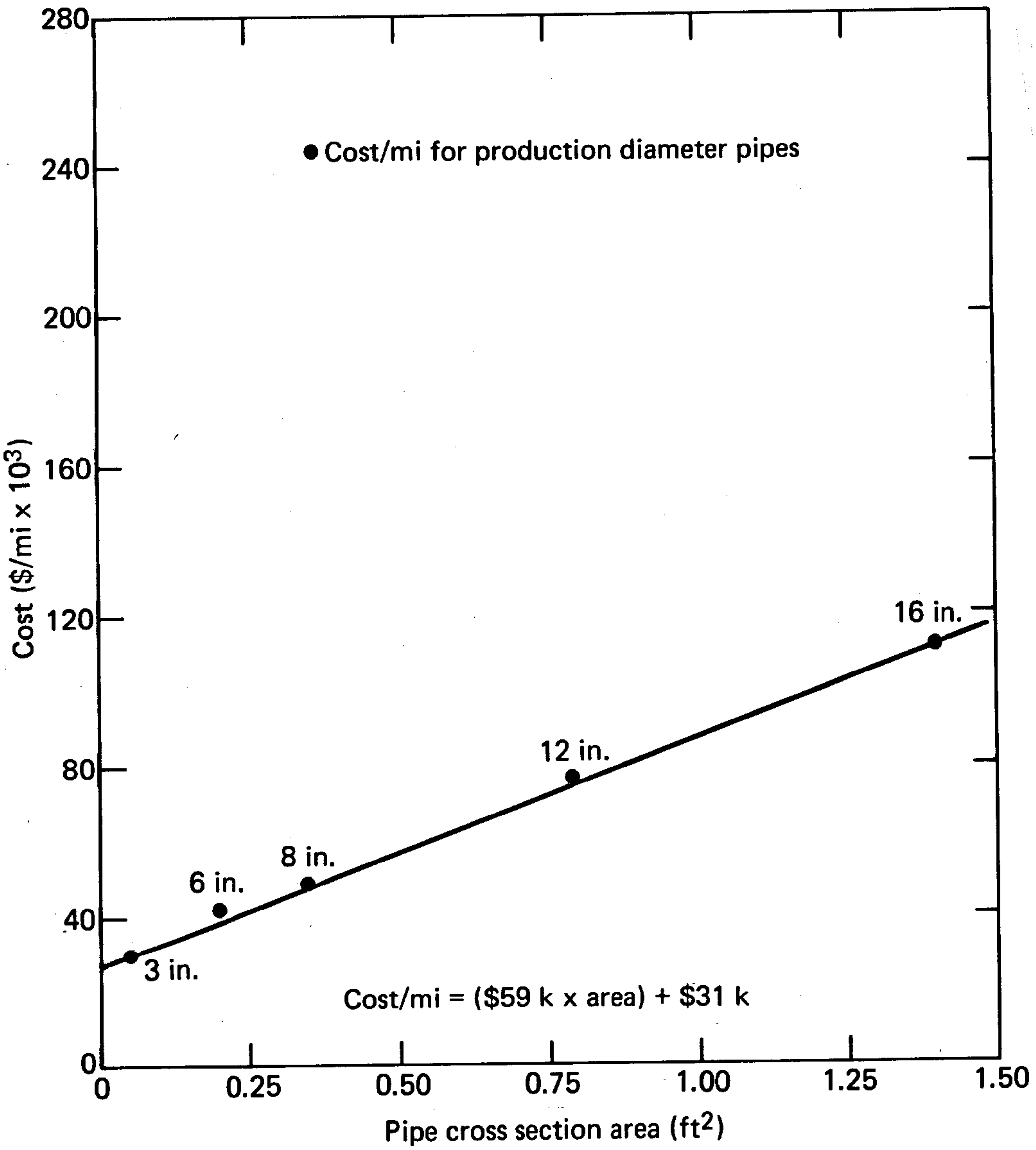


Fig. 4 Single (uninsulated) pipeline in western South Dakota (for reinjection).

