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**NON-ELECTRIC APPLICATIONS OF
GEOTHERMAL ENERGY IN SIX ALASKAN TOWNS**

FINAL REPORT, OCTOBER 1976 — NOVEMBER 1977

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November 1977

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Native Corporations

Aleut	Chaluka	North Alaskan Native Assoc.
Arctic Slope	Doyon	Sealaska
Atkasook	Inupiat	Sitnasuak
Bering Straits	Kiana	Ukpeagvik
Bin Googa	King Island Council	

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SUMMARY

This report summarizes the potential for direct (non-electric) utilization of local-gradient geothermal energy in six Alaskan towns. A major objective of this study was to stimulate development and use of the geothermal resource provided by the earth's average thermal gradient, as opposed to the few anomalies that are typically chosen for geothermal development. Hence, six towns for study were selected as being representative of remote Alaskan conditions, rather than for their proximity to known geothermal resources. The moderate-temperature heat available almost everywhere at depths of two to four kilometers into the earth's mantle could satisfy a major portion of the nation's heating requirements--but the cost must be reduced. We conclude that a geothermal demonstration in Nome would probably be successful and would promote this objective.

HEATING

It was hypothesized that the high fuel costs in most of Alaska (due to transportation) and high heating duty-cycle (due to climate) would show geothermal energy to be economically competitive. Based on space heating alone, it was found that

- a. In Nome and Wrangell, the geothermal costs are close enough to fossil costs to warrant consideration on economic criteria alone;
- b. Huslia, Nikolski, and Kiana are too small for economic development of the geothermal resources due to the high well costs--development must rely on social advantages;
- c. In Barrow, geothermal energy cannot compete economically with a natural-gas well located near the town.

The table below compares annual costs of geothermal space heating and present conventional heating. The geothermal estimates are highly conservative, including the capital, interest, and maintenance costs associated with a totally new space-heating system, whereas the conventional estimates include only fuel costs. The geothermal costs are highly

	Projected 30-Year Average Annual Cost	
	Geothermal	Conventional
Barrow	\$6,147,000	\$2,137,000
Huslia	2,779,000	178,000
Kiana	2,350,000	422,000
Nikolski	2,410,000	105,000
Nome	5,313,000	3,194,000
Wrangell	2,674,000	2,579,000

sensitive to our estimated cost of drilling in these areas. Uncertainty in the geology and the drilling costs have a major influence on the validity of cost comparisons determined in this study. Advances in drilling technology would significantly lower the costs.

OTHER APPLICATIONS

The costs of geothermal heat would be reduced by developing additional applications for hot water. Potential applications for utilization of moderate-temperature geothermal energy in the six towns studied are numerous and varied.

In villages where subsistence patterns dominate the economy, such services as community bath and wash houses, refrigeration facilities, and individual greenhouses can make major contributions to the quality of life but are difficult to equate with cash benefits in a non-cash economy. Similarly, moderate-temperature geothermal heat can enhance rates of bio-degradation for sewage treatment and soil improvement, particularly crucial applications in the Arctic. Special precautions in programs involving ground or soil heating are required in permafrost regions of Alaska including the study towns of Barrow, Nome, and Kiana.

DEMONSTRATION SITES

The decision to construct a geothermal system will be based on several criteria. The table below summarizes the ratings of each town for a

demonstration site as a function of alternative economic and social criteria.

Criterion for Demonstration	Sites					
	Nome	Wrangell	Kiana	Nikolski	Huslia	Barrow
To determine relative costs, geothermal vs. alternate	excellent	excellent	fair	poor	poor	poor
To create high visibility, low-cost installation	good	fair	excellent	good	fair	poor
To enhance regional development	good	poor	excellent	good	poor	poor
To foster social stability	poor	poor	good	excellent	poor	poor

We recommend Nome as a candidate for a demonstration of moderate-temperature applications from a hot, dry-rock reservoir. Nome's status as a regional population center and its relatively large population would make such development highly visible and dramatic, as well as potentially cost-effective. Development of the geothermal resource at Nome can be justified on the bases of cost effectiveness, visibility, and the potential economic development of the region. The establishment of social stability--important to smaller, less developed towns in Alaska--is not a major problem in Nome and therefore does not represent a main issue in determining the feasibility of geothermal utilization. Development of significant new geothermal uses or a 50-percent reduction in drilling costs would ensure economic viability of this demonstration.

Kiana's central location among other villages in the Kobuk-Selawik region, and its highly favorable social climate, make this village a promising site for a total energy system based on geothermal energy (hot,

dry-rock resource) and multiple applications. New industry is badly needed in this part of Alaska and would be readily catalyzed by such development.

Nearby geothermal resources make Nikolski a very attractive candidate for geothermal development. The local-gradient resource is expected to be relatively inexpensive to develop, though not cost-competitive for the present small population of Nikolski. An important cultural benefit that would occur with geothermal development at Nikolski is the stabilization of the Aleut culture, which is in danger of disappearing entirely in future years. This stabilization would also mean continued occupation and growth of Umnak--the oldest continuous settlement in the Western Hemisphere. In time, geothermal energy might generate a cultural and economic oasis.

The cost of geothermal development for space heating in Wrangell appears to be competitive with fuel costs over the next 30 years. Wrangell is thus an outstanding candidate for direct-use geothermal energy development. Because of its relatively strong economy and large population, the criteria of enhancing development, fostering social stability, and creating a highly visible geothermal-energy-use area are less important at Wrangell than at more remote, undeveloped areas in Alaska. Development of hydroelectric resources near Wrangell is likely and might prove to be complementary (or possibly competitive) to geothermal energy.

ALASKA VERSUS "LOWER 48"

Legal and institutional factors are expected to make geothermal development in Alaska easier than in the lower 48 states. Fewer regulations and permits currently pertain in Alaska, since much of the land with potential for geothermal development is subject to state and federal regulations but few, if any, local regulations. Most land in the areas studied is owned by the state, federal government, or native corporations. The native corporations are generally eager to cooperate in endeavors that promote development in their regions and may invest in such development when geothermal implementation becomes less speculative. Local politics and interactions between regional and local native corporations will require a judicious approach at such a time.

For further geothermal development in Alaska, improved drilling technology and concomitant reduction in the cost of drilling will be of primary importance.

Though information from this study may be extrapolated to other Alaskan towns, it is not valid to assign similar weights to the individual costs of local-gradient geothermal implementation in towns of the "lower 48." For example, whereas labor and material costs for Alaska run 1.4 to 3 times the base rate in the rest of the nation, Alaskan deep-drilling costs are around 10 times those in the contiguous United States. Reduction of these drilling costs could make utilization of normal-gradient geothermal resources in Alaska economical in the near future. The relatively low cost of drilling in the "lower 48" and the dominance of these costs in the final cost-benefit analyses suggest further consideration of local-gradient geothermal energy in the contiguous United States.

I. INTRODUCTION

In October 1976, Pacific-Sierra Research Corporation (PSR) was contracted to investigate the potential application of geothermal energy in the six Alaskan villages (see Fig. 1). The research focused exclusively on "Local-Gradient Geothermal: (LGG) resources and their direct, non-electric application, with dual objectives:

- o To specify appropriate uses, costs, and benefits within each village;
- o To gain broader insight into the validity of routinely using LGG resources in Alaska.

The towns and villages investigated in this study were chosen as exemplary of diverse geography, geology, climate, demography, and energy consumption. Each is representative of numerous Alaskan villages; study results, therefore, may be generally applied throughout the state. Subsequent sections discuss each of the towns and outline the specific considerations that must be made at each site for the implementation of geothermal energy.

Some factors, such as the critical need for space heating and the high cost of construction, are characteristics that are common to all the towns. Other factors, such as the existence of permafrost at Barrow, Kiana, and Nome have prompted us to consider these sites differently from Huslia, Nikolski, and Wrangell, where permafrost is not a problem.

