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GEOTHERMAL DISTRICT HEATING SYSTEM
FEASIBILITY ANALYSIS
Thermopolis, Wyoming

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I. SUMMARY

Thermopolis, Wyoming is located in the Bighorn Basin region of north-central Wyoming. The service population of the Thermopolis-East Thermopolis area is about 4,400 people. Historically, the regional economy has been closely tied to the utilization of its natural resources; agriculture, mining, and oil exploration and production have all been regional economic factors. Hot water utilization dates back to the initial decades of the twentieth century both in the use of private wells and through the development of Hot Springs State Park. Currently there is a new interest in exploring how to best develop the hot water resource for use in a district heating system. The purpose of this study is to determine the technical and economic feasibility of constructing and operating a district heating system to serve the residential, commercial, and public sectors in Thermopolis.

The project geothermal resource assesment, based on reviews of existing information and data, indicates that substantial hot water resources likely exist in the Rose Dome region 10 miles northeast of Thermopolis, and with quantities capable of supporting the proposed geothermal uses. Water temperatures of 160⁰F are expected at estimated depths of 1,000 feet. The water quality for district heating application is comparatively good; the geothermal water supply system will be kept under pressure to mitigate scaling and corrosion potentials.

Preliminary engineering designs were developed to serve the space heating and hot water heating demands for buildings in the Thermopolis-East Thermopolis town service area. The heating district design is based on indirect geothermal heat supply and includes production wells, transmission lines, heat exchanger units, and the closed loop distribution and collection system necessary to serve the individual customers. Three options are presented for disposal of the cooled waters--reinjection, river disposal, and agricultural reuse.

The preliminary engineering effort indicates the proposed system is technically feasible. The design is sized to serve 1,545 residences, 190 businesses, and 24 public buildings. The peak design meets a demand of 128.2 million Btu at production rates of 6400 gpm. The system's annual

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energy consumption is 320,000 million Btu. Total system costs are estimated at \$13.6 to \$15.75 million in 1982 dollars.

Economic analyses of both private and municipal development indicate that delivered energy costs for a geothermal system will be significantly less than for conventional gas fuels. The economic analyses were run for geothermal prices set initially at 80% of the equivalent cost for natural gas in 1985; thereafter, geothermal prices were escalated at 8% per year, even though gas prices increase more rapidly. Interest rates were varied between 8% and 15%, depending on the financing and the type of development under consideration.

For private, venture capital development, the discounted rates of return ranged from 12.5% to 24% for the different options. Private development by a regulated utility, combined with issuance of industrial revenue bonds to obtain lower interest rates, provide rates of return of 17.6% to 18.7%. This return should be sufficient to attract utility company involvement. Two approaches were evaluated for municipal development of the energy system. For both cases a utility reserve fund was established equivalent to a 9% rate of return. With 12% bond financing, the geothermal energy could be priced at 78% to 86% of the initial 1985 price of natural gas. If an 8% State loan is assumed for project financing, the geothermal energy could be priced at 70% to 75% of the natural gas.

Finally, for private-municipal joint development, where Wyoming Water Development Commission grant funding is assumed, project rates of return were excellent and ranged from 32.2% to 38.6% of the invested equity, based on initial geothermal pricing at 80% of the expected natural gas cost. An aggressive City effort to obtain this State funding either in the form of a one-time grant or for low interest financing, is recommended.

Study results indicate there is substantial incentive for the Town to pursue the long-term development of a geothermal system. For the cases analyzed and where geothermal energy pricing was set at 80% of the projected natural gas pricing, the typical Thermopolis resident would experience savings of over \$11,000 in 1982 dollars over the 25-year life of the system.

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The institutional and environmental analysis indicate that additional hydrological testing and evaluation will be necessary to obtain the water rights to serve the system. Also, environmental permits to either reinject the cooled fluid or to discharge the cooled waters to the Bighorn River will need to be obtained from the Wyoming Department of Environmental Quality. Finally, Federal geothermal leases will need to be obtained from the Bureau of Land Management which manages the Rose Dome production site. Based on communications with the State Water Engineer's Office, the Wyoming Department of Environmental Quality, and the Bureau of Land Management, these permits should be obtainable given proper planning and application. Initial hydrological study results indicate that the Hot Springs State Park and currently existing wells will not be affected by the proposed action; this is to be confirmed in current and future hydrologic investigations.

The proposed system is a major undertaking for a town of Thermopolis' size. Since there will be uncertainties involved about the exact nature of the geothermal reservoir until more hydrological and geological analysis is done, a staged project with a smaller first step might facilitate the development of public support and the obtaining of outside funding from public or private sources. Therefore, a primary recommendation of this study is that a staged project development should be considered and that a thorough hydrogeological analysis be performed on the potential geothermal production field located immediately north of town; this could be done concurrently with hydrologic investigations of the proposed Rose Dome production site.

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II. INTRODUCTION

A. Physical Setting

The town of Thermopolis, Wyoming is situated in the Bighorn Basin, in Hot Springs County, in the northwestern part of the State. Its location, shown on Figure 1, is just north of the Owl Creek Mountains. The city is at the junction of State Highway 120 and U.S. Highway 20, on the western bank of the Bighorn River. The city of Casper is about 130 miles, by road, to the southeast of Thermopolis. Air service to Thermopolis is by regional lines through Worland or Riverton.

The Bighorn River forms the eastern border of the city, and part of the southern border before it loops south and east again. Across the river is the small town of East Thermopolis which also contributes to the local work force. Northeast of town is the State-owned Hot Springs State Park, as shown on Figure 2. Several buildings that would be served by the district heating system, including the high school, grade school and hospital, are actually located on State Park land. The residential growth of Thermopolis tends to be to the west, where the land begins to rise relatively rapidly. The highest point that would be served by geothermal heat is about 200 feet above the river, which is the lowest point. *note*

The general climate tends to be cold, with an average of 7,248 degree heating days per year. Low temperatures can be in the range of -25°F to -35°F . Periods of up to a week at a time during which temperatures remain near their lows are not an unusual occurrence. The heat loads for space heating will vary significantly on a seasonal basis.

The county population has varied between 5,000 and 6,000, with some fairly large swings up and down, since about 1930. A large decline occurred from about 1959 to 1975, but the growth since then is expected to take the population to about 7,000 in 1985. The city itself has experienced a more steady population growth in recent years. The increase from 1970 to 1980 averaged almost 2% per year, with most of it occurring in the last half of the decade, to a population of about 4,000 in 1980. The expected continued growth rate of 2 to $2\frac{1}{2}\%$ would bring the population to 4,400 to 4,600 in 1985. The population of East Thermopolis, which would also be served by the heating district, is about 500.

LEGEND

○ Places of 25 000 to 50 000 inhabitants

U.S. DEPARTMENT OF COMMERCE
SOCIAL AND ECONOMIC STATISTICS ADMINISTRATION
BUREAU OF THE CENSUS

Figure 1. Location of Thermopolis in Hot Springs County, Wyoming

The Chicago, Burlington and Quincy Railroad cuts through the east side of town, passing along the industrial sector which was once the site of a small oil refinery; this area would be the probable location of an industrial park, should one be built, that could be a potentially relatively large, year-around user of geothermal heating. The business sector runs roughly through the center of town, while residential sections spread out on both sides, but mostly to the west of the business district. The largest consumers of energy for space heating, such as schools, clinics and hotels, are to the east.

B. Review of the Regional Economic Base

oil & gas

Thermopolis is oriented primarily towards agriculture, which implies that the most probable growth of a geothermal-inspired industry would be centered around agribusiness developments. This could include such activities as greenhouses or mushroom growing facilities whose primary heat load would be for space heating, or vegetable drying facilities for which process heat would be the major energy consuming activity. Such developments would greatly increase the economic attractiveness of a district heating system, because their heat loads would be more constant during the year, and would thus provide a better economic base for amortization of the capital investment than does residential heating.

1000000

The major employers in the city are two industrial concerns and two health care facilities. The Wyo-Ben Company, a maker of bentonite, employs about 175 people; TRW Reda Pumps, a pump manufacturer, employs about 100. The Basin Children's Clinic employs about 55 and the Gottsche Rehabilitation Center employs about 20 people.

The major industries within the county as a whole are involved with agriculture, forestry and fisheries, retail trade, mining and construction. These industries contributed about 85% of the total economic base in 1979, with the bulk of this support coming from mining and the agriculture and forestry sectors. In the same year, the county registered a total employment base of over 1,600 persons, while less than 40 were counted as being unemployed.

C. Brief Review of the Present Geothermal Base and its Usage

There is an abundant evidence of geothermal activity in and around Thermopolis. This is manifested by natural hot springs, by hot water wells of which many exhibit artesian flow, and by high bottom hole temperatures measured in a large number of oil and water wells. The largest evident geothermal activity is within the Hot Springs State Park where seven hot springs are located. The natural flow rates of these springs range from just a trickle to almost 3,000 gallons per minute. Their temperatures at the surface range from less than 100°F to over 130°F; the temperatures at the underground heat source are probably higher.

There are also four working hot water wells north of and close to the park. Drilled to depths between about 500 and 1,000 feet, they all produce hot water in artesian flow at rates that range from a few hundred to about 1,000 gallons per minute. Temperatures are in the 120°F to 130°F range.

The hot water from the wells has been used in a limited way for a number of years. One well provides irrigation water, but this water must be allowed to cool before being used. In other cases, the hot waters are used for heating the owner's homes or swimming pool waters. The heating systems are simple and straightforward, with the water passing through heating pipes beneath the floor. Scale formation and corrosion is a potential problem due to the chemistry of dissolved salts in the water. To prevent this problem, the pressure, temperature and flow velocities of the waters must be properly controlled from production to discharge or appropriate chemical treatment of the waters must be employed, and appropriate materials of construction must be used.

D. Project Objectives

The objective of this study is to provide a preliminary determination of the technical, economic, and institutional feasibilities of establishing a geothermal district heating system to serve the residential, commercial, and industrial sectors of Thermopolis. Two primary tasks have been to decide which of three possible sources of hot water should be used, and how much of the town should be served by the district. On the basis of initial, rapid design calculations and preliminary hydrological data that

were developed for the town by others, the Geothermal Work Group selected the bases for this preliminary feasibility study. These bases are that geothermal wells will be developed at the Rose Dome site about 10 miles northwest of town, and that essentially all of Thermopolis and East Thermopolis would be served. This provided the framework for the remainder of the analysis reported here. Preliminary calculations were made for pipeline routings, line sizes and materials of construction, well and pumping requirements, heat exchange requirements, and other design aspects. System costs, revenues, and rate of return were estimated for various options of design, operation and financing. The design that was developed should be reasonably close to the final, optimized design that would be developed should the decision be made to proceed with construction of the system according to these bases. Before finalizing the design, it would be reasonable to reexamine the bases to determine if a smaller system, or a system constructed in stages, perhaps initially using other well fields, would not provide a better overall rate of return. } out

III. THE THERMOPOLIS GEOTHERMAL RESOURCE

This chapter discusses the geologic and hydrologic information that serve as the basis for utilizing the Thermopolis hot water resource for district heating applications. The resource information in this chapter is drawn largely from work performed by the Department of Geology at the University of Wyoming (14) and summaries of that work by Marcotte (35). Section A is a summary of the geology and hydrology descriptive of the regional resource. Section B describes the three alternative production sites considered during the study and discusses the rationale for the selection of the Rose Dome site to serve the designated town service area. Reinjection considerations are also discussed here. Section C discusses the expected geothermal water chemistry and its impact on design considerations for the proposed system. Finally, Section D discusses water rights requirements, potentials for utilizing downhole heat exchangers, and Bureau of Land Management leasing considerations.

A. Regional Geology and Hydrology

Thermopolis, located in the Bighorn Basin of northwest Wyoming, is the site of Hot Springs State Park where numerous hot springs produce a total of 4,900 gallons per minute of 125°F to 130°F water. These springs along with five additional wells located to the north of the State Park are shown in Figure 2. The wells are artesian flow and at temperatures similar to those of the springs. They are currently used for space heating, water heating, and irrigation purposes. Many other oil and water wells have been drilled in the Thermopolis region. Hinckley et al. (14) collected and interpreted bottom-hole temperature and depth data and formation water analysis data from oil wells and water wells, and also conducted field thermal logging in efforts to establish a regional picture of the thermal mechanism governing the Thermopolis resource.

In a geologic terminology, the present springs, as well as numerous previous occurrences, are located at the crest of the Thermopolis Anticline. This is an asymmetric fold, much steeper to the south, which plunges east and northwest from Thermopolis. The anticline appears to be broken along its axis by a major basement fault and by smaller transverse faults which

Figure 2. Location of Hot Springs and Flowing Wells in Hot Springs State Park Area (after Breckenridge and Hinckley, 1978, with additions).

dissect the anticline into a series of domes. From the crest of the anticline, exposing Permian and Triassic formations, strata up through Cretaceous dip steeply southward into a sharply folded syncline, then rise gently up the north flank of the Precambrian-cored Owl Creek Mountains.