Residential geothermal space heating cost is the sum of:

Item	Cost
Well cost	Number of source wells x $155 k
Reinjection well cost	Number of reinjection wells x $155 k
Heat exchanger cost and central facility	($71 x population) + $30 k
Distribution, hookup, and conversion cost	$745 x population
Transmission cost	[($119 x population) + $61 k] x miles
Reinjection transmission costs	[($50 x population) + 31 k] x miles

Number of source wells = integer value of (1.72 x population ÷ 1300)
Number of reinjection wells = integer value of (0.86 x population ÷ 1300)

Fig. 5 Total geothermal space heating cost.

Transmission distance = 2 mi
Transmission distance to reinjection well = 1 mi

Well cost = 2 wells at $155 k per well =	$310 k
Reinjection well cost = 1 well at $155 k per well =	$155 k
Heat exchanger cost = ($71 x population) + $30 k =	$101 k
Distribution, hookup, and conversion cost = ($745 x population) =	$745 k
Transmission cost = [($119 x population) + $61 k] x miles =	$360 k
Reinjection transmission cost = [($50 x population) + $31 k] x miles =	$ 81 k
Total cost	$1752 k

Fig. 6 An example of the cost model for a town with a population of 1000 (with a reinjection well).

LPG-fired, forced-air furnaces, however, is relatively inexpensive since existing ducts would be used for hot air distribution.

The conversion cost ($795 per house) includes bringing the hot water into the house, the home heat exchanger, inserting the heat exchanger into the distribution ducting, thermostat, and wiring for automatic control.

The fixed monthly costs, assumed to be 15% per year, include capital amortization, maintenance, and services.

Conventional fuel costs is an average of 1977 prices of fuel oil and liquid propane weighted by the amount of each fuel used for space heating.

D. Cost Model Results

Figure 7 is a plot of the cost model results. It illustrates that geothermal space heating systems become competitive with conventional systems for communities of about 250 persons or more. If reinjection is required the population would have to exceed 300. Reinjection will be desirable or mandatory for many communities, therefore the larger of the two preceding populations is the more likely dividing line for judging economic utility.

Figure 8 lists the South Dakota towns and cities that lie within the Madison boundaries and which have populations of 300 or more. Each of these communities, provided that its current and predominant heating is forced-air, appears to be a likely candidate for geothermal space heating conversion. The ever-present possibility of oil embargoes, increases in fossil fuel prices, and continuing devaluation of the dollar tend to make the conversion appear even more attractive.