We have considered present energy-use substitution, as well as potential energy applications that could be implemented within the constraints of a geothermal system intended primarily to supply district heating. The energy required for greenhouse heating or other alternate uses is available from one of two sources. First, work required to provide district heating to a town over the facility lifetime requires some decimal number of geothermal wells. Since the number of real wells in a system must be increased incrementally, a demand for 0.7 wells implies that one well must be drilled, a demand for 2.3 wells implies that 3 wells must be drilled, and so forth. An excess fractional geothermal well has a finite irreversible thermodynamic availability, equivalent to some

Fig. 1--Location of the six towns (open circles)

determinable thermal power that can be utilized for a given period of time, and represents a fixed excess thermal capacity.

Second, the thermal power demanded for district heating is cyclic, with peak power required seasonally, usually between December and February. If the geothermal facilities are sized to provide peak power, then excess thermal capacity is available for alternate uses when power demand is not high. We have considered both sources of excess power capacity to determine the feasibility of utilizing geothermal energy for alternate uses in the six towns.

Based on our assessment of energy use and the geothermal resource that can be expected at each site, we have developed a geothermal-energy utilization preliminary engineering design. Our system models for each site are used to derive costs of capital equipment, quantities of direct material, and quantities of direct labor required for each installation. In addition, the models are useful for estimating such variable costs as operating and maintenance expenses. The annual cost of the geothermal system determines project feasibility, and is presented for each town.

II. INSTITUTIONAL, CULTURAL, AND LEGAL STRUCTURES

AFFECTING RESOURCE DEVELOPMENT

Every Alaskan community exists within a complex matrix of controls imposed by federal, state, local, and private authorities. Geothermal-resource development requires awareness of, and coordination with, these diverse institutions. In addition, any resource development must be undertaken with full knowledge of the delicate social, cultural, and economic fabric of the six study communities. This section describes the institutional, cultural, and legal considerations only in the most general sense; attempts to undertake geothermal-resource development in any of the subject communities should be preceded by more detailed study of these institutional and cultural concerns.

FEDERAL GOVERNMENT

The federal role in Alaska differs from that in all other states. In 1971, Alaskan natives were awarded nearly one billion dollars and forty million acres of land by the Alaska Native Land Claims Settlement Act (ANCSA). The methods chosen to distribute the land and money mandated under ANCSA are largely responsible for the present uncertainty about land ownership and regulations, as well as the existence and role of the "native corporations" (discussed below).

ANCSA mandated that title to much Alaskan land would be conveyed to Alaskan natives through the structure of regional and local corporations. (A section of ANCSA also grants the Secretary of the Interior the right to withdraw up to 110 million acres. Congress has a December 1978 deadline to determine which governmental agency will be assigned these lands.)

Land ownership in Alaska is currently in a state of flux because the majority of conveyances promised by Congress in ANCSA have not yet been completed. At present, the village sites in question are in interim conveyance; i.e., all the paperwork for each site has been completed, but actual conveyance of the land has not been legally

secured or patented. According to the Bureau of Land Management (BLM) and the Alaska State Trustees office, the village parcels of interest to this study will be conveyed--but at an unknown date.

Federal Law Governing Geothermal Development

The Federal Geothermal Steam Act of 1970 includes:

(i) All products of geothermal processes, embracing indigenous steam, hot water, and hot brines; (ii) steam and other gases, hot water and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (iii) heat or other associated energy found in geothermal formations; and (iv) any by-product derived from them (Public Law 91-581, 91st Congress, Sec. 368).

Byproducts are any mineral or minerals (exclusive of oil, hydro-carbon gas, and helium) which are found in solution or in association with geothermal steam and which have a value of less than 75 per centum of the value of the geothermal steam or are not, because of quantity, quality, or technical difficulties in extraction and production, of sufficient value to warrant extraction and production by themselves (Public Law 91-581, Sec. 2 c & d).

Thus, the moderate-temperature hydrothermal and hot, dry-rock resources considered in this study are within the guidelines of the federal act. Under Sec. 4 of the act, if one or all of the six study sites were on federal land, the lease applicant with the highest qualifications would be awarded the lease.

Federal lands exempt from geothermal leasing include those within 1) national recreation areas, 2) fish hatcheries administered by the Secretary of the Interior, 3) wildlife refuges, 4) game ranges, 5) wildlife management areas, 6) waterfowl production areas, or 7) areas acquired or reserved for the preservation of fish or wildlife threatened with extinction (Sec. 1014). These exemptions could lead to difficulties in acquisition of land surrounding some of the six villages. The ownership of these lands will not be determined until 1978, when the Alaska federal lands are reclassified by Congress. Another difficulty posed by this law is the exemption of land within fish hatcheries, since an important application of geothermal energy is the improvement of hatchery yields.

STATE GOVERNMENT

The Office of the Governor of Alaska coordinates numerous departments whose activities directly affect local welfare in rural areas. Most apparent are the Department of Community and Regional Affairs, the Department of Health and Social Services, and the Department of Education. Other state departments are involved in local affairs, proportionate to the area's economic activity.

The Department of Community and Regional Affairs is generally cognizant of such activities as geothermal utilization. Established in 1972 to provide assistance to community and regional governments, the Department comprises six divisions:

1. The Division of Local Government Assistance provides technical assistance to local governments: training of local officials, tax studies, administration of state revenue sharing and state property-tax exemption programs, collection and publication of local data.
2. The Division of Community Planning furnishes (on request) technical planning assistance to communities, administers grants-in-aid programs, and acts as liaison between communities and state and federal governments. This division also aids in policy preparation and provides planning studies on specific topics.
3. The Division of Rural Development Assistance administers Operation Mainstream and Neighborhood Youth Corps, both of which provide job experience and training for rural residents, and Rural Development Grant programs. Rural Development Grants allocate funds to small rural communities for such purposes as health clinics, fire halls, and electrification projects.
4. The Division of State Opportunity provides technical assistance for low-income individuals in technical and legal matters, especially in the fields of education, housing, health care, public safety, and community improvement.

5. The Local Boundary Commission oversees all local boundary issues, including municipal incorporation, dissolution, annexation, detachment, merger, and consolidation.
6. The Rural Affairs Commission is involved in the improvement of living conditions in rural communities and is assisted by the Division of Rural Development Assistance.

State Laws Affecting Geothermal Development

In 1971, Alaska adopted a Geothermal Resources Leasing Act governing leasing of geothermal resources on state-owned lands (*Alaska Statute* §38.05.181, 1971). The Commissioner of the Department of Natural Resources can issue prospecting permits and leases; he is further empowered to regulate operations conducted under these leases, including the following:

- the prevention of waste;
- development and conservation of geothermal and other natural resources;
- the protection of the public interest;
- assignment, segregation, extension of terms, relinquishment of leases, development contracts, utilization, pooling, and drilling agreements;
- compensatory royalty agreements, suspension of operations or production, and suspension or reduction of rentals or royalties;
- the filing of surety bonds to ensure compliance with the terms of the lease and to protect surface use and resources;
- use of the surface by a lessee or permittee of the lands embraced in his lease or permit;
- the maintenance by the lessee of an active development program;
- protection of water quality and other environmental qualities.

For the purposes of conserving the natural resources of any geothermal-resources area, or any part of them, the lessees are granted the right to unite with each other or with others, collectively operating under a cooperative or unit plan of development or operation of the geothermal-resources lands.

In addition, any person engaged in the production of geothermal resources under a lease issued by the Department of Natural Resources can commingle geothermal resources from any two or more wells without regard to whether the wells are located on lands for which the lease was issued or elsewhere. A stipulation to this provision is that the lessee has to install and maintain devices that will measure the amount of geothermal resources produced from lands for which the leases were issued.

Certain state restrictions must be considered when determining the location of any wells in the six study sites. For example, a well drilled for the discovery and production of geothermal resources is regarded as a public nuisance if it is located 1) within 300 ft of an outer boundary of the parcel of land on which it is situated or 2) within 300 ft of a public road, street, or highway dedicated before commencement of its drilling.

LOCAL GOVERNMENT

Alaska's Constitution emphasizes local (rather than state) government, encouraging and aiding rural communities in design and implementation of the type of local government best suited to their individual needs. Growth and urbanization are aided by the Department of Community and Regional Affairs through planning and initiating of new services and facilities.