Analysis of thermal data reveals that temperatures of up to 161°F occur along the crest of the Thermopolis Anticline. Thermal gradients along the anticline range from 43°F to 300°F/1000 ft in contrast with gradients of around 15°F/1000 ft for areas to the north or south. In addition to this low temperature hydrothermal resource area (approximately 30 miles²) along the Thermopolis Anticline, gradients of 15°F to 51°F/1000 ft suggest a marginal resource in the Red Spring Anticline area 8 miles east of Thermopolis. Well temperatures appear to be highest along the center of the anticline. The center runs from East Warm Spring (east of Thermopolis) to West Warm Spring, Condit's Dome, Cedar Ridge (west of Thermopolis) and Rose Dome. For example, the higher temperature of Big Spring (133°F) gives way to somewhat lower temperatures (129°F) in the wells north of the State Park. Another illustration of this point is Rose Dome area temperatures of 161°F in contrast to wells slightly north which exhibit temperatures of 120°F to 130°F. An increase in well temperatures is also evident from east to west. East Warm Spring at the easternmost end of the anticline shows temperatures of 101°F. Continuing west, Condit's Dome measures 106°F, Cedar Ridge 126°F to 145°F at the southeast end of Rose Dome, and temperatures of 150°F and 161°F further west on the Rose Dome site. The approximate geographic location of the anticline is illustrated in Figure 3.

Hydrologic investigations indicate that waters discharging at Hot Springs State Park enter upper Paleozoic aquifers which outcrop in the mountains to the south. These waters are confined by relatively impermeable Triassic siltstones and mudstones and flow under artesian pressure through the intervening syncline to surface along faults breaking the crest of the Thermopolis Anticline. The major aquifers for the Thermopolis geothermal system are the Permian Park City Formation (mostly limestone), the Pennsylvanian Tensleep Sandstone, and the Mississippian Madison Limestone. The Flathead Sandstone of Cambrian age may also yield hot waters, though at considerably greater depths. Chemical comparisons between identified

GEOLOGIC AND THERMAL DATA FOR THE THERMOPOLIS ANTICLINE 1980

Figure 3.
Source: After King, et al. 1980.

aquifer waters and the Thermopolis hot springs suggest the Madison Limestone is the major water source, though contributions from overlying units are likely. Potential yield generally increases from the Park City Formation to the Tensleep Sandstone, and again to the Madison Limestone. Individual wells into the Madison Limestone in the southern Bighorn Basin have produced nearly 3000 gpm. Existing hot wells, less than 1000 feet deep, in the area just north of Thermopolis flow up to 1000 gpm from the Park City Formation. A generalized cross section indicating the geology of the anticline is shown in Figure 4. For a more detailed geologic discussion the reader is referred to Hinckley et al. (14).

That geothermal waters are mixing between the upper formations along the Thermopolis Anticline is demonstrated by isothermal conditions in drill holes, homogeneous chemistry, and similarity of hydraulic head. Thus, drilling deeper than that necessary to secure adequate flows is unlikely to produce significantly higher temperatures, higher pressures, or superior chemical characteristics. Waters within this geothermal reservoir are similar in composition to the existing springs. Geothermal water chemistry is discussed in greater detail in Section C.

Deep circulation of water seems to be the most feasible explanation for thermal waters. It is believed that water descends the northern flank of the Owl Creek anticline in the aquifers. It moves down into an asymmetrical syncline (see Figure 5) immediately south of the Thermopolis Anticline. As the water descends into the syncline it is heated and reaches its highest temperature at the deepest point of its journey. A fault in the Precambrian basement rock could provide even deeper circulation and higher temperatures. Possible faults and fractures on the south flank of the anticline could facilitate water movement and increase permeability and allow water to rise rapidly with minimal loss of temperature. Flow and heating models indicate that the maximum temperatures likely to be produced from the system at reasonable drilling depths are 140°F in the immediate vicinity of Thermopolis, and 170°F in an area 8 miles to the northwest. Artesian pressure appears to be sufficient to ensure surface flow for wells in a broad area along the Bighorn River south and north of Thermopolis.

In summary, significant hot water resources, with extensive surface manifestations, are apparent in the Thermopolis area. Actual downhole

GENERALIZED CROSS-SECTION OF CEDAR MOUNTAIN ANTICLINE HOT SPRINGS COUNTY, WYOMING

Figure 4. Geologic cross-section through Cedar Mountain anticline

Jon King

Source: King, et al. 1980.

Owl Creek
Mountains
(recharge area)

Thermopolis
Anticline

POTENTIAL PRODUCTION SITE

Figure 5. Diagrammatic Cross-Section of Thermopolis Hydrothermal System (temperatures and depths from Rose Dome thermal model).

temperature data ranging from 125°F to 160°F from existing wells are documented. The principal hot water-producing aquifer is likely the Madison aquifer and flows from the Madison are normally good to excellent. This is evidenced by the strong and consistent flows at the Hot Springs State Park. Given the above, the geothermal resource basis for supporting district heating system applications is strong.

A principal question associated with proposed geothermal uses in the Thermopolis region is the effect which geothermal water withdrawal may have on the State Park hot springs. The definitive data necessary to answer those questions currently are not available. Potential effects on State Park flows can probably be minimized by siting production distant to the springs--such as near the Rose Dome region. The extent of communication between the reservoir there and at the Park is not known, however. Additional data will be forthcoming in the current hydrologic studies which are being conducted in parallel with this technical and economic evaluation. Still additional data would be necessary prior to obtaining the water rights necessary to supply the proposed system. The issue of interference with existing private wells and with the Park water flows is a very important one. The necessary hydrologic data will need to be obtained prior to the final design activities to insure complete protection of all existing property rights and statutory rights.

B. Geothermal Production Site Selection

The nature and extent of the geothermal resource provides the basis for the design and economic feasibility for a geothermal district heating system such as proposed for Thermopolis. For that reason, the resource assessment is very important to the economic feasibility of the entire project. A comprehensive resource assessment includes estimates of water quality, water temperatures, production rates, depth to production, areal extent of the reservoir, the reservoir source mechanism, and the physical setting.

In cooperation with University of Wyoming personnel, three possible geothermal resource production sites were identified and, to the extent possible based on existing data, the resource characteristics expected at

each of those sites were established. The production site options are: (1) Thermopolis townsite; (2) Cedar Ridge near Owl Creek; and (3) Rose Dome. The approximate locations for these sites are illustrated in Figure 6.

The Thermopolis townsite is located 0.35 miles directly north of the Thermopolis city limits near the airport runway. The estimated water temperatures at this site are 130°F with estimated production rates of 750 gpm per well. Well depths are estimated at 700 feet. The principal advantage of the Thermopolis site is its proximity to the actual users; therefore, a relatively short transmission pipeline would be required to transport the geothermal waters from the wells to the town. The negative features include the comparatively low water temperatures, 130°F, which require larger geothermal flows. It is also the closest site to Hot Springs State Park and there is greater potential for close communication with the natural flows at the Park.

The Cedar Ridge site is located 4.6 miles northwest of the Thermopolis city limits adjacent to Owl Creek. This is the site originally proposed by the University of Wyoming team for the hydrological test program which is being conducted concurrently with this study. Water temperatures at Cedar Ridge are estimated at 145°F with production rates of 750 gpm per well. The required well depth is 500 feet. Flows will have to be pumped from a depth of 200 to 400 feet. An 11 1/2 to 13 3/8 inch casing will be required to set the pump for those production rates. In summary, the Cedar Ridge site would require a medium length pipeline to deliver the water to the town. Water temperatures are moderately acceptable and water quality is estimated to be reasonably good from this site. It is located farther from the State Park which, intuitively at least, represents potentials for lesser impact on the flows at the State Park. The transmission line routing to the town would follow Highway 120 which runs to the northwest of Thermopolis.

The third site considered for geothermal production is the Rose Dome site. This site is located 9.75 miles northwest of the Thermopolis city limits, thus requiring a longer and more expensive pipeline for transmission of the fluids into town. Estimated water temperatures are 160°F with estimated water production rates of 750 gpm per well. The required well depth is 900 feet. Flows will need to be pumped from depths of approximately 500 feet. Again, an 11 1/2 to 13 3/8 inch casing will be

Figure 6. Production Site Options Considered for the

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required to set the pump for producing the required flows. The 160°F water temperature is very important and requires only one-third of the flows that would be required from the Thermopolis site, due to the fact that three times as much heat can be extracted from each pound of water at this higher temperature.

The significance of the above discussion is that these data, in conjunction with proposed service area energy loads, facilitate the selection of the production site to be used as the basis of the technical design and economic analysis. The following comments are relevant regarding the selection criteria:

- The size of the Town service area fundamentally determines the heat load served by the geothermal system and also the required water flows from the geothermal production sites.
- All three production site options appear to be technically feasible for providing hot water supply to the proposed Town district heating system.
- Preliminary hydrologic reports indicate there is strong possibility of communication between the north Thermopolis production site and the State Park hot springs. High water withdrawals without reinjection might, therefore, impact the existing springs and wells.
- Hydrologic data to confirm whether reinjection of the used waters would effectively mitigate any possible impact on existing wells and Park spring flows is not yet available.
- For the option where the entire Town is served by the district, the Rose Dome and Cedar Ridge sites could likely supply the necessary waters. The north Thermopolis production site would not be recommended for this large service area option because of the high flows required due to its low resource temperature.
- For a downtown Mini-District, the north Thermopolis production field, accompanied by reinjection, may be realistic. Further hydrologic analysis would be required to confirm this fact.
- The Rose Dome field's higher water temperature would be a more attractive heat energy supply to attract light industry and associated employment to Thermopolis, than would the two other sites exhibiting lower resource temperatures.
- Due to its location, the Rose Dome site option represents less overall potential for impacting existing water uses.

The Thermopolis Advisory Work group reviewed the above criteria, and selected the Rose Dome production site and the entire Thermopolis-East Thermopolis

service area to be the basis for the design and economic analysis of the system.

Subsequent to the Rose Dome production site selection, University of Wyoming personnel and their consulting hydrologist have recommended a reinjection site approximately 2 1/3 miles northeast of Thermopolis for disposal of the cooled waters. This specific geographic site was chosen principally on the basis of its low potential for impact on the State Park springs and existing wells. The location of the proposed reinjection is shown in Figure 8, Chapter V. Hydrologic data describing the proposed reinjection field region is limited. Additional hydrologic investigations will also need to be performed in this region to confirm its suitability to adequately accept the proposed water flows.

C. Water Chemistry Consideration

This section discusses the water chemistry of the proposed hot water production near Thermopolis. Specifically identified are those aspects of the chemistry which might affect the processing of the geothermal fluid and which may be of environmental concern. Additional discussions regarding environmental requirements are given in Chapter VII.

Inasmuch as new wells may access water from the same aquifers as existing wells and springs, the water chemistries from existing sources were used to estimate the expected water chemistry for the study area. The water analysis data considered are presented in Table 6. Due to the similarity in chemistries between the Rose Dome, Cedar Ridge, and State Park hot springs regions, and to the more detailed chemistry information available from existing hot sources, these data were used as the basis for the following discussion.

There are concerns about the accuracy of the water chemistry analyses--none of which preclude successful and economic development of the anticipated production area. These concerns become factors which influence design and processing choices, and are discussed separately in the following paragraphs.

1. Scaling Tendency--The water chemistry as given in Table 1 suggests that calcium carbonate scale may form in fairly substantial amounts. Further we are aware that calcium carbonate deposition has been a problem in certain

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Table 1. EXPECTED WATER CHEMISTRY FOR THE
THERMOPOLIS STUDY AREA ^{1,2} (14)

	Production Areas	
	Rose Dome and Cedar Ridge (Madison)	Thermopolis Townsite (Hot Springs and Wells)
Ca	318	353
Mg	86	81
Na + K	230	299
HCO ₃	697	734
SO ₄	743	754
Cl	223	301
TDS	1950	2317
Na	--	249
K	--	51
CO ₃	--	0
F	--	4.8
NO ₃	--	0.04
SiO ₂	--	40
S	--	0.001
B	--	0.54
Fe	--	0.2
pH	--	6.9
H ₂ S	--	2.7
As	--	< 0.05
Cu	--	< 0.01
Mn	--	< 0.05
Zn	--	< 0.02
Ba	--	< 0.5
Cd	--	< 0.01
Cr	--	< 0.1
Pb	--	< 0.1
Sc	--	< 0.001
Ag	--	< 0.5
Hg	--	< 0.001
Ni	--	< 0.1

¹ Values stated are mean values in mg/l.