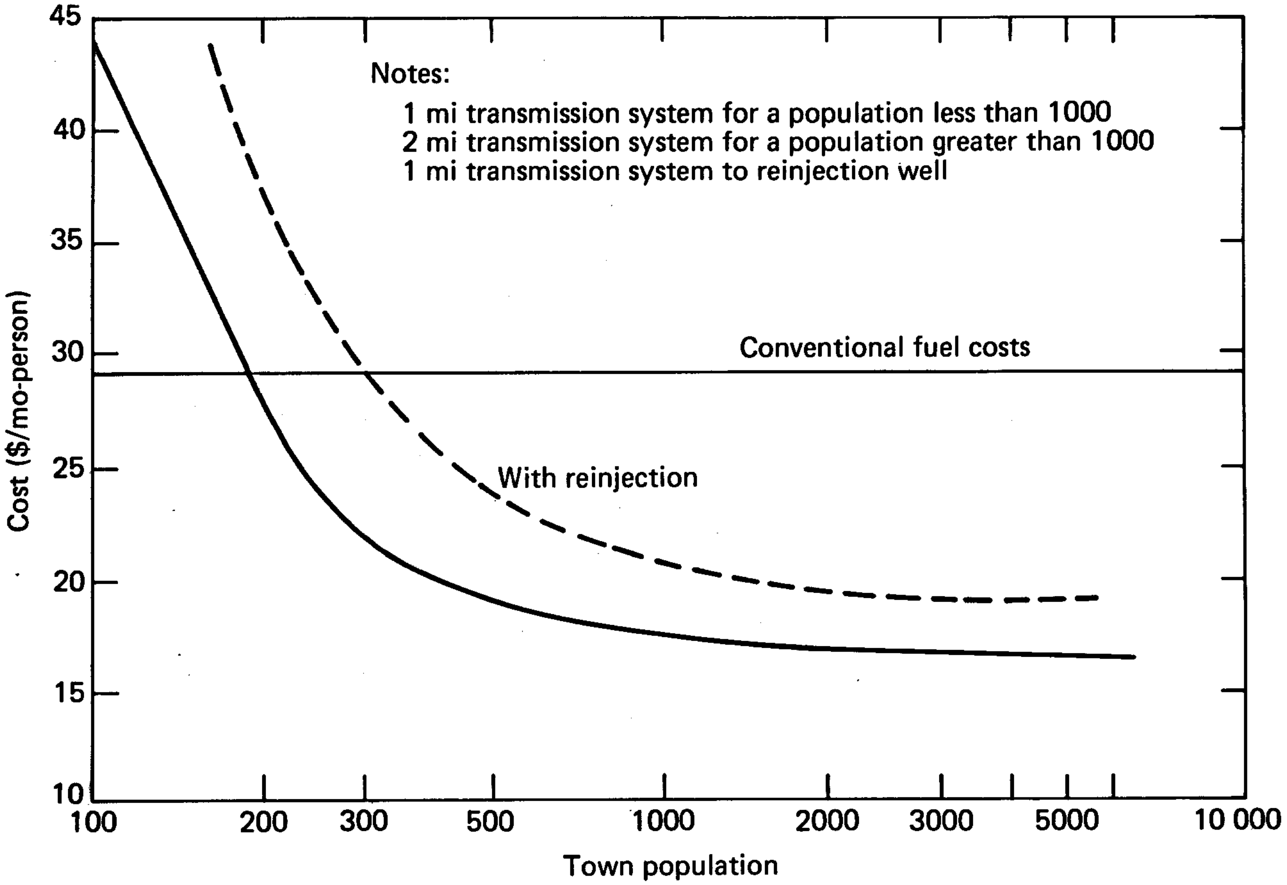


Fig. 7 South Dakota Madison geothermal space heating cost model.

Population	300 to 500	500 to 1000	1000 to 2000	2000 to 10,000
Towns	Bison Blunt Buffalo Hosmer Isabel Java Midland New Underwood Pollock Roscoe	Box Elder Dupree Eagle Butte Faith Herreid Hoven Kadoka Leola McIntosh Murdo Newell Onida Philip Selby Timberlake Wall Wanblee	Eureka Edgemont Fort Pierre Gettysburg Ipswith Lemmon Kyle	Mobridge Pierre Hot Springs

Fig. 8 Towns for which geothermal space heating is economically feasible.

VI. FINANCING GEOTHERMAL PROJECTS

As discussed in previous sections, the Madison is one of the better known geothermal resources in the United States. Hot water of good quality is available readily in many locales while in others, particularly in the northwestern part of the state, more precise reservoir and well data are needed and some innovative technology will probably be needed to demonstrate how their more corrosive waters might be exploited economically.

In these latter areas projects are better classified as developmental or demonstration rather than production and federal assistance may be available through Department of Energy grants or cost-sharing programs discussed below.

In all locales, communities that are contemplating geothermal space heating conversions are faced with project costs on the order of several million dollars. The most appropriate financing procedure may be municipal bond issues; for others, conventional loans. The federal government, through several of its Departments, offers assistance in loans and the guaranty of loans. Some of the more promising possibilities are cited below.

A. Department of Energy

1. Grant and Cost-sharing Programs

DOE provides grants and participates in cost-sharing programs to a limited extent for geothermal projects in the private sector. Projects of interest are made known to the public by Program Research and Development Announcements (PRDA) and Program Opportunity Notices (PON).

a. PRDA

Each PRDA solicits proposals for studies and analyses that will lead to new and improved technology for extracting and utilizing energy from geothermal resources. PRDAs are issued from the DOE San Francisco Operations Office and provide sharing of costs when a proposer could benefit independently from participation in a project. State, municipal, or noncommercial applicants are chosen on a competitive basis.

As examples, the South Dakota School of Mines and Technology responded to a 1976 PRDA and won support for a 12 month study of the Madison aquifer; the Edgemont School District responded to a 1977 PRDA and won support for designing a geothermal system for space heating its local school complex.

b. PON

A PON solicits proposals for geothermal field experiments and applications that will demonstrate the adequacy of the reservoir as well as provide technical and economic data, and will address legal, environmental, and institutional issues for assessing the practicability of further resource usage. PONs are issued from the DOE San Francisco Operations Office. Applicants are selected competitively and projects are funded through federal and local cost-sharing.