The state of Alaska recognizes the city and the borough as the only local government forms that may be given power of taxation. In addition, city and borough governments funnel state services to the local level.

The entire state is divided into boroughs, formally designated as "organized" or "unorganized." The organized borough is legally a municipal corporation. The unorganized borough is not a corporation, and was conceived as a means of decentralizing state services and

encouraging the local government to develop fiscal and administrative ability to support regional functions. Factors determining a region's progression towards organized government include population, geography, resources, and transportation. According to the original intent of the state Constitution, each unorganized borough will eventually become organized. The only community considered in this study that now exists in an organized borough is Barrow, seat of the North Slope Borough, incorporated in 1972.

Title 29 of the Alaska Statutes (Municipal Government, October 1972) allows two classes of "city." Classification, determined by population, specifies the number of members of the governing body or council, selection and responsibility of the mayor, and taxation authority. "First-class cities" (in an unorganized borough) are also school districts; "second-class cities," although not school districts, have schools operated by the Bureau of Indian Affairs or the State. Of the communities considered in this study, three are first-class cities (Nome, Barrow, and Wrangell), two are second-class cities (Huslia and Kiana), and one is designated a village (Nikolski).

ROLE OF THE NATIVE CORPORATIONS

Formed in response to ANCSA, native corporations are profit-making organizations. Stockholders are the Alaskan natives entitled under the Act; capital is that granted by the federal government under ANCSA. By virtue of this constituency and economic base, the native corporations constitute a powerful institutional force in Alaska.

Native corporations exist on both regional and local levels. The village corporation and the regional corporation jointly administer the claims settlements. Payments are initially made to the regional corporations. They retain some funds, pay individual natives, and transfer the remainder to the village corporation. Within the first five years, at least 10 percent of the regional corporation's settlement must be paid to its stockholders, and at least 45 percent to village corporations in that region. The regional corporations also assist village corporations in planning claims-money use and in land selection.

The six study communities are associated with the following corporations:

City/Community	Regional Corporation	Village Corporation(s)
Nome	Bering Straits	Sitnasuak, King Island Council
Barrow	Arctic Slope	Atkasook, Ukpeagvik, Inupiat
Kiana	North Alaskan Native Association (NANA)	Kiana
Huslia	Doyon	Bin Googa
Nikolski	Aleut	Chaluka
Wrangell	Sealaska	(none)

The regional corporation represents the village corporation in matters of economic, social, and cultural needs. In practice, however, many schisms have developed between regional and village corporations. These rifts in government have evolved largely because village corporations desire to maintain traditional lifestyles whereas regional corporations emphasize development and investments. The degree of regional-village cooperation bears directly on geothermal-resource development: Section 12 of ANCSA grants surface rights to village holdings to the village corporation and subsurface rights of village holdings to the regional corporation. One stipulation states that the regional corporation may not develop subsurface property underlying village lands without official sanction of the village corporation.

Development must involve both the surface and subsurface resources, and thus both village and regional corporations. Other issues pertaining to acquisition of land for geothermal development include 1) the regional corporation's interest in development of the resource for a specific village and/or industrial application (greenhouses, mining enterprises, fish hatcheries, etc.); and 2) handling of royalties and

payments to the corporations where the village holds surface rights and the regional corporation holds subsurface rights.

Though it must be understood that regional and village interests may differ, these differences should not prevent geothermal-resource development. Disagreements reflect divergent priorities assigned to common values. Resource development that is economically beneficial and socially nondisruptive should easily achieve broad approval.

ECONOMIC CHARACTER OF THE SIX COMMUNITIES

In Alaska, particularly, conventional cost-benefit analysis techniques must be applied carefully when evaluating geothermal applications. Innovative technology is the typical domain of such analysis, usually applied to assess the relative impact on the host system (here, the six communities) of each of several hypothetical alternatives. However, the economic and sociocultural characteristics of several of the studied communities rule out straightforward calculation of costs, benefits, and risks.

Five of the six communities are economically unlike towns in the contiguous United States. Wrangell alone boasts a "modern" economy; the other five towns exhibit varying mixes of subsistence and cash-economic bases. Dalton (1965) classifies economies according to the dominance of market exchange; the six communities appear to fit his scheme as follows:

TYPE I (subsistence, marketless)	TYPE II (subsistence-cash mix; peripheral markets only)	TYPE III (cash, market- dominated)
	Kiana Barrow Nikolski	Wrangell
	Huslia	^a ←Nome→

^aNome exhibits a wide economic range because it incorporates a subsistence-based native economy into a cash-based native/non-native economy.

Traditional methods for performing cost-benefit analysis assume the existence of a purely cash-based, market-dominated economy. The more "primitive" economies (Nikolski, Huslia, Kiana) lack formal labor markets, capital markets, and distribution systems. Thus, typical economic indicators (e.g., employment) will gauge neither the quality nor extent of economic impact.

We cannot presume that any of the six communities will respond in a typical way to technologically created economic change. Providing cheap space heating through geothermal resources may free considerable cash, now spent on fuel oil, for other uses. It is difficult to predict the impact of a cash surplus on a given local economy. Two likely possibilities are equally confounding to classic economic analysis. First, the cash surplus may not materialize; people may no longer attempt to acquire the cash, since it is no longer crucial to sustaining life. Our observations and discussions suggest that many rural Alaskans will maximize leisure rather than money. This choice is in part due to individual preference and in part to traditional community pressure for maintaining economic equality.

Second, surplus cash may be distributed in ways that confound classic analytical methods. As Nash (1964) has reported in summarizing primitive economies: "Most peasant and primitive societies have a way of scrambling wealth to inhibit reinvestment in technical advance, and this prevents crystallization of class lines on an economic base" (p. 175). In this light, consider that the "potlatch"* was widely practiced throughout Alaska until fifty years ago (McFeat, 1966). Although the phenomenon is no longer institutionalized, our experience suggests that the sentiment and value system that underlay it lives on. Personal observation bears this out, as does recent literature on present-day Alaskan natives (Graburn and Strong, 1973; Jones, 1976). Moreover, discussions with community leaders revealed that available jobs are assigned according to need rather than capability, as a means to equalize wealth.

*The potlatch was a community or intercommunity gathering, ostensibly held to celebrate or mourn, where individuals or communities established social rank in direct proportion to one's ability and willingness to give away or destroy possessions. Charity and goodwill had nothing to do with it; Tlingit Indians spoke of it as war, and regarded it every bit as seriously.

SOCIOCULTURAL CHARACTERISTICS OF THE SIX COMMUNITIES

Plans for and eventual construction of geothermal-based systems in Alaska must reflect the nature and values of four distinct cultural groups: Eskimo, Athapascan Indian, Aleut, and non-native Alaskan. Each culture--and its embodiment within a particular settlement--exhibits a unique and diversified value system, world-view, and resilience (as shown by historical response to cultural and technological perturbation).

The Eskimo

The Eskimo is the predominant native group within the six subject communities, comprising about 90 percent of Barrow's population, 60 percent of Nome's, and 96 percent of Kiana's. Generally characterized in the literature as pragmatic, industrious, and competitive, the rural Eskimos have maintained a degree of cultural integrity despite several decades of economic and technological change. Alaskan Eskimos appear remarkably successful in selecting and adapting (or adapting to) the products and aspects of Western culture that further their aims.

The successful transition of the Eskimo culture is partly due to the coincidental near-identity of certain Western and Eskimo values (e.g., pragmatism and materialism). The major source of harmony, however, lies in the intrinsic adaptability of Eskimos, a quality essential to continued survival in the Arctic environment. This adaptability--which permeates the culture and its extensions--is manifested as self-reliance, cooperation, and a fatalistic acceptance of nature and her caprice. There is no Eskimo linguistic construct to indicate inevitability, i.e., "when I go"; instead, all clauses are conditional, i.e., "if I go" (Chance, 1966). This awareness of and respect for nature is deeply ingrained (Oswalt, 1967; Graburn and Strong, 1973) and should be considered in the evaluation and design of any technological innovation whose central purpose is the control of natural forces.