² Number of samples varies from 2 to 14.

existing wells in the Thermopolis area. In the Thermopolis situation, we view the occurrence of calcium carbonate scale as being associated with a reduction in pressure which allows CO_2 gas to escape from the fluid. This, in turn, causes the pH to rise and the three carbonate species present in the fluid, $\text{CO}_2(\text{aq})$, HCO_3^- , and $\text{CO}_3^{=}$, to increasingly convert to the $\text{CO}_3^{=}$ species. With calcium readily available, calcium carbonate precipitate results. Scaling may be prevented, however, by maintaining a pressure over the fluid, such that the CO_2 gas is kept dissolved in the solution and the pH is kept low enough to prevent formation of significant amounts of the $\text{CO}_3^{=}$ species. Experience with similar situations elsewhere confirm this, and there are some indications from the Thermopolis area supporting this contention. Some wells in the Thermopolis area are producing under slight pressure and do not appear to have scaling problems. Also, the chemical analysis determinations resulting in the water chemistry of Table 1 were made from samples not taken under pressure.

Pressurized samples of the wellhead fluid, providing no scaling has taken place, would reveal the true total concentration of carbonate species in the brine. This, together with a downhole pH measurement, would enable calculation of the distribution of the carbonate species at downhole conditions. This should indicate that there is no scaling tendency. Such measurements would also allow determination of the pressure necessary to keep the CO_2 gases in solution. We have made preliminary estimates of this pressure that are in the range of 25 to 40 psia, or an average of about 32.5 psia (about 75' water).

It is our opinion that keeping the geothermal fluids under pressure will avoid scaling problems. At the disposal end of the process, if pressure is released, scale may form. This could be the case for the irrigation and river disposal options, as well as for the injection option.

2. Hydrogen Sulfide Concentration and Corrosion--The chemistry data give a value of nearly 3 ppm H_2S . This amount is enough to cause a nuisance odor and it prevents use of copper tubing and fittings. Carbon steel pumps and piping will be acceptable if oxygen is prevented from entering the system.

Corrosion is greatly enhanced by the presence of oxygen. If the fluids never contact air then this possibility is minimized. This may be

accomplished by operating the process under a pressure greater than atmospheric pressure at all points in the system. In addition, keeping the system under pressure will keep H_2S gas from escaping, and the possible odor problem will also be avoided.

3. Environmental Aspects--In addition to the H_2S concentration mentioned, the geothermal fluid exhibits other characteristics to consider further from an environmental concern. For river disposal, these characteristics include total dissolved solids, sulfates, fluorides, and the temperature of the fluid. For disposal as irrigation water, important characteristics include the total dissolved solids level and temperature. Additional discussions regarding environmental factors are presented in Chapter VII.

4. Summary--The analysis provided is based on water chemistries anticipated in the production area. Samples should be taken from the actual drilled wells to substantiate this basis. These samples should be taken under pressure.

System operation under enough pressure to prevent CO_2 from escaping the fluid should prevent calcium carbonate scaling from taking place within the process equipment. It further helps to minimize corrosion because oxygen would then not get into the system. Post-drilling fluid samples taken under pressure, along with a downhole pH determination, will allow better determination of this minimum design pressure. Due to the presence of H_2S , copper tubing and fittings should not be used in the piping carrying the geothermal waters.

D. Water Rights and Resource Leasing Requirements

1. Water Rights--Water use patterns and water rights in Wyoming are governed by Appropriation Water Law. Essentially, the first party to utilize the water resource for beneficial use establishes a water right. Water rights established junior to that original use may not infringe upon the rights of those holding senior rights to continue to utilize the resource. Thus, water rights are considered property and as such may be purchased for compensation or traded. Heat extraction is considered a beneficial use in Wyoming; also, generally speaking, the Madison aquifer

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is not over appropriated in the Thermopolis region (52). Therefore, given no other impacts to existing wells or springs, it would be possible to establish adjudicated rights on the geothermal waters to be used in the new district heating system. The existing wells near the State Park do have water rights substantially senior to the proposed geothermal use and the State Park springs are protected by statute. Therefore, prior to being assigned an official right to produce the required water quantities, project activities will have to demonstrate that injury will not occur to those sources.

The process for demonstrating that fact will be rigorous and time consuming. An Application for Permit to Appropriate Groundwater will need to be filed (52). Production estimates are filed at that time and that filing data establishes the date of use for water rights purposes in the future. The protection of existing uses is a visible concern in the Thermopolis region. To develop the necessary hydrological information such that both the legal sector and the public concerns are adequately addressed, a two-year \$500,000 hydrological program will likely be required (60). As part of this effort, two full-size production wells would be drilled and four to six observation wells would be drilled in the Rose Dome area and also in the Cedar Ridge and Thermopolis town areas; the production wells would then be pumped at flow rates encompassing expected production flows while the observation wells are monitored to ascertain whether any impact exists. The results of this testing would be filed with the Wyoming Office of the State Engineer in the Statement of Completion and Description of the well; a public hearing would also probably be held. If the State Engineer concludes no injury will occur, the water right is then granted the applicant.

For the Thermopolis circumstance, we would recommend the Town obtain the necessary rights or be substantially along in the hydrological testing prior to committing to the final design and subsequent construction of the proposed district system. Additional hydrological data will also be required to confirm aquifer characteristics of the reinjection field. Again, those characteristics should be defined to the greatest extent possible prior to the commitment to proceed with detailed engineering steps. In a positive note, the two production sized wells drilled during the hydro-

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logical confirmation phase could be integrated into the well field, thereby reducing by two the number of wells drilled in the well field development steps. The hydrological testing-water rights costs are not included in the capital cost estimates of the proposed system.

2. Bureau of Land Management Leasing--The Rose Dome resource area is on Federal land managed by the Bureau of Land Management (BLM) and consequently a lease must be obtained for development and use of the resource. The procedures and requirements for obtaining and exercising a lease are only slightly different for the cases of a municipal lessee and a private lessee. For the municipal case the town must enact a resolution authorizing it to hold a geothermal lease. An application is then submitted for the lease of the geothermal resource. Prior to the lease being issued, the BLM performs a geophysical/geological study to decide if the lease is warranted. The lease takes an estimated 6 months for issuance. Prior to conducting any geothermal activities, a plan of operations must be submitted to and approved by the U.S. Geological Survey (USGS). Most plans require an environmental analysis to be conducted by the USGS and review by numerous organizations and individuals. BLM review is required and the analysis must be approved jointly by the USGS and BLM.

Applications for waivers on royalties and for rent may be submitted. A \$10,000 lease compliance bond and a \$5,000 protection bond are required from the town.

For the private lessee case the above approach also applies; however, the issues of royalties and rent will have to be additionally negotiated, especially with respect to possible waivers which may be applicable to this specific circumstance. The specific information required in the various applications differs depending on the lessee being municipal or private. Details of the leasing requirements are given in Title 43, Chapter II, Subchapter C, Part 3200, entitled "Geothermal Resources," published in 38 F.R. 35082, December 21, 1973.

IV. THE SYSTEM DESIGN BASIS

The design and sizing of the district heating system proposed for Thermopolis is principally dependent on two factors: (1) the demand for energy for space heating and hot water heating applications; and (2) the demand associated specifically with industrial process uses. Industrial applications within the designated service area are minimal. Thus, the principal focus of the energy demand projections was to accurately determine the space heating and hot water heating demands for residential units, for businesses, and for identified public buildings.

The following analysis documents the market of potential users in Thermopolis, the geographic distribution of potential customers, the seasonal fluctuation of heat demands, and documented current natural gas use and cost for the Thermopolis market. The discussion of natural gas cost projections for future years is presented in Chapter VII.

A. Projected Energy Loads

1. Estimated User Count--The procedure for estimating the peak design capacity and the annual estimated energy use for the Thermopolis system was threefold. First, the number of residential and commercial users was identified. Second, current natural gas consumption to these consumers was documented and then corrected to reflect energy use for an average year representative of the 30-year average of climatic conditions between 1940 and 1970. Projected peak loads were then calculated using these data combined with estimated loadings based on recommended design weather conditions and typical housing and commercial building characteristics for the region.

Considerable effort was expended to establish a sound, fundamental basis for estimating the number of residential and commercial entities comprising the customer base for the proposed system. Three data sources were utilized. First, 1980 census data were obtained and interpreted. Second, gas service records from Wyoming Gas Company were obtained. Third, both of these data sources were confirmed and complemented by a block-by-block structure count of the town service area.

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The 1980 census data indicated a total of 1,710 and 216 living units in Thermopolis and East Thermopolis, respectively. Of those totals, 210 units are vacant and 76 of the East Thermopolis units are a part of the Canyon Village elderly housing complex. These living units include rental apartments, mobile homes, and small and large single family residences; the census count is generally confirmed by the customer count of the Thermopolis potable water system. Of the 1,710 Thermopolis units, 1,292 are single family dwellings including mobile homes (22).

Wyoming Gas Company provided significant, additional useful data. In early 1982, Wyoming Gas served 1,233 natural gas residential units (44). This number does not include multiple unit apartment complexes which are served as part of the commercial category. Alternate fuels such as electricity constitute a low minority of the homes and likely not more than 15 to 25 in number. Finally, the block-by-block structure count from 1979 areal mapping indicated approximately 1,100 residential units. These data are summarized in Table 2 below.

Table 2. RESIDENTIAL UNIT COUNT

Census Count -- 1980

Thermopolis	--	1,710 Living Units
		1,534 Occupied Units
		1,292 Single Family Units
		418 Multiple Dwelling Units
East Thermopolis	--	216 Living Units
		182 Occupied Units
		76 Units -- Canyon Village

Wyoming Gas Company Data (1982)

1,233 Residential Units (Thermopolis Only)
179 Commercial Units (Thermopolis Only)

Coury and Associates Structure Count (1979 Mapping)

Residential Units -- ~1,100 Units

The data presented above is reasonably consistent in most respects. The chosen 1980 residential count basis for the proposed system is given in Table 3.

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Table 3. DESIGN BASIS: RESIDENTIAL USER COUNT

	<u>1980</u>	<u>1985</u>
Thermopolis	1,275	1,405
East Thermopolis	125	140
TOTAL	<u>1,400</u>	<u>1,545</u>

During the past five years, Thermopolis has been experiencing a 2% to 2.5% annual growth rate. The data in Table 2 is for the 1979 to 1982 time frame. The most realistic implementation plan for the proposed system projects a system on-line date of late 1985. Therefore, the initial sizing of the system is based on the 1980 data and projected to the 1985 date. Therefore, the system basis for design is 1,545 residential-type units.

With respect to commercial users, Town administrative officials estimate that approximately 170 businesses are active in the community. Certain of these are in the same building structures. Wyoming Gas is currently serving 181 commercial customers; this figure includes multiple apartment units and two businesses outside the City limits, but is exclusive of the majority of the Town's public buildings which are located on Hot Springs State Park land. For purposes of the current study, a 1980 basis commercial building count of 172 units was adopted. The 1985 system design basis is for the equivalent of 190 commercial units.

Finally, 24 significant public buildings were identified. These are listed in Table 6. This public sector building count of 24 was used for the 1985 basis count.

To summarize, the proposed geothermal district heating system is designed to supply the space heating needs and the domestic hot water heating needs of 1,545 residences, 190 commercial buildings, and 24 public buildings. In addition, the long distance transmission and disposal lines, and the main arterials in potential areas of growth are sized larger than this basis to allow for an approximately 35% total growth of typical residential and business users during the next 15 to 20 years. The 1985 user basis of the proposed geothermal system is given in Table 4.

Table 4.. SUMMARY OF GEOTHERMAL ENERGY USERS,
THERMOPOLIS, WYOMING - 1985 SYSTEM

Residential Count	1,545
Commercial Count	190
Public Sector Count	24

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For both design and revenue projection purposes, 95% of the design energy loading is assumed hooked up to the system.

2. Annual Energy Use--Excellent, documentable data are available through Wyoming Gas Company records, on which to base annual energy use for the residential, commercial, and public sectors. A sound basis for establishing the annual energy use data is very important since these figures form the basis for the revenue projections and hence the cash flow over the life of the system. The Wyoming Gas Records for the 1980-1981 heating season are given in Table 5 for residential and commercial units and in Table 6 for public structures. Experience has shown that for buildings requiring an inside air temperature of approximately 70°F, the heat energy input required per day is proportional to the number of degrees that the average outside temperature falls below 65°F. Thus by definition, the number of degree days per day, 65° base, is the difference between 65°F and the daily mean temperature when the latter is less than 65°F. Likewise, the number of degree days for longer periods, such as for one year, is the summation of the daily degree days for as many days as the period covers. Data were obtained from the National Weather Service giving occurrence of degree days for a 30-year period. For the 1940 to 1970 30-year period, Thermopolis averaged 7,248 degree days; during the 1980-1981 heating period, there were 6,399 heating degree days. Therefore, the 1980-1981 gas use data were corrected upwards to reflect gas use data in a typical average year.

Table 5. RESIDENTIAL AND COMMERCIAL UNIT
AVERAGE GAS CONSUMPTION:
1980 to 1981 SEASON

Residential	118 mcf*
Commercial	485 mcf*

*mcf denotes 1,000 cubic feet of natural gas.