Of 22 proposals submitted in response to a 1977 PON, 8 were selected (4 in South Dakota). The 4 in South Dakota were to the School of Mines and Technology for heating ranch buildings and agriculture uses; to the community of Box Elder for heating the Douglas School complex; to the Haakon School District for heating school buildings in Phillip; and to the St. Mary's Hospital in Pierre for space heating the hospital and neighboring business structures.

2. Loan Guaranty Program

This program is intended to assist lenders in the private sector by guarantying them against loss of principal or interest on loans made for evaluating potential of geothermal reservoirs, for research and development in the technology of extracting and utilizing resources, for obtaining rights in resources, and for developing, constructing, and operating geothermal energy producing facilities.

The DOE San Francisco Office is responsible for supplying information on the program and for analyzing guaranty applications from South Dakota.

B. Department of Agriculture

Consultation with the Assistant Secretary of Agriculture for Rural Development established that the most appropriate participation of this department in a geothermal project would be for a loan or loan guaranty after engineering design and specifications for the project have been completed. Such loans or guaranties would be requested through the department's Farmers Home Administration.

1. Community Facilities Loans

Low interest (currently 5%) loans are made to qualifying communities for projects that supply essential facilities to rural residents. The funds are administered by the community. Applications for loans are made through the local Farmers Home Administration County Office.

2. Home Mortgage Loans

Moderate interest (currently 8.25%) loans to home owners are available for various types of improvement. The interest rate would be considerably lower for occupants of subsidized housing. Applications are made through the local Farmers Home Administration County Office.

C. Department of Housing and Urban Development

Block grants are available to towns on the basis of (a) home rehabilitation and (b) upgrading the standard of a utility. As above, grants would be for well engineered projects and any community grant application would be in competition with all other applications within the HUD region (region 8 for South Dakota). A major consideration in awarding grants is the inclusion of low income housing.

VII. TECHNICAL AND ADMINISTRATIVE ASSISTANCE

Few of the communities in the Madison area have the total resources needed to undertake a geothermal space heating project on their own; cooperation with and assistance from other state organizations and institutions will be mandatory. The primary ones and their areas of contribution are listed below.

A. Universities

The universities and colleges in South Dakota have been and will continue to be major contributors to the science and technology of geothermal application. The State University has established an Energy Department recently, and the School of Mines and Technology has been very active in geothermal research for some time. The latter institution has completed its comprehensive study and survey of the Madison with primary emphasis on space heating. This report, in addition to assistance already given to several communities, establishes the school as an effective state resource for developing further plans and proposals for geothermal heating.

B. District Planning Commission

The 5th and 6th District Planning and Development Commissions can provide administrative assistance to communities by informing them of available grants and cost-sharing programs for geothermal energy projects as well as working with community personnel to assure proper filing procedures. Legal advice is also available in the councils.

C. Water Conservancy Subdistricts

These organizations are concerned with surface and ground water issues, water conservation, and future water prospects for their areas of responsibility. Therefore, they should be aware of and involved in programs that tap major water sources so as to advise on handling waste water and on long term effects. The Black Hills Subdistrict, for example, has been consulted and has stated its interest and willingness to participate in geothermal project planning and development.

VIII. LEGAL ISSUES AND LAWS

Title 46 of the South Dakota Compiled Laws (SDCL 1967) addresses waters and water rights in the state. Chapter 46-6, specifically, is concerned with ground water and wells and clearly defines ground water as water under the surface of the ground "whatever may be the geologic reservoir in which it is standing or moving" (46-1-6). Artesian water and wells are included as one category of ground water and wells.

New statutes and amendments to previous statutes enacted through 1977 reflect interest in broader applications of ground water, but there is no specific reference to use of the heat content of ground water for beneficial use. Although it might appear that such water use is permitted by the existing South Dakota Laws, it is a point that legislators may be required to address explicitly.

A. Water Use

The people of the state have a paramount interest in the use of the state water but the state determines what water can be converted to public use (46-1-1) and the ways it should be developed for the greatest public benefit (46-1-2). Both surface and underground waters are listed explicitly. Section 46-1-3 declares that all water within the state is the property of the people but that the right to use may be acquired by legal appropriation. Furthermore, domestic use of the water takes precedence over appropriative rights (46-1-5) and the use of ground water by municipal systems is defined as domestic use (46-1-6).