The capability for adaptation characteristic of the Eskimo has been extensively studied, in part to construct guidelines for effective and harmonious introduction of new technology. Of special note are five factors identified as essential qualities of nondisruptive technological implementation (Chance, 1966):

1. Change must not disrupt or diminish the intense interactions and communications among Eskimo communities in transition;
2. Change must not disturb the intricate kinship system;
3. If expectations are created by the technological transfer, the people must have (or be provided with) means to fulfill them;
4. Change must not limit the effectiveness of the traditional Eskimo leadership;
5. The Eskimo community must retain autonomy and independence.

The Indian

The people of Huslia are generally Athapascan Indian in descent. Despite considerable adaptation, Huslia's society and value system remain essentially Athapascan, stressing unity, equal distribution of wealth, and community independence to the point of isolation. These cultural traits are discussed in the anthropological literature, widely stated by other Alaskans (native and non-native alike), and borne out by our observations. The villagers are very sophisticated, protective of their community, and keenly aware that technology and technologists can be disruptive. Huslia appears in an extended period of a "nativistic movement," its people reaffirming and buttressing traditional cultural values.

VanStone (1974) provides an observation on Athapascan culture that is relevant to this study and the methods to be applied. He speaks at length of the Athapascan as

intimately concerned (although perhaps below the level of consciousness) with man's place in a harmonious natural environment. To people concerned with their role in a harmonious universe, it is expected that man should be controlled by his world and should attempt to control it in more or less equal parts.

The Aleut

Aleut culture and its extensions are difficult to discern. The Aleut have a long and violent history of contact with other cultures.

They have invariably emerged the worse: five centuries of conflict and exploitation (at the hands of Tlingit Indians, Russians, Americans, and Japanese) have reduced the total Aleut population from approximately 25,000 to 1,700. Originally, Aleut culture mirrored other subsistence societies confronting a harsh natural environment, stressing mutual aid, community harmony, and minimizing (at least the appearance of) individual economic and social advantage. Earlier studies of Aleut communities describe a progressive breakdown of cultural values and ethnic identification (Berreman, 1954; 1964). Cultural disintegration (exemplified by the expressed desires of every Nikolski child over age nine to emigrate as soon as possible) is attributed to the introduction of compulsory English education, the monetization of the economy, and other changes imposed by remote bureaucracies.

A more recent study (Jones, 1976) finds that some Aleut communities have reconstituted. These villages have done so through almost total embrace of Western culture, as opposed to the successful selective adaptations of the Eskimos and Athapaskan. Such cultural revival is possible only in the larger villages, which offer the native means for realizing the increased material expectations that invariably accompany "Westernization."

III. BARROW

INTRODUCTION

This section describes the town of Barrow--climate, demography, energy consumption, etc.--then develops in turn 1) a model of the geothermal potential underlying the town, 2) a candidate design for a system fulfilling Barrow's space-heating needs, and 3) the costs and benefits expected to accrue to the proposed system.

Sections IV through VIII treat each of the other candidate villages in a similar manner.

THE TOWN OF BARROW

The physical characteristics of Barrow, as well as the way of life of its residents, are very much a result of geographic location. Situated at $71^{\circ}17'30''$ N and $156^{\circ}47'15''$ W, Barrow is in the West Arctic Subregion of Alaska as designated by the Joint State-Federal Land Use Commission of Alaska. The city's population of about 2500 represents more than half of Alaska's total Arctic population (Selkregg, 1975). Barrow overlooks the Chukchi Sea to the west; to the northeast lies the Beaufort Sea. In winter, the land is contiguous with a vast ice shelf extending into the sea, which is then open as far as the Arctic Ice Pack; inland, snow-covered tundra extends as far as the eye can see. In summer months, much of this land is revealed as shallow thaw lakes and marshes.

Because Barrow is located far north of the Arctic Circle, three months of winter pass in continual darkness; and a negative heat balance (outgoing radiation exceeding incoming radiation) exists from September through March. Even during the long daylight periods of summer, the low angle of the sun reduces the intensity of solar radiation, so that net radiation is insufficient to thaw the ground below 30 in. The permafrost, which in the Barrow region reaches depths of 1300 ft, makes winter the optimum time to move vehicles and heavy equipment across the tundra. Such travel in summer months is extremely destructive to the land.

Geologically, Barrow is located on the Arctic Coastal Plain. In this region, Paleozoic rock layers abutting early Mesozoic layers have

formed impermeable pockets of oil and gas deposits. Above these layers are Cretaceous sandstone, conglomerate, and shale; and Tertiary sandstone, conglomerate, and siltstone. The latter is, in turn, overlain by Quaternary and recent unconsolidated deposits (till formed by glaciers of the Brooks Range during the Pleistocene era and consequently deposited on the coastal plain). The prevalence of these silty deposits in the soil around Barrow results in poor growing conditions and technical difficulties in building construction.

Although no notable metallic ore deposits have been found in this region, oil, gas, coal, and oil-shale deposits are prevalent. A small gas field at Barrow was originally tapped for the local military base thirty years ago and used until 1964 for space heating of government buildings. In 1964, the Bureau of Indian Affairs initiated a "temporary" system of gas lines to provide space heating for private residences but never replaced that system with a permanent one, leaving the city of Barrow with a dangerous, potentially explosive, energy source. Figure 2 shows some typical dwellings and a gas-line overpass. Predictions indicate that the currently used gas field will be exhausted in eight to ten years. Virtually all space heating and cooking is provided by natural gas. Electricity for other needs is provided at a cost of 15¢/kWhr by two 750-kW gas generators and by one dual-source (gas-diesel) 450-kW standby generator. The North Slope Borough uses a 2.5-MW generator through an agreement with Barrow Utilities Incorporated (BUI).

A central water-treatment plant derives water from the Isatkoak Lagoon. Though some federal facilities have piped water, most of the town has water delivered by truck; and some people still cut out and melt ice for their water supply. Since Barrow has limited sewage-treatment facilities, most of the town uses either chemical toilets or "honey buckets" (which are collected by truck for incineration).

The small amount of precipitation, the poor quality of the soil, the relative lack of sunlight, and the low ground temperature limit the variety of plant and animal life near Barrow. Grasses, berries, and wild flowers, and other small plants, when exposed, support caribou in the summer. The berries and shoots of young plants are gathered for

Fig. 2--Housing in Barrow, Alaska. Structure over street in background supports above-ground pipe for natural-gas distribution system.

human consumption. Whaling is the major subsistence contribution to the local diet. Hunting of caribou and waterfowl, and fishing for salmon, smelt, and cod also supplement the local diet. A local grocery sells staple and luxury food items.

As in many Alaskan towns, government is the largest local employer. Other employment is often seasonal and includes construction, services, trade, and transportation. Total estimated employment in 1974 was 641 people with an average family income of \$8560 (Dupere & Assoc., July 1974). Barrow has a twelve-bed hospital and clinic, and two doctors and one dentist. The one elementary and one secondary school have enrollments of 115 and 41 students, respectively.

Barrow is served by daily Wien Airlines flights from Anchorage via Fairbanks. The frequency and availability of commercial air service seem to have great impact on community life, since the local people are likely to travel to Alaska's major population centers and also are in continuous contact with other Alaskans and tourists. Nevertheless, only a relatively small number of people visit Barrow even in the summer months; but locals are endeavoring to increase tourism. To this end, the Arctic Slope Regional Corporation has constructed a modern hotel.

The commercial airline regularly carries freight to Barrow, providing a continuous (though expensive) supply of groceries, including fresh produce, and other provisions. Building materials and other large items may be airlifted in during the winter. Cargo ships are able to reach Barrow only during the months of July through October, as the coast is otherwise icebound, accumulation of pack ice usually beginning in mid-September. Since ocean barges are generally the least expensive means of transporting bulk freight, most fuel (other than local natural gas), vehicles, and building materials are brought to Barrow in this manner.