Finally, approximately 25% of the heat energy in gas combustion escapes with the flue gas. Since geothermal energy is 100% efficient, equivalent natural gas energy values must be reduced by 25% to obtain the equivalent loading for a geothermal system. Given the above procedural methodologies, the estimated annual energy use for the proposed geothermal

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Table 6. PUBLIC BUILDINGS ANNUAL ENERGY USE

Structure	1980-1981 Gas Consumption (mcf)
1. School District Bus Barn	227
2. County Shop	1,045
3. Fairgrounds Building	777
4. High School	8,076
5. High School--New Auditorium, to be added	1,861
6. Middle School	
6a. and Elementary School	7,598
7. Court House Annex	373
8. County Library	1,276
9. Senior Citizens Center	837
10. Sewage Treatment Plant	775
11. State Park Maintenance Building	566
12. Pioneer Home (State of Wyoming)	12,435
13. Memorial Hospital	13,875
14.* State Park Maintenance Building	800
15. Big Horn Basin Children's Center	1,596
16.* Canyon Village (FmHA financed housing for elderly)	10,000
17. Big Horn Enterprises (training school for mentally handicapped)	910
18. Town Hall and Volunteer Fire Department	676
19. County Court House	2,073
20.* Current Court House Addition	3,000
21.* Joint Law Enforcement Facility	1,000
22.** Old Hill School (elementary building to be used for administration)	526
23. Town Water Treatment Plant and Town Maintenance Shop	3,863

* Estimated based on approximate building area.

** 1978 data

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system is given in Table 7. For revenue projection purposes, this was incremented annually at a 2.3% rate to reflect projected Town growth over the initial 1985 design capacity of the system.

Table 7. ESTIMATED GEOTHERMAL SYSTEM ANNUAL ENERGY USAGE

Residential	163,200	10^6 Btu/year
Commercial	90,400	10^6 Btu/year
Public	<u>66,400</u>	10^6 Btu/year
TOTALS	320,000	10^6 Btu/year

One last point is noteworthy here; due to the lack of industrial loadings, the Thermopolis system energy use will be heavily seasonal. Greater than 70% of the annual energy use, and hence the revenues, will originate in the September through February time frame.

3. Residential, Commercial, and Public Sector Peak Load Calculations--

The geothermal system peak design capability is critical to the overall analysis since the peak design establishes the basis for the system capital cost. Geothermal systems are capital intensive and the largest single annual expense factor is the debt service. Therefore, the system capital cost directly impacts the economic analysis and the final estimated delivered energy cost.

The system peak load determination for Thermopolis was approached in two ways. The first uses established relationships between peak loads and average annual loads. Ratios of peak loads to average hourly annual loads normally vary between 3 to 1 and 5 to 1 for residences. This approach is the most suitable to take for the Thermopolis case, due to the availability of excellent natural gas data. Second, these results were then compared to peak loadings estimated from known climatic conditions for the region. For residential use, the peak to annual energy use ratio as determined on an hourly basis for Thermopolis is expected to be about 4 to 1. This results in an average residential energy peak demand of 48,220 Btu/hour.

Peak loadings using weather data were also developed. To do this, peak space heating and hot water heating requirements were estimated for an "average" or typical home. This is somewhat of an imperfect procedure since Thermopolis residential sectors vary considerably in size and building

construction that reflect mobile homes, small homes of older construction, and new larger homes with higher quality insulating characteristics. Nevertheless, these factors will tend to offset each other in many cases and the calculation provides a useful comparison for establishing reasonable peak loading levels. The typical structure for Thermopolis was assumed to be a one-story frame home with approximately 1,300 square feet of floor space. The floor surface area, dimensions, height, insulation, window area, and construction materials are important since the heat load analysis uses the basic heat transfer relationship as given in Equation 1 to calculate the heat losses.

The overall heat loss equation is:

$$Q = U \times A \times T \quad (1)$$

where

Q = peak residential heat loss in Btu/hr

U = heat transfer coefficient in Btu/hr-°F-ft²

A = exposed surface area, ft²

T = temperature difference between inside and outside conditions, °F

A -25°F design temperature was adopted based on documented weather data for the area. Assuming a 65°F inside temperature level, the value of T would equal 90°F.

The individual heat loss calculations for all exposed surfaces are similar, with the value of U changing for each type of material. For example, the U value for a typical wall is calculated below. The heat loss must be calculated for the total surface area of walls, ceilings, roofs, windows, etc., individually. The results are then summed to evaluate total heat losses.

The total outside exposed wall surface area of the home is 980 square feet. The wall construction is framed of 2x4's supporting 1/2-inch sheet-rock on the interior, an R-11 insulation in the walls, and 5/8-inch plywood outside covered with a wood siding. Table 8 gives the R-values of each layer of the building materials and the inside and outside air films.

Table 8. WALL CONSTRUCTION AND RESISTANCES
($R = \text{hr} \cdot ^\circ\text{F} \cdot \text{ft}^2 / \text{Btu}$)

Outside film coefficient	$R = 0.17$
Outside wall siding	$R = 0.81$
5/8-inch plywood	$R = 0.78$
Air space	$R = 11.00$
1/2-inch sheetrock	$R = 0.45$
Inside film coefficient	$R = 0.68$
TOTAL	13.89

The sum of the R values, for each distinct layer through which heat transfer occurs, is the inverse of the heat transfer coefficient, U. For this example, the overall heat transfer coefficient is $0.07 \text{ Btu/hr} \cdot ^\circ\text{F} \cdot \text{ft}^2$. The resistance of the 2x4's was not counted, but the wood studding occupies up to 20 percent of the interior wall space; therefore, the value of U should be increased by about 10 percent, giving a U value of 0.079. The total peak heat flux through the walls thus calculated from Equation 1 is 6,970 Btu/hr.

Similar computational procedures were used for the doors, windows, ceiling, and floor. Ten percent of the wall area was assumed to be windows. Windows were all designated as single pane; ceilings were assumed to be insulated to R-11 values. Roofs were assumed to comprise composition shingles over plywood sheet. Finally, outside air infiltration gives a heat loss of 9.6 Btu/hr per square foot of floor surface, based on ASHRAE standards.

The total homepeak heat loss was then found by adding the six heat loss components as summarized in Table 9. The total calculated loading is 45,000 Btu/hr. An additional extra loading is then necessary for domestic hot water use. For purposes here, this was assumed to be 1/7 of the daily hot water requirements and amounted to 5,500 Btu/hr (15). Based on these design weather calculations one would expect residential peak demands of 50,500 Btu/hr per unit. This 50,500 Btu/hr loading is reasonably consistent with the 48,220 Btu/hr loading estimated from the natural gas base and is consistent with our experience in other cities. The gas data is thought to represent the most valid base for design purposes and was used as the study basis for this work.

Table 9. PROJECTED RESIDENTIAL PEAK HEATING LOADS

Component	Heat Loss (Btu/hr)
Walls	6,970
Doors	1,240
Windows	6,160
Floor	10,000
Ceiling, roof	8,630
Infiltration	<u>12,000</u>
Subtotal	45,000
Domestic hot water	<u>5,500</u>
TOTAL	50,500 Btu/hr

Commercial and public sector structures illustrate even less homogeneity than do residential housing units. Again, a peak to annual ratio is useful, and a 3 to 1 peak to annual ratio is applicable for this determination. The 3 to 1 ratio is appropriate, as compared to the 4 to 1 residential figure, because of the different utilization of schools, hospitals, and businesses. Given the above, Table 10 summarizes the peak system demand used for the design of the proposed system as part of the current feasibility analysis.

Table 10. SUMMARY OF GEOTHERMAL SYSTEM PEAK DEMANDS

Residential	74.5	10^6	Btu/hour
Business	31.0	10^6	Btu/hour
Public	<u>22.7</u>	10^6	Btu/hour
TOTAL PEAK DEMAND	128.2	10^6	Btu/hour

B. Geographic Distribution of Users

The routing of the distribution piping network was developed from the user demand data collected as part of this study. Major trunklines serve eight principal service regions; trunklines are oversized to accommodate additional growth for approximately a 15-year period. Smaller branch lines serving individual streets are sized to meet those specific loads. Detailed layout maps identifying major trunklines and service areas are shown in Figures 8 and 9 of Chapter V.

C. Alternative Energy Costs

The principal alternative to the geothermal system in future years is natural gas. Current costs of natural gas are as follows (44):

For initial 300 mcf -- Cost = \$3.53 per mcf.

For use greater than 300 mcf -- Cost = \$3.43 per mcf.

After correcting for the 25% efficiency decrease due to heat loss in the flue, the equivalent delivered cost of gas energy is \$4.47 per 10^6 Btu for the first 300 mcf and \$4.35 per 10^6 Btu for usage greater than 300 mcf.

D. Interpretation of User Interest

During January 1982, a survey questionnaire was sent to prospective users to ascertain their interest in participating in a geothermal system; approximately 75 percent of the respondents expressed positive interest. ✓ In addition, the proposed system is intending to shoulder a high percentage of the individual homeowner hookup costs, thereby making individual participation more attractive. Clearly, it will be very important to disseminate and explain to Thermopolis residents and businesses the essential economic conclusions of this study and their impact on user energy costs for the coming 20 to 30 years.

V. DISTRICT HEATING SYSTEM DESIGN

This chapter presents the Base Case design and two design options for heating systems in Thermopolis. Chapter IV developed a detailed discussion of the peak and annual estimated energy consumption for service to the entire town. The heating system is a two-loop system where geothermal water is used to heat a secondary circulating fluid which in turn provides heat to the individual user.

Section A presents a system description for the Base Case design. Section B reviews the major system components. Section C discusses the system operation and control. Section D reviews the designs for two additional options which differ from the Base Case only in the method for the cooled water disposal.

A. Base Case System Description

A schematic diagram of the district heating system is shown in Figure 7. Geothermal fluid is pumped from production wells, through a transmission pipeline, to a bank of heat exchangers where it heats a secondary fluid consisting of municipal water. The heated municipal water is then circulated in a closed loop through the distribution pipelines by means of one to four pumps, depending on user demand, and returned to the heat exchangers. Municipal water provides makeup to the circulating water system. The geothermal fluid leaving the heat exchanger is piped directly to injection wells for disposal.

Drawings showing the production site, the distribution and collection main arterials, and the reinjection site northeast of town are shown in Figures 8 and 9. Geothermal fluid is withdrawn in the Rose Dome area well field and pumped through a 10.3-mile transmission line to the principal control building located near the intersection of Highway 120 and 14th Street. The control building will house the heat exchangers necessary to transfer heat from the geothermal fluid to the secondary fluid which is circulated to the users. The geothermal fluid exiting the heat exchangers is piped to reinjection wells. The location of the reinjection wells has been selected so as to minimize the impact of reinjection on geothermal water drawn from production zones, on Hot Springs State Park flows, and on already

Figure 7. Schematic Diagram of the Thermopolis System

Figure 9. Base Case Distribution and Collection System--Main Trunklines

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existing wells located north of Thermopolis. The selection indicated will probably accomplish that, but when more data is available, a lower cost option may be found for the reinjection site.

The secondary circulating fluid will be delivered, by circulating water pumps also located in the control house, to users through various supply and return trunklines, branch lines, and feeder pipes. The main trunkline supply and return lines run along 14th Street, 1/2 block north of Broadway, along 7th Street, and along Broadway in East Thermopolis. The routings for the trunklines were chosen based on the distribution of the total heating load and location of available street and alley rights-of-way; alley routings were utilized wherever possible in order to minimize disturbances resulting from road construction. The trunklines service both individual users and 36 smaller branch lines. Feeder pipes carry water from the trunklines and branch lines to the users. There will be 1,545 residential, 190 commercial, and 24 public users on the distribution system when it is initially put into service. The total peak circulating flow requirement to heat all of these users is 6,400 gpm. The initial design allows for immediate expansion to 6,750 gpm without additional capital equipment. Trunkline piping is sized to accommodate flows to 8,500 gpm over the next 15 years--for an increased capacity of 38% over the initial capacity, assuming 95% of the potential users tie into the system.

B. Major System Components

The major system components for the district heating system are the wells, pumps, heat exchangers, distribution and collection piping, and the reinjection wells.

1. Wells--Ten production wells are required for the peak load--nine operating and one spare. The production field piping grid system is based on 1/4-mile well spacing and is illustrated in Figure 10. Each well is to produce a maximum of 750 gpm at expected temperatures of 160°F. The wells are assumed to be drilled to an average depth of 1,000 feet. The wells will have 11 3/4-inch OD casing to depths of 900 feet. Drilling is expected to be fairly easy as compared to hard rock drilling experienced in other locations. No unusual completion requirements are expected.

Figure 10

ROSE DOME PRODUCTION FIELD

GRID DRAWING

1/4 MILE WELL SPACING

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Ten reinjection wells are also included in the design. Each well will handle up to 750 gpm at temperatures averaging 100°F to 105°F. These wells are assumed to be drilled to depths of 900 feet. The wells are cased with nominal 8 5/8-inch casing.

2. Pumps--The production pumps will be downhole submersible pumps. There will be one pump per well with the pump set at 525 feet below surface. The pumps will be sized to handle 750 gpm at an 800-foot head and at temperatures of 160°F. Each pump will have a 250-hp motor. The pumps are of carbon steel construction.