1. Restrictions

A 1972 amendment (46-1-2) specifically limits the quantity of impounded water that can be withdrawn annually: it shall not exceed the quantity of the average estimated annual recharge.

2. Proposals and Permits

Proposals for the appropriation of ground water are submitted to the State Water Rights Commission for approval (46-6-3) prior to the issuance of well drilling licences (46-6-9). The commission is authorized (46-6-6-1) to adopt special rules for large capacity wells. As more precise data from test installations become available the commission should be able to further refine these rules and, as needed, have them submitted for inclusion in the legal code.

B. Appropriation of Water Use

Domestic use of ground water, when the user is a family, is one exception to the requirement for filing a proposal for appropriation to the State Water Rights Commission. Only notice of intent needs to be given. However, municipalities, nonprofit rural water supply companies, and sanitary districts must file a proposal. If the proposed usage rate is greater than 10 000 acre-ft per year, the commission must submit the proposal to the State Legislature for approval. This rate (33×10^8 gal/yr) is 5 to 8 times greater than the single-well flows assumed for community space heating requirements.

C. Beneficial Use of Water

As defined in 46-1-6, beneficial use is "any use of water that is reasonable and useful and beneficial to the appropriator, and at the same time is consistent with the interests of the public in the best utilization of water supplies."

As in all of the statutes concerning water and water rights in the state, no mention is made of water temperature or the potentially beneficial use of hot water or other geothermal fluids, vapors, and gases.

Various states have proposed or are drafting proposals for geothermal energy resources acts. The proposals or drafts seen to date define geothermal resources as different from water and minerals. For example, the Alabama proposal includes indigenous steam, hot water, and brines; the same plus other gases that might result from artifically introducing fluids or gases into geothermal formations; heat or other energy found in geothermal formations; and minerals that might be present in solution or association with the geothermal steam, water, or brines.

It is recommended, therefore, that the water and water rights statutes be examined to see if they are adequate to protect the geothermal resources and the rights to them, and thus permit their beneficial use.

D. Withdrawal from Aquifers

The 1972 amendment previously cited established a limit on the quantity of ground water that can be withdrawn. Since this is stated in terms of the average estimated recharge rate, it is important that more data be collected as soon as possible to improve estimates. It may be important also to consider the totality of geothermal resources as mentioned by other states in their proposed legislation, above.

E. Status of Indian Reservations

Standing Rock and Cheyenne River Indian reservations lie entirely within the boundaries of the Madison formation. Crow Creek, Pine Ridge, and Rosebud reservations lie partially within the boundaries. The Indians hold "reserved water rights" in the reservations (Winters versus U.S., 1908) and a set of regulations controlling use of reservation waters has been proposed (1977) for enactment by the Secretary of the Interior. The impact of these regulations on development of the geothermal resources remains to be determined.

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Appendix A

GEOTHERMAL SPACE AND HEATING COST MODEL

This Appendix contains the information used to develop a cost model for geothermal residential space heating. The cost model was determined to be a function of these eight basic components: source well cost, reinjection well cost, source transmission cost, reinjection cost, heat exchangers, distribution cost, hookup cost, and conversion cost. The cost of each of the eight basic components is illustrated on the following pages. These component costs are linearly related to population. To represent a typical municipality in western South Dakota a town of 120 residences with a population of 312 (based upon 2.6 people/residence) and distributed along the feedlines in Fig. 2 was used to generate the cost model.

SYSTEM DESIGN PARAMETERS FOR RESIDENTIAL SPACE HEATING

Average volume per house (ft^3)	8960*
Heat loss factor ($Btu/h\text{-}ft^3$)	7.7 †
Based on: 70°F inside design temperature -20°F outside design temperature Insulate roof only	
Heat load per residence (btu/h)	6.9×10^4
Transmission and distribution loss (%)	10
Future growth (%)	10
System design size (Btu/h)	9.9×10^6
Well flow rate (gpm)	1300
Well temperature (°F)	140
Well depth (ft)	3800

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* "Geothermal Application on the Madison Aquifer System in South Dakota, 6 months Progress Report", South Dakota School of Mines and Technology, March 1977.

† C. Strock, Handbook of Air Conditioning, Heating, and Ventilating, Industrial Press, New York, NY.
and
"CASES, Thermal Analysis of a Community, Task B Report", APL/JHU ltr, August 1977.