PRESENT ENERGY CONSIDERATIONS AND REQUIREMENTS FOR BARROW

Climate

Barrow is in the Arctic Climate Zone and, although located on the Arctic Ocean, does not have typically coastal weather. Temperatures are generally low, with little variation. Summer temperatures generally

range from 29°F to 44°F; winter temperatures, from -25°F to -6°F; and yearly extremes, from 78°F to -56°F. Figure 3 shows monthly heating degree days and fuel use. The average wind of 10.6 kn in the ENE direction, and extreme west winds of 55 kn make the wind-chill factor even colder. Barrow has about 20,000 heating degree days per year. The total annual precipitation average of 5 in. (including the rainfall equivalent of 29 in. of snow) makes this region an "Arctic desert."

Buildings

Although Barrow is only about 200 mi from Prudhoe Bay, the town has had little impact from the Trans-Alaskan Pipeline. Like many smaller Alaskan villages, Barrow is in a period of transition. Changes in economic and social patterns are obvious in the physical appearance of the village. Gone is the old village, and taking shape is a small town. This change is reflected by the present juxtaposition of older shacks and huts and modern dwellings. Barrow's 500 residences can be divided into three types. The first, comprising approximately 30 percent of the buildings, consists of "improved shacks" that have been partially insulated. The second consists of shacks built of plywood and scrap materials covered with tarpaper and having plastic sheets over the windows for additional insulation. This type of structure makes up about 35 percent of the dwellings. The remaining 35 percent of the residences are newer prefabricated buildings of either plywood or corrugated aluminum. Most houses in Barrow are 20 ft × 25 ft, but the newer ones are larger with approximate dimensions of 26 ft × 32 ft (see Fig. 2, p. 25).

There are 83 commercial buildings in Barrow, including one hotel-restaurant complex, the public health office, a hospital, a high school, and borough and native corporation offices. About 15 of these larger buildings house federal agencies.

Present Fuel Use and Costs

Virtually all space heating and cooling is done with natural gas. This gas is purchased from the federal government at an artificially low price by BUI. The utility company serves approximately 570 buildings. Baseboard heat and radiant-convective heat (stoves) are common, whereas

Fig. 3--Monthly heating degree days and heating fuel for Barrow

forced-air systems are unusual and found in only about 5 percent of the buildings. Two hundred buildings have gas-fueled water heaters; in the remaining buildings, domestic water is heated on stoves. Total gas consumption for the town's heating needs in 1976 was 250,000 cu ft (MCF) at an average annual cost of about \$400,000 to the town of Barrow and the federal government. (Gas rates in December of 1976 were 32.4¢/MCF to the Barrow user and 61.4¢/MCF to the federal government buildings.)

At the beginning of this study, the gas reserves supplying fuel to Barrow were expected to be depleted in eight to ten years. A recent discovery, though not yet well-delimited, is estimated to be sufficient to supply fuel to Barrow for another thirty years. A recent report for the Alaskan Power Administration (R. W. Beck & Assoc., August 1977) states:

Remaining reserves in the South Barrow Gas Field plus those in the potential new discovery have been estimated by some at approximately 75 billion cubic feet of natural gas. Based on these estimates a comparison of reserve and demand figures indicate the natural gas reserves for Barrow could exceed the projected demands to the year 2000 by a very substantial margin.

This report continues, recommending that natural gas is the lowest-cost energy source (compared with coal, oil, gas, and wind) for Barrow in the next thirty years, with a projected annual cost of \$1,090,000 to \$1,600,000 for both space heating and electrical-power generation.

Although the gas fields here are included in the Naval Petroleum Reserve No. 4, and therefore are under the jurisdiction of the Department of the Interior (since their transfer from the U. S. Navy, 1 June 1977), gas rates are "guaranteed" to Barrow in the future by the same public law that has previously ensured such rates. Public Law 94-258, Subsection (e) of Section 104 states:

(e) Until the reserve is transferred to the jurisdiction of the Secretary of the Interior, the Secretary of the Navy is authorized to develop and continue operation of the South Barrow gas field, or such other fields as may be necessary, to supply gas at reasonable and equitable rates to the native village of Barrow, and other communities and installations at or near Point Barrow, Alaska, and to installations of the Department of Defense and other agencies of the

United States located at or near Point Barrow, Alaska. After such transfer, the Secretary of the Interior shall take such actions as may be necessary to continue such service to such village, communities, installations, and agencies at reasonable and equitable rates.

As in other Alaskan towns, multiple uses of non-electric geothermal energy would be possible. These uses include sewage treatment, and community swimming pool, fish farming, greenhouses, algae culture and animal husbandry, and ice melting for drinking water.

BARROW RESERVOIR MODEL

The Barrow area is underlain by sand, gravel, clay, and sandstone to a depth of about 300 ft. Clay shales, sandstones, siltstones, and shales extend to a total depth of approximately 3000 ft. Below these formations lies a pre-Mesozoic basement of dense black argillite (see Appendix A). The upper level of the surficial deposits is interlaced with ice, and general permafrost conditions exist to a depth of approximately 700 ft. The Barrow area has been tested for oil and gas, and geologic assessment of the area (from Appendix A) indicates that:

Barrow is underlain by the so-called "Barrow High," a structural high which brings the basement up to relatively shallow depths under the Barrow area. In this case, basement is the argillite which was penetrated by the deeper Barrow test holes. Argillite was penetrated at approximately 3385 ft in the South Barrow #1 test well, where the bottom hole temperature was 85°F (30°C). This hole was located one mile southwest of Barrow village, and about 1500 ft south of the coastline. Although there were faint shows of oil in sandstone beds between 3045 and 3165 ft, formation tests recovered no oil or gas. Gas has been produced for local uses from several wells in this area. Brine has been associated with gas blows in at least two test wells. The water chemistry indicates that the waters are probably connate brines rather than sea water.

The more reliable downhole gradient measurements obtained from the test holes indicates that the average geothermal gradient is about 26°C/km under the Barrow area.

Based on our assessment of detailed geologic data for the Barrow site, we have developed a resource model that describes the specific

thermal gradient ($26^{\circ}\text{C}/\text{km}$) expected. In addition, the geologic analysis indicates the nature of the geothermal resource and the physical properties of the sections that would be encountered at depth. The required resource temperature, site-specific temperature gradient, and physical characteristics of the thermal reservoir impose some broad limits on possible geothermal system configurations and suggest a conceptual approach of how the geothermal resource might be exploited. The resultant heat extraction and utilization systems are then based on realistic judgments of resource potential and capacity. An accurate resource model provides a reasonable base upon which to judge the feasibility and the cost of geothermal power for Barrow.

The important physical characteristic of the rock groups underlying Barrow is the existence of relatively impermeable, monolithic rock that is expected at depths between 9000 ft and 17,000 ft. We have concluded that a hot (121°C), dry-rock heat source can be expected at a depth of 15,300 ft. Since the "Barrow High" brings basement rock to within 3400 ft of the surface, a thick, relatively impermeable layer of argillite can be expected at depths between 3400 ft and 9000 ft. We estimate, therefore, that the expected volume of sea-water encroachment due to migration through surface fracture systems is negligible and certainly insufficient to provide the capacity required for consideration as a heat-transfer medium.

Because no known hydrothermal reservoirs exist at Barrow, two methods of using the hot, dry rock were considered--a one-well and a two-well method. Preliminary calculations indicated that the quantity of thermal power available from a single well with a downhole heat exchanger using conventional well-bore dimensions would not be sufficient.

The two-hole method of heat extraction considered is based on use of a hydrofracturing process to generate a large-diameter, thin "wafer"-shaped crack that would provide a large downhole heat-transfer area. Water would be circulated down one well, through the crack fissure, and up the second well to remove heat from the hot rock. Hydraulically induced rock fractures have been generated by oil companies in the past to increase localized permeability in the vicinity of well-bore holes. The techniques for downhole crack propagation are well developed, and

the dense, black argillite structures of Barrow could probably be cracked extensively.

The use of hydrofracting, however, has not been proved satisfactory for a continuous-use geothermal-power application. Theoretically, good communication could be established between two wells by means of a hydraulically induced and maintained vertically oriented fissure that intersects both bore holes. Cold water injected into one well at the surface would circulate through the thin wafer crack, extracting heat from the rock. The hydrostatic head in the "cold" well would tend to drive hot, less dense water up the second well. A surface heat exchanger could extract thermal power as a function of fluid-flow rate. A circulating water pump could then complete the loop, discharging cooled water into the first well. In a frictionless system, it would be expected that the circulating pump could be removed from the loop at steady-state conditions because the density difference in the two wells would make the system self-driving.