No injection pumps will be required; hydrostatic head developed in coming from the Rose Dome site will be utilized to transmit the cooled waters to the reinjection site 2 1/3 miles northeast of the town and then into the receiving aquifer.

Four recirculating pumps (1 spare) will be required to circulate hot water to individual users. They will be horizontal centrifugal pumps sized to provide 2250 gpm at a 130 psi discharge head. They will utilize bronze or carbon steel wetted parts, and will be rated for temperatures of 160°F.

3. Heat Exchangers--Two heat exchangers will be required for the Base Case. These heat exchangers will be plate exchangers with approximate dimensions of 10 feet high, 4 feet wide, and 22 feet long. Design conditions are presented in Table 11. The exchanger internals will be constructed of 316 stainless steel.

4. Transmission Piping--The transmission piping carries the fluid from the wellhead to the heat exchanger where it gives up a portion of its heat to the City water in the circulating loop. The cooled geothermal water is then carried to the disposal site. Due to the piping length and terrain, the design of the transmission pipeline was especially important. The design considerations included identification of pipe materials and sizes and of the pumping system parameters, such that the overall system constraints and requirements are met while minimizing complexity and costs. The several constraints and requirements that factored into the design process are noted below:

Table 11. HEAT EXCHANGER SPECIFICATION (PER EXCHANGER)

Fluids	
Hot side	Geothermal water
Cold side	Domestic water
Design heat load	67.6 million Btu/hr
Maximum pressure	200 psig
Approach temperature	3°F.
Design flow rates	
Hot side	3375 gpm
Cold side	3375 gpm
Design pressure drops	
Geothermal side	10 psi
Circulating side	10 psi

Table 12. PIPE REQUIREMENTS FOR FULL DEVELOPMENT OF THERMOPOLIS

<u>Pipe Diameter (inches)</u>	<u>Delivery and Collection Length (feet)</u>
3	71,310
4	39,600
6	11,500
8	1,200
10	11,320
12	5,420
16	4,960
20	3,300

System Constraints--

--For practical considerations, piping routes along existing highways are preferred as they present fewer difficulties in both obtaining right-of-way permits and in getting easy access to the right-of-way area.

--As discussed in Section III-C on the chemical analysis of the well waters, the system will be pressurized to prevent evolution of dissolved gases and subsequent scale formation. In the pipeline design we have set a minimum system pressure of 75 feet of head. The pressure should not go below this value anywhere in the pipeline network.

--Based on temperature, pressure, chemical analysis, and cost, asbestos concrete was selected for the transmission piping service. Use of this pipe does, however, impose a constraint on the maximum operating line pressure of 185 psia.

--The expandability of the system flow to allow for future growth is desirable; the maximum pipeline flow rate is 8500, which will allow a system growth of up to 35%.

Although various pipeline routes were considered, the routes paralleling the old and new roads between Thermopolis and Meeteetse were preferred as they gave shorter pipeline distances and lower pumping requirements, as well as being consistent with the practical considerations mentioned above. The elevation-distance profile for this route is shown in Figure 11.

General Design Considerations--At high flow rates the pressure loss by friction increases for a given pipe size. Enough pressure at the wellhead is required to allow for this friction loss and to maintain a pressure in excess of the minimum system pressure. The elevation-distance profile for the pipeline route indicates that once the flow is past the second hill, which occurs at a distance 47,000 feet from the wellhead, flow all the way to the reinjection site can be by gravity as long as excessive frictional pressure drops are not encountered. Once past the second hill, and thus at lower elevations where static head contributes to the pressure, there is a concern for excessive pipeline pressure, particularly at low flow rates where frictional loss of pressure is small. To prevent excessive pressures, pressure must be dissipated in the down-sloping pipeline section between the second hill and the heat exchanger. Standard baffled pipe section designs are suitable for this pressure reduction.

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Specific Pipeline Design--For a given wellhead pressure, system pressures were calculated at several points along the pipeline. This was done for a range of flow rates and piping diameters. Only certain combinations of wellhead pressures and piping diameters gave satisfactory designs with respect to the design constraints. The design with the lowest wellhead pressure was favored and the smallest pipe diameters were chosen when a choice existed. The design results are summarized below with reference to Figure 11. The pipeline will include air release valves at the high points for release of air during filling. Blowoff valves will be located at the low points to allow for drainage prior to any repair and servicing of the line that might be required.

Segment A -- 44,000 feet of 24-inch line
Segment B -- 10,500 feet of 18-inch line
Segment C -- 13,500 feet of 20-inch line

5. Distribution and Collection Piping--The distribution and collection piping network provides for circulating the closed loop City water to and from individual users. The important design parameters considered in specifying piping network requirements are line velocities, materials of construction, insulation, installation and special provisions.

The piping system was designed to provide an average velocity of 6 feet per second (fps) for the circulating waters. This average velocity provides a good compromise between smaller pipe diameters which decrease capital costs and larger diameters which reduce pressure losses and, hence, operating costs. Table 12 presents the lengths and diameters of pipe required for the Base Case system.

The maximum operating conditions for the geothermal water and the circulating water are 130 psig at 160°F. For these conditions, asbestos concrete piping is recommended due to widespread experience with it in similar systems elsewhere and due to its competitive cost position. Insulated piping will be used on the supply pipeline going to the users, and uninsulated piping will be used for the return lines to the heat exchangers. The temperature loss due to the uninsulated portion of the line will be small, and does not justify the additional cost of insulation. All pipelines will be buried at a minimum depth of 5 feet to be under the frost line. Both the supply and return pipeline will be buried in the same trench with a separation of 1 foot. Figure 12 is a schematic of a typical trenching method for pipeline burial.

Figure 11. Approximate Profile of Pipeline

--From Rose Dome Field to Town
--From Town to Injection Site

Figure 12. Typical Trench Section

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Special provisions required for the pipeline system include thrust blocks, breaker valves, check valves, isolation valves and drain lines. Thrust blocks will be placed at points where the pipelines change direction. Air release and vacuum breaker valves are incorporated at least every 3,000 feet or at every local high point, to permit the escape of any entrapped air after startup, and to control the pipeline pressures during cooldown. Check valves are incorporated on the discharge side of each user to prevent back-flow during servicing. Isolation valves are installed at strategic points to permit shutdown of portions of the system when maintenance or repairs are required, while still keeping the remainder operational. Provisions to drain the lines in case of prolonged downtimes are included at system low points; these drain valves will be opened and closed manually.

C. Operation

The district heating system is designed to operate over a wide range of conditions which may vary both daily and seasonally. It must automatically respond to heating changes in a manner to minimize operator attention, power consumption, equipment wear, and use of the geothermal resource. The following discussion reviews both the overall system control requirements and the controls necessary for individual users.

Figure 13 is a generalized schematic of the piping system for the Base Case Thermopolis heating system. The major elements in the control scheme are the minimum flow control bypass valves, the number of circulating pumps and heat exchangers in operation, the temperature of circulating water leaving the heat exchangers, and the flow rate from and the number of the geothermal production wells in operation. Other wells and heat exchangers will be instrumented in the same manner.

A flow control bypass valve will be provided in each of the 36 branch lines to maintain a minimum 60 gpm flow rate. This will insure adequate flows at the end of the branch line and minimize "dead-heading" the circulating fluid.

The circulating pumps and heat exchanger will be operated on user demand as indicated by the flow rate in the main supply trunkline. A minimum flow of 2250 gpm will be maintained at low heating loads by operating only one

circulating pump and one heat exchanger. As user demand and flow rates increase, additional pumps and heat exchangers will be brought on-line.

The temperature of circulating water leaving the heat exchanger will be maintained at 155°F by controlling the flow rate from the wells and the number of geothermal wells in operation. As the temperature falls below the lower control level, the flow rate of geothermal fluid will be increased. If the required flow rate exceeds the maximum flow rate available from the wells in operation, an additional well will automatically be placed on-line.

Instrumentation in addition to that needed for the major control elements is shown in Figure 13. These variables are monitored to give an indication of how equipment is performing and whether maintenance or corrective action is necessary. They include parameters such as pump discharge pressures, heat exchanger inlet and outlet temperatures, and flow rate of city makeup water.

A typical control system for an individual user is shown in Figure 14. The system includes block valves on both sides of the supply and return lines, to allow isolation of home heating systems for routine maintenance or servicing. A constant flow valve assures a uniform flow of hot water entering the home. A Btu meter will record the energy use. A thermostatic controller operates a solenoid valve which controls the flow of hot water into the house. A check valve is positioned on the discharge line to prevent backflow into the home.

D. Alternative Design Options

Substantive costs are associated with the Base Case option requiring disposal of the cooled waters by reinjection at a well field site 2 1/3 miles northeast of the heat exchanger location. The transmission line cost and the well drilling costs with that option amount to \$2.5 million. In view of the above, two additional design options were developed and are presented here. The first proposes discharge of the geothermal waters to the Bighorn River. A cooling tower is included in this option to cool waters to less than 90°F prior to their discharge. Environmental concerns related to this option are discussed further in Chapter VII, Environmental Review. For purposes of this study, we shall refer to this option as Option I--River Discharge.

Figure 14. Schematic Diagram for Individual User Control System

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The second option considered is based on impoundment and subsequent reuse of the cooled waters for agricultural irrigation. In this instance, an independent company would pay the City to obtain the used waters, construct impoundment facilities, and then distribute the waters to prospective agricultural users. Approximately 2,800 acre-feet of water per year could be sold under this type of arrangement. The water was conservatively valued at \$10 per acre-foot for the economic analysis of this alternative. The impoundment reuse option is referred to as Option II--Agricultural Reuse, in this study.

For both Options I and II described above, all other design considerations remain the same as the Base Case design described earlier in this chapter.

VI. USER RETROFIT SYSTEMS AND COST

A major part of the district heating system involves getting hot water to the user, and providing the equipment to use the heat within the building. Three factors have the greatest influence on the cost and complexity of the user systems--the water temperature, the peak heating load in the building, and the nature of the existing heating system. The impact of the last two factors is relatively clear: as the heating load gets larger, the required hot water flow and the heating system size both increase; and the type of system already in use and the amount of space available in the building affect the difficulty of converting the existing heating system to work with the municipal hot water, as is discussed below.

The effect of the water temperature is less direct. The key factor here is how much heat can be removed from each pound of water circulated within the building. It is desirable to remove as much heat as possible in order to reduce the required flow rate of water, because this then allows small lines, valves and fittings to be used and reduces the installation cost. On the other hand, as more heat is removed from each pound, the return water temperature becomes lower and the heat transfer system within the building, whether it is baseboard heating or a central air system, becomes larger. This effect due to the lower temperature of return water is not very important when the initial hot water temperature is high, at 200°F or hotter, but the effect rapidly becomes more and more important as the top temperature gets lower. In every case, an optimization must be made to balance the savings in line size that are gained as more heat is withdrawn from the water, against the increased heater costs inside the building.

The optimum for the Thermopolis system calls for approximately a drop in temperature of 40°F between the hot municipal water entering each building and the cold return water. Thus, water entering at about 150°F will leave at about 110°F. The costs for the service lines, from the trunk lines to each building, will vary according to the diameter and length of the lines. An estimate has been made that the typical cost will be about \$1,100, which consists of the following components:

Pipeline to and from building-----	\$480
Meter-----	200
Isolation valves and flow control-----	180
Installation labor-----	240

Part of these costs is included in the total system costs to be borne by the developer, as is discussed in Section VIII.

Within the buildings themselves, the range of possibilities for retrofitting space heating systems is quite large, depending on the system that is already in place. The primary possibilities are discussed below. In some cases, a minimum of work will be required for conversion. In many cases, the type of retrofit work required will be within the capability of qualified "do-it-yourself" homeowners. The estimated cost range in each case is based on a typical space heating peak demand of 48,000 Btu/hour.

1) Conversion of Existing Hot Water Systems--These systems typically burn gas, and often oil or propane to heat a circulating water stream. The operating temperature of the hot water ranges between 180°F and 215°F, and the systems are designed for temperature drops of 40°F to 60°F. The retrofitting needs to convert these systems to geothermal water would be minimal, requiring only that the municipal geothermal heating fluid be connected into the building's circulating water system. In some cases, additional radiator capacity may be needed. The estimated cost range for this conversion system is \$100 to \$800.

2) Conversion of Existing Forced-Air System--Retrofit conversion of forced-air systems is also fairly straightforward. It requires only that the furnace be replaced with a heating coil with hot water flowing through the tubes of the coil and building air flowing over the coil. In many cases, the burner element can be removed and the coil can be placed in the furnace itself. This type of conversion is suitable to users who have gas, oil, or propane fueled forced-air systems. The estimated cost range for this conversion is \$500 to \$1,100.

3) New Baseboard Radiators--This type of heating conversion would be applicable to users who do not already have either a standard hot water system or a forced-air system. Standard baseboard radiators with finned tubes are installed in each room, and the room air is heated as it flows over the tubes in a natural convection pattern. The geothermally heated

municipal water is piped to each of the radiators. In essence, this is a standard hot water heating system without a boiler. The range of costs for this installation is estimated to be \$1,100 to \$2,300.