CENTRAL HEAT EXCHANGER DESIGN*

Design parameters

Design heat load (kcal/h)	2.5 × 10
Well water inlet temperature (°C)	60
Well water outlet temperature (°C)	40
Cold water inlet temperature (°C)	30
Cold water outlet temperature (°C)	55
Overall heat transfer coefficient (kcal/m^3-hr-°c)	3050
Logarithmic mean temperature (°C)	7.5
Heat transfer coefficient	2.9
Heat exchanger surface area (m^3)	110

Heat exchanger — plate type

Heating surface per plate (m^3)	0.53
Number of plates required	207
Maximum number of plates	320
Maximum heating surface (m^3)	170
Normal plate guage (mm)	1.0
Plate spacing (mm)	5.0 - 5.3
Maximum temperature of rubber gaskets (°C)	140
Suitable flow rate per channel (m^3/h)	4 - 8
Maximum flow rate recommended (m^3/h)	125
Maximum design pressure (atm)	15
Heat exchange surface	Stainless steel
Plate gasket material	Nitril

Heat Exchanger Cost*

$17 000

The exchanger is arranged for one pass on each side. Removable covers permit ready access for inspection and cleaning of heat exchange surface. The plate type heat exchanger is extremely reliable and easy to repair. Therefore a backup heat exchanger is not required.

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* American Heat Reclaiming Corporation, P.O. Box 860, 1181 U.S. Highway 202S, Somerville, NJ 08876.

RESIDENTIAL HEATING COIL DESIGN*

Design parameters

Design heat load (Btu/h)	6.9×10^4
Hot water inlet temperature (°F)	130
Hot water outlet temperature (°F)	93
Air inlet temperature (°F)	70
Air outlet temperature (°F)	117
Air velocity (ft/min)	600
Air flow rate (ft^3/min)	1485
Logarithmic mean temperature (°F)	9.9

Heating coil

Net finned area (in^2)	15 × 24
Number of rows	8
Number of fins per inch	14

Heating Coil Cost*	$342

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* Singer, Climate Control Division, 602 Sunnyvale Drive, Wilmington, NC 28401.

WELL COSTS*

			Unit Cost ($)	External Cost ($)
1.1	Mobilization	lump sum	5 000.00	5 000
1.2	12 in. diameter bore hole	1000 ft	19.00	19 000
1.3	9 3/4 in. diameter bore hole	2500 ft	16.00	40 000
1.4	6 1/2 in. diameter bore hole	300 ft	13.00	3 900
1.5	10 in. casing	1000 ft	13.50	13 500
1.6	7 in. casing	2500 ft	10.25	25 625
1.7	Electronic logging	lump sum	6 200.00	6 200
1.8	Cement grouting	lump sum	10 960.00	10 960
1.9	Well development and test pumping	lump sum	7 250.00	7 250
1.10	Pitless adapter	lump sum	3 500.00	3 500
1.11	Discharge piping	350 ft	5.50	1 925
1.12	Pump, motor, and appurtenances	lump sum	9 200.00	9 200
	Subtotal			146 060
2.1	Well house and appurtenances	lump sum	5 000.00	5 000
2.2	6 in. AC water line	30 ft	22.00	660
2.3	6 in. gate valve and box	1 each	620.00	620
	Subtotal			6 280
	Total Cost			152 340

* Francis-Meador-Gellhaus, Inc., 1823 West Main, Rapid City, SD 57701.

PIPE AND INSTALLATION COST

Cement Asbestos Class 150 Pipe

Size (in.)	Pipe Cost* ($/ft)
3	2.80
6	4.46
8	5.45
12	8.70
16	13.70

1 in. on-site foam insulation $0.75/ft^2 †

Installation Costs**

Excavation Costs	2.63
Back Fill Costs	0.42
Compact Costs	6.14

Assumptions †

Compact only across roads

Bury pipe 5 ft deep

Feedpipe insulated

Return pipe uninsulated

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* 1977 Dodge Guide, McGraw-Hill Information Systems, 1976.

† Telephone Conversation with R. D. Sanders, Idaho National Engineering Laboratory, Raft River Project, 20 October 1977.

** C. Engelsman, 1977 Heavy Construction Cost File, Van Nostrand Peinhold Company, 1977.

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