Two factors must be considered before feasibility of such a hot, dry-rock system can be ensured. The first factor is the rate of decay of rock temperature at the crack faces as temperature drop is affected by the load requirements. We assume in this study that mean crack diameter will not exceed 3500 ft. Based on the required loads, a required lifetime for the geothermal facility at Barrow determines the number of wells required (see Appendix B). The resource lifetime for the facility is set equal to the amortization period for the purposes of energy-cost comparisons (presented in Secs. III through VIII).

The second factor to be considered is the downhole interwell pressure resistance that will be encountered under normal operating flow conditions. Research conducted at LASL indicates that system pressure resistance can in some instances be quite high. The pressure drop is not related to friction losses through the well casing or piping but is due to the extremely thin spacing between the rock faces at the fissure plane. Technical difficulties must be overcome before the design of a thermal-power production facility is finalized.

For this study, we assume that a vertical well will be drilled to a depth where the site-specific thermal gradient will provide a satisfactory source. A hydraulically induced vertical crack would be propagated;

and the hydrofractured "wafer," or possibly "potato-chip" shaped cavity, would be accurately mapped. We expect that techniques for accurate crack mapping will be demonstrated in the very near future. A second well would be slant-drilled in a plane perpendicular to the surface of symmetry of the crack. We emphasize that accurate knowledge of the hydrofractured crack orientation and well placement are critical to maintenance of reasonably low-impedance downhole interwell communication.

The crack impedance to circulating water flow is estimated to be an inverse function of the cube of the average crack width at operating pressure. Crack width is considered to be on the order of one millimeter for our "unproped" (non-overpressured) crack. For system operation flow rates required, we expect that system operating pressure will be quite high at the proposed Barrow facility. We estimate differential crack-pressure to be about 1500 psig; and the range between minimum crack-entrance pressure and crack-propagation pressure, on the order of 200 psig to 500 psig. We anticipate, therefore, that a pump discharge pressure-control system will be used.

We base the system performance and equipment requirements on the somewhat optimistic assumption that impedance due to crack fissure will be around 0.8 psi/gpm. We hope that continued research at Los Alamos will demonstrate that this impedance is reasonable.

SYSTEM DESIGN

Hot unsaturated water can be considered as a candidate for meeting some of the energy needs of Barrow only if its use is economically competitive with other means of heating. To determine if geothermal energy is competitive with other sources, we have developed a preliminary system for extraction and distribution.

Since we are concerned with developing an overall model that represents a workable implementation scheme for the town of Barrow, we performed our analysis as a preliminary engineering exercise and not a parametric study of system costs. We began our technical investigation by determining the thermal power required for district heating. Based on the specific geothermal resource considered, we have developed a

preliminary resource utilization model, in accordance with good engineering practice, to site-specific design criteria. We subsequently performed sizing calculations and developed preliminary process specifications for the materials and equipment required for a district heating system in Barrow. With the help of many vendors, we have obtained cost quotations and estimates based on our specifications. Our system design criteria are 1) safety to inhabitants and to the permafrost region; 2) high system reliability; 3) low initial cost; and 4) low O&M cost and complexity.

The resource utilization model is divided into the energy-extraction subsystem, discussed above (see p. 30), and the distribution-piping subsystem. Figure 4 shows the energy-extraction subsystem; Fig. 5, a preliminary distribution-piping subsystem.

ENERGY-EXTRACTION SUBSYSTEM

In developing the geothermal energy-extraction subsystem, we consider it critical that system safety considerations be given high priority. Because of the permafrost underlying Barrow, we have assumed that the spudding-in, drilling, and mud- and cement-injection procedures are identical to those used by deep oil-well drillers when drilling in permafrost. We consider high-pressure casing necessary because of the relatively high pressure required for hydrofracturing and normal system operation. Valve and pipe ratings and end connections are in accordance with ASME and ANSI specifications for water service at 1500 psig. The system includes a shell-and-tube counterflow heat exchanger. Although other, low-pressure heat exchangers were considered, we determined that a shell-and-tube heat exchanger with a high-pressure rating on the tubes and tubesheets was required for a hot, dry-rock resource application. Fittings and pump casings in the extraction system are also rated for high-pressure service. Cost estimates include allowances for system safety valving and instrumentation, alarms, and control logic devices. We have sized equipment so that flow rates generated by operation of the geothermal system will result in noise levels well within OSHA-specified limits.

Fig. 4--Preliminary geothermal-energy extraction subsystem for Barrow

Fig. 5--Preliminary distribution-piping subsystem for Barrow

DISTRIBUTION-PIPING SUBSYSTEM

Figure 5 shows the candidate water-distribution subsystem to be used for district heating.

Water temperature in the distribution subsystem is not to exceed 180°F. Primary safety criteria are that system pressure shall be maintained within reasonable limits, normal system operation shall have a negligible effect on the permafrost region, and no single piping failure shall cause significant damage to the permafrost region. To meet the safety criteria, we determined that maximum distribution-system design pressure be 100 psig. Further, the distribution-piping subsystem should be adequately insulated and isolated from the permafrost region. In addition, no major piping failure should go undetected, and shutoff capability should be placed at intervals throughout the system.

Because the climate imposes such a high duty-cycle on any heating system in Barrow, high system reliability is defined as high availability to the users, with provisions that system failures be repaired quickly at any time of the year. We determined that the type of piping to be used in the system must have an extensive history of reliable operation in similar applications. To ensure high reliability, the distribution system is divided into a header system with periodic crossties provided to bypass failures. Virtually all residences are considered to have service connections in parallel so that individual heaters can be operated independently. We anticipate that at least once in the lifetime of the system the entire secondary loop will be inoperative. Therefore, drain valves at low points in the piping system--necessary for freeze protection--are included in the cost estimate.

Low initial cost is a difficult objective to attain in Barrow because of the high cost of direct labor, indirect labor, and materials handling (see Appendix C). To meet the criterion of low initial cost, we considered lightweight piping systems that require minimal skilled labor for assembly and that meet the reliability and safety criteria. The candidate selected for this study is a preinsulated, aluminum-jacketed, fiberglass epoxy pipe that has been used extensively in Alaskan and Antarctic services. The bulk of the system is made up of 8-in. and 2-in.

pipe sections. Each section is a spool 20-ft long and is insulated with 2 in. of polyurethane foam. The pipe spools can be handled easily by two men and assembled by relatively unskilled labor.

We initially considered installation of underground piping. Installation of such a system in permafrost or cyclically freezing soil is a major problem, however, both in terms of man-hours required and of eventual damage to the utilidor or piping system. Burying a piping system that would distribute water at temperatures up to 180°F almost certainly implies the use of utilidors, utiliducts, and a forced-air utilidor-cooling system to maintain the integrity of the permafrost. Failures in an underground piping system would likely go undetected for an extended period. Consequently, because of the relatively high temperature of the water, a high probability exists that extensive local melting of the permafrost would occur.

The resulting subsidence phenomenon could cause extensive damage to the district heating system, as well as possible collapse of ground and structural formations in the immediate area. We estimate that the cost of installing a utilidor system would be in the neighborhood of \$200 to \$250 per linear foot. For the system proposed for Barrow, the buried utilidor system alone would cost in the neighborhood of \$8.6 to \$10.7 million. The cost of installing the utilidor does not include the costs of individual service connections, estimated for Barrow to be in the neighborhood of \$2900 per house. Because of the likelihood of damage from undetected failures, and because of the high cost of installation, we do not recommend an underground piping system for Barrow. We recommend, instead, that the piping be placed in surface-mounted utilidors.