4) New Fan-Assisted Convection or Cabinet Convectors--This type of conversion is similar to the baseboard radiator conversion; the fan-assisted cabinet convector is more compact than the baseboard radiators, however, since a greater heating capacity can be obtained from standard radiator sizes. The municipal hot water is piped to each convector unit. The probable range of costs for this option is \$1,000 to \$2,000.

5) New Forced-Air System--An alternative to the new baseboard radiators and new fan-assisted convector units is a new, central forced-air system. This type of conversion tends to be the most expensive. It is most suitable for users who have either a crawl space or attic areas which facilitate ease of installation. This is the highest cost option, with the range of estimated costs being \$1,800 to \$2,700.

As indicated above, the costs incurred inside the building can vary greatly from one case to another depending on the type of existing system and the amount of working space available. Most of the systems in Thermopolis are central forced-air units, so that the average cost of retrofitting will be on the low side.

About 15 percent of the potential total annual heat demand is associated with hot water heating, which is a more nearly constant load over the year as compared to space heating. The most direct method for retrofitting domestic hot water supplies is the use of commercially available equipment developed for the solar industry, or the use of fast-response heat exchangers without storage. Either of these options would be especially suitable for multifamily apartments, motels and hotels, hospitals and other buildings with large water heating loads. They are also applicable for the individual residence, but a more satisfactory approach here may be to use the existing hot water heater as a storage tank, and to install a separate heat exchanger wherein domestic water would be heated by the municipal hot water. This option could be expected to cost between \$200 and \$500.

For larger applications, the cost of domestic hot water systems developed for the solar industry would begin at about \$1,500. This system consists of two modules packaged as a unit: a storage tank module, and a heat exchanger module which includes the pumps and controls. Various size storage tanks are available ranging in size from about 50 gallons to several hundred gallons. The heat exchangers are designed to take a hot fluid from the solar collector, at a temperature in the range of 140°F to 180°F, as the energy source for heating domestic water. Thus, the municipal water at 150°F would be an ideal fluid to replace the solar-heated water, since the heat exchanger functions in the same way, whatever the energy source.

The second option is to use a fast-response heat exchanger without hot water storage. Small plate and frame heat exchangers, of the same type as is used to heat the municipal circulating water with geothermal well water, are suitable for this service because they are small in size and they do not contain a high weight of metal that has to get hot before heating of the domestic water begins. In this case, a very small flow of municipal water would pass through the heat exchanger at all times to keep it warm. Then, when there is a demand for domestic hot water, the municipal water will automatically begin to flow at its full rate and will continue to flow full until the demand quits. The time lapse before water would be provided to the user would be in the tens of seconds. This type of unit would cost in the range of \$1,000 to \$1,500 for small units, but the increase in cost for larger units would be relatively small.

VII. ENVIRONMENTAL AND INSTITUTIONAL REVIEW

The objectives of the environmental and institutional review for this report are to ascertain whether significant environmental impacts will occur as a result of the development of the proposed geothermal system; if significant potential impacts are identified, recommendations are to be made as to how those issues might be addressed and successfully mitigated. Second, from an institutional and regulatory perspective, the important permitting requirements are identified such that implementation of the proposed project can proceed in a timely fashion. Section A reviews the environmental findings. Section B reviews the applicable institutional and permitting requirements.

A. Environmental Evaluation

The purpose of an environmental evaluation for the proposed geothermal development at Thermopolis is to insure that environmental concerns are addressed in advance of final commitments to the engineering and construction of the system that will eventually tap the resource and distribute the hot water to the Town. The approach utilized for the Thermopolis review was to (1) identify the primary environmental issues that should normally be addressed in this type of development; (2) establish documentation of previous environmental analyses of the Thermopolis region; and (3) develop conclusions as to whether any significant environmental concerns do in fact exist relative to the proposed action.

Normally, the major environmental topics to be addressed prior to beginning a geothermal development program are:

1. Effects of the development on surrounding wells, springs, and streams.
2. Potential subsidence effects caused by lowering of reservoir pressures.
3. Adverse environmental effects which might result from disposal of spent geothermal fluids whether surface or subsurface.

In a comprehensive environmental impact assessment, other potential environmental, legal, and social concerns relating to the project are identified and plans to mitigate or resolve the issues are set forth.

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Typical concerns that might be addressed, if applicable, are: (1) air quality--wind-blown dust, hydrogen sulfide emissions; (2) noise--human disturbance, particularly during drilling operations, and disturbance of sensitive or protected species; (3) land--disturbance of land for drill site and access roads, erosion; (4) seismicity--not a major concern except in very seismically active areas; (5) ecology--disturbance of sensitive species, destruction of habitats, contamination of aquatic areas; (6) socioeconomics--increased demands on housing and community services; alteration of community patterns; and (7) heritage resources--disturbance or destruction of historical, archaeological, paleontological, or cultural resources.

Subsequent to preliminary analysis of these factors for the Thermopolis case, appropriate Federal and State agencies were contacted to document the extent of existing environmental data for the region and highlight areas of specific concern. These contacts included the following:

Wyoming Department of Environmental Quality. (DEQ)

U.S. Department of the Interior, Bureau of Land Management,
Worland, Wyoming.

U.S. Department of the Interior, Bureau of Reclamation, Upper
Missouri Region.

Wyoming Office of the State Engineer.

National Oceanic and Atmospheric Administration.

U.S. Department of Energy, Western Area.

Power Administration.

Private Consultants who may have worked on projects in the region.

Response from these contacts indicates that no large or significant environmental analysis of the region has been conducted. We have found that the Western Area Power Authority of DOE is planning a 1982 environmental impact statement of the region as part of a proposed action to upgrade the Thermopolis-Alcova electrical transmission system. Results of that effort will be available prior to final decisions to proceed with the Thermopolis geothermal system and will be useful in identifying environmental concerns relative to particularly sensitive ecologies, currently

unknown archaeological or historical concerns, socioeconomic constraints, and other nongeothermal environmental concerns. No significant or unusual environmental issues of the type that would preclude system development have been identified as a result of these investigations.

The principal environmental concern for the Thermopolis site is the potential impact of the proposed system on existing wells and the springs at the Hot Springs State Park. This issue has been previously discussed in depth in Chapter III. Due to its distance from town, the selection of the Rose Dome production site is likely to minimize any potential impact on existing rights; a substantial hydrological investigation will be required to establish the technical information and base necessary to confirm that finding.

These hydrological studies will also prove useful in addressing the subsidence issue. Currently, professional judgment indicates that should not be a problem particularly in the light of comparatively large flows from existing wells and springs.

Additional potential environmental effects may vary depending on the phase or aspect of the total project considered; these factors include exploration and drilling, production and distribution, and disposal of spent geothermal fluids. The Rose Dome site is located approximately 10 miles northwest of the Town limits. No major road construction is anticipated. Drilling noise at the well field will exist for a limited time period. Disposal of drilling fluids and test fluids will be similar in nature to fluids of normal water well drilling activities. Proper attention and procedure should adequately address these concerns.

Upon completion of well testing and securing of all production permits, a transmission line will be constructed and buried extending from the wells to the heat exchanger facility; distribution and collection piping will be installed in town. Once in place, the piping system is not expected to have any impact on the surrounding environment.

The method of handling the spent geothermal fluids will depend on two principal factors--proposed further use, if any, and the chemical and thermal properties of the water. ReInjection to a receiving aquifer is one disposal alternative. This proposal may have positive attributes of

minimizing any potential subsidence impact from water withdrawal and loss of pressure. It also provides immediate recharge to the general zone that may be providing pressures for flows in Hot Springs State Park.

An alternative surface disposal option of discharging the fluid to the Bighorn River is also proposed. The thermal water discharge must be cooled to at least 90°F. The chemical content of discharged waters is also controlled by the DEQ. Total dissolved solids and sulfates appear to be the primary concerns. The final regulatory acceptability of the river discharge option will be dependent on National Pollutant Discharge Elimination System permitting discussions with the Wyoming DEQ.

For the reuse option, the water would be returned to a surface impoundment site for further distribution as irrigation water. The quality of the water must meet standards for intended use and the impoundment site would have to conform to State criteria for assurance of noncontamination of groundwater.

Deleterious impacts to surface and groundwater systems are of concern during both drilling of the wells and operation of the system. It will be important that domestic and irrigation aquifers are not contaminated with geothermal fluids. The geothermal wells will be cased and cemented through shallow groundwater aquifers to reduce the possibility of intermingling of fluids through the wellbore. Proper design of wells, piping system, and discharge system should adequately address these issues.

B. Institutional and Regulatory Permitting

As with any project of this type which includes construction, water withdrawal, use and disposal, a series of permits will be required. Processing of permit applications should be initiated in a timely fashion. The time lapse between submittal and approval is varied and some permits have special conditions and public hearings on certain issues will be required. The specific permits required for the Thermopolis geothermal project will depend, in part, on the disposal option selected.

Each Wyoming county and incorporated municipality has the statutory right to control the use of land on private and public lands within their jurisdictions. Generally, the controls take the form of zoning laws,

building codes, and construction performance standards. Permitting, including the obtaining of adjudicated water rights, Bureau of Land Management leases, and DEQ disposal permits for groundwater injection or river discharge will cumulatively extend 2 to 3 years, even when obtained concurrently. Contacts with the permitting personnel of these various agencies indicated promising attitudes of joint cooperation towards working through the various issues associated with specific permit issuances. The following is a listing of agencies and their respective permits to be obtained. Reference (37) provides additional useful discussions of Wyoming permitting requirements.

Table 13. LISTING OF AGENCIES AND PERMITS LIKELY REQUIRED FOR THERMOPOLIS GEOTHERMAL DEVELOPMENT

City Agency	Permit
City Planning Commission	Zoning
City Building Inspector	Building Permit Certificate of Occupancy
County Agency	Permit
County Planning Commission/Board of Adjustment	Zoning
County Clerk	Building Permit
State Agency	Permit
Wyoming Department of Highways	Permit for Encroachment of Existing Right-of-Way
State Engineer	Permit to Appropriate Groundwater
Department of Environmental Quality	
Air Quality Division	Construction Permit--Likely not Needed
Land Quality Division	"Reclamation" Permit
Water Quality Division	Construction Permit. National Pollution Discharge Elimination System Permit
Public Service Commission	Certificate of Public Convenience and Necessity. May not be needed, depending on municipal versus private development.

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<u>Federal Agency</u>	<u>Permit</u>
U.S. Department of the Interior Bureau of Land Management	Permit for pre-lease Operation. Lease for BLM Lands Plant Siting Permit Approval of Operation Plans with U.S. Geological Survey
U.S. Fish and Wildlife Service	Advise and Consent on En- vironmental Impact State- ments
U.S. Environmental Protection Agency	Review and Approval of En- vironmental Impact Statements
U.S. Department of the Interior Geological Survey	Conduct Site Specific En- vironmental Analyses and Approval of Operation and Development Plans Exploration Environmental Baseline Data Development Utilization Production

VIII. ECONOMIC ANALYSIS

The key question to be answered is what the delivered cost of energy will be for the energy users of the geothermal system and how does it compare to costs of other energy sources. For Thermopolis, the primary alternate to the geothermal system is natural gas. The cost of energy must generate enough revenue to pay for all operating, maintenance, and debt service costs. If private development funds build the system, revenues must also sustain an adequate return on the invested capital, or the necessary capital will not be attracted. This chapter summarizes the economic analysis results of the current study. Section A reviews the economic impact of both private development and municipal development. Section B outlines the economic evaluation model and includes the bases of the study including interest and inflation rate assumptions and alternative energy pricing. Section C interprets the results of the economic analysis task and, finally, Section D contains recommendations for developing the Thermopolis system. This discussion summarizes the options, but it is not an exhaustive presentation of all financing options.

A. Development Options

1. Private Sector Development--Two types of private sector development are presented. First, a geothermal energy development company could develop and market the energy. In this case, the company would raise all necessary capital, obtain the necessary leases and permits, construct the transmission and distribution piping, market the energy, and then ultimately dispose of the utilized waters. The company would assume all risks in the production and rejection well field development phases and would rely on venture capital financing. Venture capital financing requires a very high rate of return on invested capital of as much as 25% to 30%, and a rapid payback time for the capital of as little as four years. A rapid payback is difficult for geothermal systems since they are capital intensive and since their revenues increase with time due to system growth and to the effect of inflation on prices. To offset these revenue requirements, significant private sector tax incentives apply to geothermal investments, including an additional 15% investment tax credit, intangible drilling deductions, accelerated depreciation schedules, and depletion allowance.

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Personal communications with Denver area investment banking firms indicated that long-term commercial financing may be difficult to obtain since geothermal energy technology is still perceived to be high risk and since the collateral for the loan cannot be easily recaptured. The large East or West Coast banking communities who are more familiar with long-standing geothermal accomplishments would probably have to be utilized for nonequity positions.