Most of the structures in Barrow are built with floors raised off the ground, supported by framing. Generally, enough subfloor space exists to accommodate a pipe and utilidor enclosure above-ground. For the purposes of cost optimization, the distribution piping is considered to run directly beneath the structures (see Fig. 5). Piping connections made near or under structures would include tee connections with reducers and cap fittings. Individual user connections to the hot and return distribution lines could be easily installed at the above-ground connections. We estimate that the distribution subsystem would be supported by

a system of wooden cradles with pipe supports and slide plates. We expect that thrust blocks would be placed and anchored to support points where the piping changes direction.

The piping system could cross small streets by means of a simple riser and downcomer separated by a supported, relatively short, straight spool, similar to the present gas-line crossings. For larger streets, the geothermal-heating lines might be laid under the street in a slightly oversized culvert section.

SYSTEM COSTS

Table 1 develops detailed costs for the 30-yr life of the system required to supply heat to Barrow. (Appendix C discusses the methods used in deriving these costs and the assumptions that underlie their calculation.) The costs shown include all capital investment, summarized as Research and Development Costs (RDC), Production Costs (PC), and Initial Deployment Costs (IDC). The final cost category, Recurring Costs (RC), includes operating and maintenance costs exclusive of taxes, royalties, and interest on capital.

The base-case cost estimates for the Barrow system are in turn used to calculate: 1) owning costs, expressed as capital investment amortized over the system lifetime at 10-percent simple interest; 2) annual cost, the sum of that year's owning cost, recurring cost, taxes, and royalties. Table 2 displays these calculations and resulting cost estimates for the Barrow LGG system.

SYSTEM BENEFITS

In accordance with the design philosophy of direct substitution for existing fuel sources, system benefits are equal to present and projected village expenditures for space heating. Figure 6 displays these expenditures under three alternative assumptions about future natural-gas price rises.

COST-BENEFIT COMPARISON

Major uncertainties make reliable cost-benefit comparison virtually impossible. The present natural-gas system is nearing the end of its life cycle; the distribution system is reported to be "in poor condition and in need of replacement" (Beck and Associates, 1977). Moreover, the gas wells used to supply Barrow are estimated to be exhausted in eight to ten years.

The high costs estimated herein, however, make detailed analysis an academic exercise. The average annual cost of the LGG system--\$6.1 million--cannot compare with that estimated for a totally new natural-gas system--\$1.1 million to \$1.6 million. The natural-gas system would meet all of Barrow's energy needs (including the Naval Arctic Research Laboratory), as opposed to the LGG-based system for space heating alone. The disparity between these alternatives rules out LGG as a likely candidate for implementation in Barrow.

Table 1

BARROW BASE-CASE COSTS
(in \$ thousands)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
1. <u>RESEARCH AND DEVELOPMENT COST (RDC)</u>						
1.1 Survey	10					10
1.2 Site Selection	10	7	5			22
1.3 Permits	5	3	2			10
TOTAL RDC	25	10	7			42
2. <u>PRODUCTION COST (PC)</u>						
2.1 Drilling and Well Preparation						
2.1.1 Material						
2.1.2 Labor	12,450	11,130	7,079			30,659
2.1.3 Mobilization	92					92
2.1.4 Loss and Repair	125	111	71			307
2.1.5 Rig Relocation	50	106	112			268
2.2 Wellhead						
2.2.1 Material	298	316	335			949
2.2.2 Labor	61	65	69			195
2.2.3 Transportation	34	36	38			108
2.3 Utilidor	507	537	568			1,612
2.4 Distribution						
2.4.1 Material	311	330	350			991
2.4.2 Labor	27	29	31			87
2.4.3 Transportation	28	30	32			90
TOTAL PC	13,983	12,690	8,685			35,358

(continued on next page)

Table 1 (continued)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
3. INITIAL DEVELOPMENT COST (IDC)						
3.1 System Start-Up						
3.3.1 Training	8	8	9			25
3.3.2 Technical Data	6					6
3.2 Installation--Checkout						
3.2.1 Initial Spares Stockage	37	39	41			117
3.3.2 Labor	82	87	90			259
3.3 Demobilization			78			78
TOTAL IDC	133	134	318			585
4. RECURRING COST (RC)						
4.1 Monitoring, Operation, and Maintenance						
4.1.1 Spares Inventory Replenishment		4	8	13	774	799
4.1.2 Labor		95	203	320	18,930	19,548
TOTAL RC		99	211	333	19,704	20,347
OWNERSHIP COST:						
RDC	25	10	7			42
PC	13,983	12,690	8,685			35,358
IDC	133	134	318			585
RC		99	211	333	19,704	20,347
GRAND TOTAL	14,141	13,033	9,221	333	19,704	56,322

Table 2

BARROW BASE-CASE FINANCIAL SUMMARY

Total capital investment	\$ 35,985,000
30-yr ownership cost (at 10%)	143,940,000
Average annual ownership cost	4,798,000

Annual Cost--Including Capital Cost, Recurring Cost, Tax (2.25% of Gross Receipts), and Royalties (10% of Gross Receipts)

Year	Cost	Year	Cost	Year	Cost
1980	\$4798	1990	\$5969	2000	\$6286
1981	4897	1991	6000	2001	6319
1982	5009	1992	6031	2002	6352
1983	5756	1993	6062	2003	6385
1984	5786	1994	6093	2004	6418
1985	5816	1995	6125	2005	6451
1986	5846	1996	6157	2006	6485
1987	5877	1997	6189	2007	6519
1988	5907	1998	6221	2008	6553
1989	5938	1999	6253	2009	6588

Average Annual Total Cost \$6,147,000

Fig. 6--Increase in natural-gas price for space heating in Barrow compared with the cost of a geothermal system

IV. HUSLIA

THE VILLAGE OF HUSLIA

Huslia is located on the left bank of the Koyukuk River, about 300 mi northwest of Fairbanks. A village of about 150 Athapascan Indians, Huslia is far removed from urban Alaska. Although a mail plane stops in the village three times a week, communications with the outside are very limited.

The people in this region exist largely in a subsistence manner. The Indians hunt moose for meat and leather, and run trap lines for pelts in the winter. Professional guides and sport hunters are strongly discouraged from taking game in the territory around Huslia. The Athapascan women sew moccasins and mukluks from home-tanned leather and use fur skins for making outer clothing. Salmon running in the Koyukuk River are a major food source in the summer. As in many other parts of Alaska, berries are abundant in season. Subsistence living is supplemented by such items as snowmobiles and groceries that are barged into the village twice a year. Since Huslia has no exportable produce, many young men must go elsewhere to find temporary seasonal work. Outside work has included the Trans-Alaskan Pipeline, sawmills, and mining operations.

Three diesel generators, rated at 160 kW, 75 kW, and 50 kW, supply Huslia with electricity through the Alaskan Village Electric Cooperative, Inc. (AVEC). In 1974 a water-distribution system was installed, serving most of the village, and septic tanks and flush toilets were installed. Space heating is accomplished by burning spruce in individual wood-burning stoves. Snowmobiles and sleds are used to haul dead or fallen trees to the village, a distance of about six miles. Buildings in Huslia are typically single-story and log-walled (see Fig. 7). Figure 8 presents heating degree days.

Direct representation is a successful form of local government in Huslia. The village, a second-class city, is ruled by a quorum consisting of all council members plus 50 percent of the village. Meetings are held once a month, but additional meetings are called whenever a topic needs to be discussed. The village is very closely tied to Bin Googa, Inc., the local corporation, through many officials common to both.

Fig. 7--Single-story log-wall buildings in Huslia

Fig. 8--Monthly heating degree days for Huslia

Discussions with local officials indicate that Huslia, although interested in less expensive sources of energy, is generally cautious in accepting technological change and concerned about the impact that such change would have on the village.

SPACE-HEATING ENERGY USE

We estimate that Huslia consumes 210 cords of firewood per year for space heating. The current wood supply, six miles from the town, is hauled in by sled (pulled by snowmobile). By assigning shadow prices to the wood and the labor required to cut and transport it, we have arrived at a 1976 energy-cost estimate of \$67,000 applicable to space heating.