The second private sector approach would be for a regulated utility such as the Wyoming Gas Company or its natural gas supplier, Montana-Dakota Utilities, to develop the system. If this were the case, Industrial Revenue Bonds (IRB) could be issued by the County and the City to lower the effective interest rate for the financing. Since the IRB's would be a public issue, interest earned would be exempt from Federal income tax. Some type of joint City-County approach would be required since Wyoming law limits IRB's to a maximum of \$10 million. Responsibility for repayment of Industrial Revenue Bonds would rest with the company developing the project. Therefore, a strong utility company involvement is important to obtain the necessary letters of credit to obtain low interest rates and still effectively market the bonds. An offsetting disadvantage is that tax incentives, such as the investment tax credit and accelerated depreciation, are not applicable to regulated utilities.

2. Municipal Development--The second development option is for the municipality or an alternate public sector jurisdiction to develop and operate the proposed system. Municipal bonds or alternately some type of special district bonds would be issued; again, interest rates are lower for public sector financing since interest income to bond holders is tax exempt. General obligation bonds are limited to 4% of the district's assessed valuation; this debt limit is not applicable to water supply projects. It is not clear as to whether a geothermal water system would be subject to this debt limitation, and a specific ruling would have to be obtained on this point. If the debt limit is applicable, general obligation bonds would not be an option since the Thermopolis valuation is not high enough to finance the system.

Revenue bonds are payable solely from the revenues of the project, and they are not subject to the constitutional debt limitation of the City.

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Revenue bonds are a major source of capital for public utility projects. The principal restraint on the use of revenue bonds for geothermal district heating projects is that bond buyers, like financial institutions, are reluctant to invest in a system using unfamiliar technology and with limited demonstrated earnings potential.

Two additional special cases were analyzed as part of the current work. The first would be a wholly and municipal development where the entire financing of the project would be derived through a long-term 25-year low-interest loan from the Wyoming Water Development Commission. This option should have a reasonable probability of success since, for example, the Water Development Commission has recently issued long-term loans to Cheyenne for water supply development. A second similar approach is for a joint private-municipal development. The private sector would develop the well field, transmission lines, and reinjection system, while the municipality would develop the in-town distribution system. For this case it is assumed the municipality would apply for and receive an outright grant from the Water Development Commission as equity financing for the distribution portion of the system. The private sector would develop the higher risk portions of the system, operate the entire system, and market the energy, exactly as in the case of complete private development. The significance of this approach is that the reduced venture capital requirements would facilitate a high enough return on the equity investment such that the private capital could be more easily attracted.

The results of the economic analysis for each of these cases are discussed in Section C.

B. Basis of the Economic Analysis

1. Cost Estimates--Feasibility level estimates of the capital and operating costs were developed for the three design cases outlined in Chapter V; these estimates are summarized in Tables 14, 15, and 16. Hydrological testing, final engineering design, and construction are estimated to require about 3½ years. Therefore, the capital costs have been escalated to 1985 dollars by increasing present costs at an 8% general inflation rate, and operating costs were escalated at an 8.75% rate. The operating cost estimate includes the price of electricity for well

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Table 14. COST SUMMARY, BASE CASE DESIGN--REINJECTION DISPOSAL

Production Well Field Cost-----	\$ 1,800,000
Transmission to Heat Exchangers-----	3,480,000
Distribution and Collection Piping-----	3,700,000
Miscellaneous, Valves, Flow Control, Tees, Elbows-----	400,000
Reinjection Piping and Well Field-----	1,960,000
Heat Exchanger-----	345,000
Electrical Supply, Controls, Control House, Telemetry-----	340,000
Pumps-----	80,000
Engineering-----	1,000,000
Residential and Commercial Hookup Costs-----	1,215,000
Contingency at 10%-----	<u>1,430,000</u>
TOTAL 1982 DOLLAR COST-----	\$15,750,000
 Total Escalated 1985 Cost-----	 \$19,845,000
1985 Operating Costs-----	\$ 639,000/year

Table 15. COST SUMMARY, OPTION 1--BIGHORN RIVER DISPOSAL

Production Well Field Cost-----	\$ 1,800,000
Transmission to Heat Exchangers-----	3,480,000
Distribution and Collection Piping-----	3,700,000
Piping to Bighorn River-----	375,000
Heat Exchanger-----	345,000
Electrical Supply, Controls, Control House, Telemetry-----	320,000
Pumps-----	80,000
Miscellaneous, Valves, Flow Control, Tees, Elbows, and Cooling Tower-----	\$ 500,000
Engineering-----	950,000
Residential and Commercial Hookup Costs-----	1,215,000
Contingency at 10%-----	<u>1,275,000</u>
TOTAL 1982 DOLLAR COST-----	\$14,040,000
Total Escalated 1985 Cost-----	\$17,690,000
1985 Operating Cost-----	\$ 639,000/year

Table 16. COST SUMMARY, OPTION 2--AGRICULTURAL REUSE

Production Well Field Cost-----	\$ 1,800,000
Transmission to Heat Exchangers-----	3,480,000
Distribution and Collection Piping-----	3,700,000
Piping to Battery Limits-----	52,000
Heat Exchanger-----	345,000
Electrical Supply, Controls, Control House, Telemetry--	320,000
Pumps-----	80,000
Miscellaneous, Valves, Flow Control, Tees, Elbows-----	400,000
Engineering-----	950,000
Residential and Commercial Hookup Costs-----	1,215,000
Contingency at 10%-----	<u>1,228,000</u>
TOTAL 1982 DOLLAR COST-----	\$13,570,000
Total Escalated 1985 Dollar Cost-----	\$17,100,000
1985 Operating Cost-----	\$ 639,000/year

field and in-town circulating pumps, and the cost of repairs, maintenance, and administrative personnel. The electrical cost estimate was based on Hot Springs County REA rates and on in-town rates of 4.5¢/kilowatt hour.

The capital cost of the system includes \$700 for each residential and small commercial user, or about 63% of the cost for the service lines that carry municipal hot water from the feeder lines to the industrial buildings, as was discussed in Chapter VI. The selection of 63% was an arbitrary choice, and the final decision as to what percentage of the service line costs should be borne by the central system is a policy matter of primary importance. The reason that the central system would assume part of these costs, which are then repaid over time by the users as part of the monthly billings, is to make it easier for individual users to afford to hook onto the system. Since the rate of return on investment would be reduced greatly if a large number of potential users do not tie into the system at an early date, taking this step will be beneficial to the central system and to all users since it helps to assure that a high level of participation is achieved in the first year.

2. Estimated Revenue, Interest Rate, and Inflation Rate--Revenue estimates were developed by establishing the first-year energy prices for geothermal heat at attractive levels as compared to the projected price for natural gas in 1985. Considerable effort was made to document the best projections of gas prices over the life of the project (5, 23, 45, 53). These projections are difficult to make because of several factors: the unknown effects of current natural gas deregulation efforts; the percentage mix of old and new gas in current gas supplies; and the expected increased cost for drilling and marketing new gas reserves. Trends over the past 3 to 5 years in Thermopolis show annual increases of 20% to 35% in the price of gas. The deregulation process is expected to continue until 1985; therefore, high rate increases are expected through 1985 with lower increases occurring after that time. On the basis of these data, the gas rates for this study were escalated from 1982 rates at 24% per year until 1985 and at 11% per year thereafter. The mid-year 1985 gas cost is thus projected at \$8.74 per million Btu. Geothermal sales during the project life were escalated at the general inflation rate: two different levels were assumed for this analysis, 8% and 11%, to determine the impact of this factor, and

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the rate of return was determined in each case. System growth due to new customers was set at 2.20% per year for 15 years, to match the expected rate of population increase. Electrical costs and other operating costs were escalated at 8% per year. Finally, the interest rates were also set at various levels and the rate of return was calculated for each case to determine the impact of interest rates. For private sector development, interest rates of 12% and 15% were used with a 15-year loan life. For private sector development with Industrial Revenue Bonds, interest rates of 10% and 12% over 15 years were used. For municipal development, bond rates of 12% at 25 years were assumed; for the case of municipal development with long-term State loan monies, an 8% interest rate was used. Finally, for the joint private-municipal case where grant money is received from State funds, a 15% debt basis over 15 years was used for the private portion of the financing. For all private financing cases, the equity investment was set at 30% of capital requirements, with the remainder being long-term debt.

3. Economic Evaluation Model

a) Model description--The mathematical model used to evaluate the economic feasibility of the proposed district heating development is applicable to both private and municipal financing. In addition to indicating the general economic feasibility of the project, the model allows a rapid indication and evaluation of how changes in several parameters can affect the investment picture. Thus, it allows one to determine what are the more attractive investment approaches for funding the development.

For private financing both the discounted cash flow rate of return on the investment, and the time period required to pay out the original cost are used as indicators of the investment attractiveness. For the municipal case, in addition to these two parameters, a yearly ratio of revenues to expenses is also determined. The impact of tax laws on cash flow is so great that the model specifically considers the following related items for the private investment case:

- investment tax credit
- energy tax credit
- intangible drilling cost deductions
- minimum add-on tax for preference income
- depletion allowance
- depreciation
- loans and leverage

- tax loss carry-forward
- inflation

The exact analysis of these items is based on the tax policy as developed in the Economic Recovery Tax Act of 1981, as has been presented in the published literature and from personal communications. Each cash flow is discounted back to the first year. The interest rate that results in the sum of the discounted cash flows equaling the capital cost is the rate of return. In a leverage situation where a portion of the capital cost is financed, the rate of return is based on the equity value.

In addition to tax policy, the rate of inflation and the interest rate on long-term loans have a major impact on the project profitability. This is especially true for the district heating system where up-front capital expenditures are the major cost item. The model evaluates the impact of inflation rate on both revenues and expenses, and the impact of interest rates, as was discussed earlier. The data provided to the computer model, and the results printed by the computer are given in Tables 17 and 18.

b) Tax Incentives for Geothermal Development--The principal legislation and regulations governing energy credits and incentives available from the Federal government are summarized on the following pages. These regulations apply to the following areas, each of which is discussed further below.

- Energy Tax Credit--an investment tax credit that may be applicable in addition to the existing investment tax credit
- Intangible Drilling Cost Deductions
- Depletion Allowance
- Depreciation--recovery of capital costs
- Minimum Tax
- Miscellaneous factors.

The following summaries represent our best understanding of the impact of the tax law on the basis of a review of pertinent documents and our communication with other members of the geothermal community. Tax law and the regulations that provide guidance for compliance are detailed, complex subjects. We suggest that this material be used only as the basis

Table 17. INPUT DATA TO ECONOMIC EVALUATION MODEL

Cost Parameters

First Year Revenue
First Year Operating Cost
Capital Cost
Loan Amount
Project Life

Inflation Factors

Annual Revenue Rate of Increase
Annual Operating Cost Rate of Increase

Loan Parameters

Loan Life
Number Payments Per Year
Annual Interest Rate

Depreciation Parameters

Depreciation Life
Percent Depreciation
Salvage Value

Tax Parameters

Tax Rate
Investment Tax Credit Factor
Time Limit on Tax Credit Carry-Forward
Time Limit on Tax Loss Carry-Forward
Minimum Add-on Tax Factor

Intangible Drilling and Depletion Parameters

Intangible Drilling Costs
Depletion Factor
Depletion Limit Factor

Table 18. OUTPUT DATA FROM ECONOMIC MODEL

I. Private Investment Case

--By Year: Revenue
Operating Cost
Depreciation
Interest
Pretax Income
Tax
After Tax Income
Cash Flow
Loan Balance

--Discounted Cash Flow Rate of Return

--Years to Payout

II. Municipal Investment Case

--By Year: Revenue
Operating Cost
Debt Service
Cash Flow
Ratio of Revenue/Costs
Interest
Loan Balance

--Discounted Cash Flow Rate of Return

--Years to Payout

for additional discussions with a tax consultant. The IRS Publication No. 334 is a particularly helpful reference.

1. Federal Energy Tax Credit--Currently, the Federal government allows an investment tax credit of 10%. The credit may not exceed the lesser of the income tax required, or \$25,000 plus 90% of the tax that is more than \$25,000. The Alternative Energy Tax Credit provides for an additional 15% investment tax credit, above the 10% regular investment credit for geothermal equipment. It may offset 100% of the tax liability remaining after applying the regular credit. This alternative energy credit expires in 1985, which is an important factor to consider in the current analysis. Unused investment taxes may be carried back three years and generally forward 15 years. The reader is referred to IRS Publication 572 for more details.

2. Intangible Drilling Cost Deductions--For tax purposes, the costs of drilling and completing a geothermal well are divided into two classes: intangible drilling costs and capital costs. Capital costs must be recovered through depreciation.

Intangible drilling costs are those incurred which, in themselves have no salvage value and which are "incident to and necessary for the drilling of wells." They may be expensed (deducted as expenses) in the year in which they were incurred or they may be capitalized and deducted over a certain period of time as depreciation. Allowing a taxpayer to expense (deduct) all the intangibles in the year in which they were incurred gives the taxpayer an "accelerated depreciation." Any associated energy credits will be lost, however, if this accelerated depreciation approach is used.

3. Depletion Allowance--The owner of an economic interest in a geothermal resource may recover his cost through Federal tax deductions for depletion over the economic life of the property.

The IRS provides two methods of computing a depletion allowance: cost depletion and percentage depletion. Cost depletion provides for a deduction for the taxpayer's basis (cost) in the property in relation to the production and sale of minerals from the property. On the other hand, percentage depletion is a statutory concept that provides for a deduction

of specified percentages of the gross income from the property. The deduction, however, cannot exceed 50% of the net income from the property. For the geothermal case, percentage depletion is used.

The allowable percentage depletion on income from geothermal deposits in 1982 is 18%. It will be 16% in 1983 and 15% thereafter.

4. Depreciation--Recovery of Capital Costs--The Economic Recovery Act of 1981 provides for accelerated recoveries of capital costs. Under the Accelerated Cost Recovery System (ACRS), geothermal equipment may be written off over a period of five years. The yearly deduction percentages until 1985 are set at 15% for the first year, 22% for the second year, and 21% for the third through the fifth year. Salvage values are not subtracted from the initial bases when figuring the deductions. Straight line depreciation over 12 and 25 year periods are alternatives for depreciation.

5. Preference Income-Minimum Tax--Some types of income are given preferential treatment by special provisions of the tax law. A minimum tax applies to a number of items that are considered to be of a tax-preference nature. These types of income include accelerated depreciation on real and leased property, capital gains, stock options and income offset by depletion, amortization and intangible drilling costs. For geothermal development, intangible drilling costs are not a preference item unless the corporation is a Subchapter S corporation or a holding company. Percentage depletion costs are preference items for geothermal resources. Depreciation on machinery and equipment is not a preference item.

6. Royalties, Sales Tax, and Property Taxes--Bureau of Land Management communications indicated that lease royalties from the Rose Dome production field may or may not be required, depending on private or municipal development and other lease characteristics. Royalties have not been factored into the current economic analyses. If royalties are required to the BLM for private sector development, production costs could rise by as much as 5% to 10%. Sales tax and property tax also have not been factored into the economic model; their application depends on the exact nature of the corporate or municipal entity marketing the energy.

Sales tax, if applied to private development, could increase costs 3%; current property tax levels are 58.06 mils applied to a 25% assessed valuation. For the Base Case system costing about 19 million dollars, these property tax assessments could amount to \$280,000 per year.

C. Results of the Economic Analysis

In general, for the large number of cases that were evaluated, the rates of return and the payout times are moderately interesting. The returns are not high enough to spark an immediate outpouring of venture capital, yet they are high enough to indicate that this situation might be reversed if different design options are taken to reduce costs, such as the staged development, or if an attractive form of financing is developed.

The analysis is complicated because of the several options available and because of the several critical uncertainties that exist, as is discussed below. The results for the four ownership options are presented below and, in each case, two or three of the development options are evaluated: the Base Case and Options I or II. However, it is the uncertainties about economic trends that are most critical to the analysis, and that led to a need for making several additional calculations; in this way, the impact of several possible future occurrences can be considered. The variations in the two most critical parameters, the interest rate on borrowed money and the inflation rate, are reviewed briefly below.

The future rate of inflation is certainly not known. This is complicated even more by the probability that inflation rates will be different for different commodities. It has been usually assumed that the revenues from the district heating system will increase at the same rate as the general level of inflation, and two possible levels of inflation, 8% and 11%, were evaluated.

The interest rate that will prevail at the time the project might be undertaken is not known either. Current interest rates are very high, and have been considerably above the general rate of inflation of the last two or three years; before that, interest rates had been less than the inflation rate for several years. It is believed that an equilibrium will be eventually established, and that interest rates will remain at their historic level of 2% to 4% above the rate of inflation; therefore,

one set of calculations calls for an interest rate that is, conservatively, four percentage points higher than the rate of inflation, or interest at 12% when inflation is at 8%. Other evaluations were made with a much higher interest rate, of 15% for 8% inflation, to provide data more consistent with the present spread. No evaluations were made with interest rates less than the inflation rate, because that situation is not expected to reoccur. In general, lower interest rates were used for the cases of municipal or public utility financing.

Some of these results are presented below for certain combinations of the many parameters. The trends exhibited by the full set of calculations led to the conclusions and recommendations that are presented in this report.

1. Private Development--The rates of return and the payout time on investment are given for the Base Case project, followed by values in parentheses that apply to Option I--River Disposal. In the first case, geothermal prices are set initially at 80% of the equivalent cost for natural gas in 1985; thereafter, geothermal prices escalate at the 8% inflation rate, even though gas prices increase more rapidly. Then, with a 15% interest rate, the discounted rate of return on equity is 12.5% (15.1%) and the payout time is 12.3 years (10.8 years). Other combinations of parameters were then analyzed to determine what set of circumstances is required to reduce the payout time closer to the 4- to 5-year level that is generally required by private investors.

If geothermal prices increase at the same rate as natural gas prices, the rate of return becomes 20.2% (22.2%) and the payout time decreases to 8.7 years (9.3 years).

At an interest rate of 12% and inflation at 8%, with geothermal prices again increasing at the same 11% rate as natural gas prices, the rate of return is 18.8% (24%), and the payout time is 9.4 years (7.7 years).

The payout time can be reduced to less than 7 years if the initial geothermal price is set at 95% of the natural gas price, and if it escalates at only the general inflation rate.

2. Utility-Based Private Development, with Industrial Revenue Bond Financing--A private venture by a strongly financed utility company is perhaps a more attractive approach for development of the Thermopolis resource, in part because a utility may be able to obtain lower interest rates. In addition, the normal return requirement for a utility of 15% to 20% on equity is generally less than that required by capital venture. Utility company involvement also brings to the project a corporate management that is experienced in energy development and marketing systems.

With Industrial Revenue Bond interest rates at 12% over 15 years, a general inflation rate of 8%, and geothermal energy priced initially at 80% of the gas price, the rate of return is 15.5% (17.6%) with a payout time of 10.7 years (9.3 years).

Industrial Revenue Bond rates of 10% have been historically attainable. If this were achieved in the future, with other factors as above, the rate of return becomes 16% (18.7%) with a payout time of 9.7 years (8.4 years).

3. Municipal Development--Two approaches were evaluated for municipal development of the energy system, each involving 100% financing of the capital cost: the first case considered bond financing at a 12% rate, and the second case is based on a low interest rate, 8% loan from the State of Wyoming. For both cases, over the project life of 25 years, a utility reserve fund was established at an accumulation rate of 9%. In either case, the cash flow required that the repayment schedule would have to be structured such that early year interest payments are deferred until later years when the cash flow exceeds the needs of the reserve fund. This financing approach is often taken with the issuance of municipal reserve bonds, but it requires that investors be convinced of the long-term financial stability of the project.

In the first case, with 12% bonds financing the project, the payout period was 15.1 years (14.7 years). To meet the goals of the reserve fund required that geothermal energy be priced at 86% (78%) of the natural gas price.

In the second case with an 8% loan from the State, the geothermal price was 75% (70%) of the natural gas price.

4. Private/Municipal Joint Development--This special case was designed to address an unusual cooperative program, where private venture capital provides for the development of the higher risk portions of the project, such as the production well field and the transmission lines. Other portions of the project, such as the in-town distribution and collection system, pumps and controls, would be financed by a State grant from the State Water Development Commission. For purposes of the analysis here, a 50-50 split of private and public sector capital was assumed, and all net revenues were applied to the private sector to achieve the rate of return demanded by venture capital financing. For this case, private capital was attained at an interest rate of 15%, the general inflation rate was set at 8%, and geothermal energy was initially priced at 80% of gas prices. The Base Case and both Options 1 and 2 for disposal of cooled geothermal water were evaluated.

For each option, the rate of return was between ^{32%}35% and 40%, and the payout time was between 3½ and 4 years. This specific set of conditions could be modified to consider variations with respect to both the split of capital involvement between the private investor and the City, and the split of net revenues. It would also require the most aggressive marketing effort of the various approaches since two groups, the State and private investors, would have to be pursued. It is probable, however, that this approach would be successful if its basic concept were accepted.

5. Cost Savings to Energy Users--The residential or small commercial user would incur up-front costs to hook onto the geothermal system. These costs would pay for the service lines running from the trunkline to the building, and for converting the existing heating system to work on geothermal energy. These costs were discussed in Chapter VI. The economic analysis is based on the central system assuming 70% of the cost of the service line; thus 30% of a typical cost of \$1100, or \$330, would be paid by the typical small user to tie into the system. Internal retrofitting costs will vary, of course, but it is expected that most installations will be covered by a \$400 to \$1000 investment. Thus, most individual small users can expect to pay a first cost between \$730 and \$1330. This cost can be reduced by income tax credits, so that the net cost depending on income would be between \$440 and \$800.

The first year price of geothermal energy is set at 80% of the expected natural gas cost in that year. Assuming that system startup is in

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1985, each user will then save \$1.75 per million Btu, or about \$180 for the average small user. Thereafter, the price of geothermal energy increases at 8% per year in step with the general inflation rate while natural gas prices increase at an expected 11% rate as was discussed earlier in this chapter. Thus, the savings to the user will increase each year.

On this basis, the average small user will save enough on energy costs so that the initial investment of between \$730 and \$1330 will be repaid within 3 to 5 years. When income tax credits are taken into account, the payout time will be reduced to 2 to 4 years. Just as important, the savings will continue every year thereafter. If the spread between the rate of increase of natural gas prices and the inflation rate continues over 25 years, the user will then be saving about 60% of what natural gas would have cost. The total savings over this 25-year time period would then be quite large; they amount to over \$50,000 in actual, inflated dollars, and to over \$11,000 in constant-value dollars discounted back to a 1982 basis.

The savings will be relatively much larger for the larger commercial users and for the larger public buildings. As indicated on Table 6, most of the large users consume energy at a rate 5 times faster to 140 times faster than the average small consumer. Thus, their savings in energy costs will be 5 to 140 times greater than those indicated above. Yet, the installation costs for large users will not increase that rapidly because of the economy of scale that is achieved on larger projects. Thus, a system that is, say, 10 times larger in heat consumption than the average residential use may have a retrofitting cost that is only 4 to 6 times more the cost of residential retrofitting; but the savings would be 10 times greater.

D. Summary and Recommendations

It is clear from the study results that considerable incentive exists for pursuing the long-term development of the proposed geothermal system. The substantially lower energy costs seen over the 25-year project life, and which would continue beyond that time, represent a significant economic advantage to the residents and businesses of Thermopolis. This would especially be the case for the low, fixed income segments of the community.

The proposed geothermal system is very large, and represents such a significant undertaking for a city the size of Thermopolis that a smaller first step might be a worthwhile consideration. Therefore, before a final decision is made regarding the designated construction of the full system or utilization of the Rose Dome site, it would be prudent to still evaluate other possible alternatives. These other evaluations were not made a part of this study because of the budgetary constraints; the decision was made on the basis of a preliminary overview that the full system analysis would provide the best Base Case for the required long-range planning. The results of this Base Case study, however, indicate that an additional analysis would be valuable for several reasons, including:

- the possibility that the overall rate of return will be higher with a smaller or a staged approach;
- the possibility that other approaches may be more attractive to potential private investors;
- the possibilities that water rights questions will be more tractable with other approaches.

Since there will be uncertainties involved about the exact nature of the geothermal reservoir until considerable more geological and drilling work is done, a staged project with a smaller first step might facilitate the development of public support and the obtaining of outside funding from public or private sources. Thus, one primary recommendation is that a staged approach be reexamined. The first stage of a project built in steps would encompass the development of a geothermal field just north of town, while recognizing the potential problems and advantages associated with this approach.

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The primary potential problem with this approach is the uncertainty as to the exact impact of a geothermal field at this location on the hot springs in the State Park. There is evidence that the two areas are hydrologically connected, but considerable more work needs to be done to define the extent of the interconnection. It may be that the energy load of the district heating system is small compared to the energy load carried by the underground aquifer that feeds the park, such that, although connected, the impact will be small.

Thus, a second major recommendation is that a thorough hydrogeological examination be made of the potential geothermal field north of town.

In addition, an analysis of the field north of town may demonstrate that reinjection of used waters may be feasible at this site, thus saving considerable capital costs as compared to the present reinjection site northeast of the State Park. It may also show that reinjection here effectively accomplishes a return of the Rose Dome waters to their original aquifer, such that appropriated water rights for the produced water will not be required.

Another potential advantage for a staged development is that it could increase the rate of return on the investment. This would occur, in part, because the development speed would be greater than for the full development. It would also result from the fact that the smaller number of users, and the much larger average size of the users, for the first stage would mean that the full capacity of the system would be used at an earlier date. Then, when the first stage is in successful operation and becomes highly visible, public support and additional funding for the later stages would be more easily generated.

Finally, there is still uncertainty about reservoir conditions at both the production site, at Rose Dome, and at the injection site northeast of the park. The third recommendation is that the hydrological investigations of these sites proceed.

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