HUSLIA RESOURCE MODEL

It is reasonable to assume that the geothermal gradient under Huslia is similar to that measured in the Nulato #1 test well, as geologic mapping indicates that both localities are underlain by the same formational rock units. Data from the Nulato well indicate that the thermal gradient at Huslia is 18.6°C/km. The minimum fluid temperature considered practical for direct-use applications is 150°F (65.5°C). We have therefore chosen a model that assumes the existence of an aquifer at a depth of 11,600 ft (3.52 km).

We first considered various aquifer and utilization system models, including heat-pump topping and continuous blowdown configurations. Because the total cost of the geothermal facility at Huslia is dominated by the cost of drilling, we chose a system that minimizes drilling depth and, therefore, resource brine temperature. We attempted to avoid the cost and complexity of a reinjection well. Unfortunately, the fluid would be rejected as warm (120°F) brine, and would certainly mix with the Koyukuk River water. Because of the impact on the river salmon and the town's potable water supply, we determined that brine blowdown should not be considered, and that reinjection of spent brine is required. Because of the extremely low thermal load in Huslia (1.00 MW), we determined that topping is not required.

If a typical connate brine exists under hydrostatic pressure at 11,600 ft, bottom-hole pressure would be

$$(11,600)(0.437)(2.4) = 12,166 \text{ psig.}$$

Wellhead pressure then could reasonably be expected to be

$$12,166 - (11,600)(0.437) = 7100 \text{ psi.}$$

Since the Nulato well did not exhibit high final-flow pressure, we have no reason to believe that the aquifer at Huslia would exhibit the characteristics of a geo-pressured resource; therefore, final hydrostatic head should be much less than 7100 psig. We do, however, assume an artesian condition so that a pressure-reducing valve could be placed at the wellhead and the system would be self-driving.

Based on the above reservoir model, a heat-extraction subsystem and a distribution subsystem were developed, sized, and estimated. System details and cost conclusions are discussed below.

SYSTEM DESIGN

As in Barrow, we have modeled an overall geothermal-energy utilization system for Huslia so that realistic cost estimates can be made. The resource utilization model is divided into the energy-extraction subsystem, which is based on the expected resource discussed above, and the distribution-piping subsystem.

The design criteria that we feel are important at Huslia are 1) high system reliability, 2) low initial cost, and 3) low O&M cost and complexity. The system is described below, and Appendix D presents detailed calculations for the town. Since the geothermal resource expected at Huslia is not a high-pressure resource, the system is inherently safe for the town's inhabitants. In addition, preliminary investigation indicates that permafrost protection is not a system constraint, obviating the need for a surface utilidor system.

ENERGY-EXTRACTION SUBSYSTEM

Figure 9 represents the preliminary geothermal-energy extraction subsystem. Materials and equipment are rated for the intended service. Piping and valves can be standard schedule, unlike the high-pressure equipment required for Barrow. The heat exchanger is a plate-type counter-flow, low-pressure device with inherently high heat-transfer characteristics. Added advantages of plate-type heat exchangers are that they are very simple to disassemble and clean, they can be designed for brine service, and they can be maintained by relatively unskilled personnel. Pumps and pressure-control valves have been specified for low-pressure service. As in Barrow, cost estimates include allowance for block valves, instrumentation alarms, and control logic devices.

DISTRIBUTION-PIPING SUBSYSTEM

Figure 10 shows the candidate water-distribution subsystem to be used for district heating. Because of the relatively low resource temperature at Huslia, temperature in the distribution subsystem will not exceed 150°F. As in the Barrow facility, operating pressure should not exceed 100 psig.

The distribution-piping subsystem should be insulated to minimize heat loss between heat exchanger and users. As in Barrow, no major piping failure should go undetected, and shutoff capability should be placed at intervals throughout the system. Because of the critical need for heating, the system must be highly reliable, with provisions for quick repair of system failures at any time of year. We determined that the type of piping to be used in the system must have a history of reliable operation in similar applications. To ensure high availability, the distribution subsystem is divided into a header system with periodic crossties provided to bypass failures. Virtually all residences are designed with service connections in parallel so that individual heaters can be operated independently. We anticipate that at least once in the lifetime of the system the entire secondary loop will be inoperative. Therefore, the drain valves at low points in the piping subsystem--necessary for freeze protection--are included in the cost estimate.

Fig. 9--Preliminary geothermal-energy extraction subsystem for Huslia

Fig. 10--Preliminary distribution-piping subsystem for Huslia

As in other remote Alaskan towns, low initial system cost is difficult to attain in Huslia because of the high cost of direct labor, indirect labor, and materials handling (see Appendix C). To minimize initial cost, we considered lightweight piping systems that require minimal skilled labor for assembly and that meet the reliability and safety criteria. The candidate selected for this study is a preinsulated, aluminum-jacketed, fiberglass epoxy pipe (as was suggested for Barrow). The bulk of the piping system is made up of 3-in. pipe sections. Each section is a 20-ft spool insulated with 2 in. of polyurethane foam. The pipe spools can be handled easily by two men and assembled by relatively unskilled labor.

Lacking evidence of permafrost at Huslia, we have based our cost estimate on a buried piping system. For aesthetic reasons, and for protection from accidental mechanical damage, we believe that piping should be buried unless permafrost conditions exist. Individual user connections to the hot and return distribution lines could easily be installed by connecting service lines and short risers to each house. In town, the piping spools could run directly beneath the streets.

SYSTEM COSTS AND BENEFITS

Table 3 details costs for the Huslia LGG system, and the table below summarizes the full life-cycle costs that would need to be repaid over the system lifetime. We will dispense with further cost-benefit analysis because:

- The population of Huslia is too small to consider financing such a system;
- No opportunities exist for developing an industrial or agricultural rationale for system development;
- The future fuel supply for Huslia appears secure: wood remains plentiful; bulk fuel storage tanks have been constructed, and the Koyukuk River provides summer access to the storage facility; though the use of the bulk tanks is currently uncertain, economic pressures will dictate their use long before an LGG-based system;

Table 3

HUSLIA BASE-CASE COSTS
(in \$ thousands)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
1. <u>RESEARCH AND DEVELOPMENT COST (RDC)</u>						
1.1 Survey	4					4
1.2 Site Selection	4					4
1.3 Permits	5					5
TOTAL RDC	13					13
2. <u>PRODUCTION COST (PC)</u>						
2.1 Drilling and Well Preparation						
2.1.1 Material	15,000					15,000
2.1.2 Labor						
2.1.3 Mobilization	90					90
2.1.4 Loss and Repair	150					150
2.1.5 Rig Relocation	50					50
2.2 Wellhead						
2.2.1 Material	76					76
2.2.2 Labor	24					24
2.2.3 Transportation	5					5
2.3 Utilidor	23					23
2.4 Distribution						
2.4.1 Material	186					186
2.4.2 Labor	174					174
2.4.3 Transportation	20					20
TOTAL PC	16,698					16,698

(continued on next page)

Table 3 (continued)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
3. INITIAL DEVELOPMENT COST (IDC)						
3.1 System Start-Up						
3.3.1 Training	8					8
3.3.2 Technical Data	6					6
3.2 Installation--Checkout						
3.2.1 Initial Spares Stockage	16					16
3.3.2 Labor	82					82
3.3 Demobilization		60				60
TOTAL IDC	112	60				172
4. RECURRING COST (RC)						
4.1 Monitoring, Operation, and Maintenance						
4.1.1 Spares Inventory Replenishment		2	2	2	106	112
4.1.2 Labor		95	101	107	6,336	6,639
TOTAL RC		97	103	109	6,442	6,751
OWNERSHIP COST:						
RDC	13					13
PC	16,698					16,698
IDC	112	60				172
RC		97	103	109	6,442	6,751
GRAND TOTAL	16,823	157	103	109	6,442	23,634

- Huslia demonstrates no compelling social or environmental need for substituting geothermal for surface resources.

Total capital investment	\$16,883,000
30-yr ownership cost (at 10%)	67,532,000
Average annual ownership cost	2,251,000
Average annual cost	2,779,000

V. KIANA

THE VILLAGE OF KIANA

Kiana is an Inupiat Eskimo village of about 300 people, located on the right bank of the Kobuk River about 60-mi east of Kotzebue. Kiana lies in the Kobuk-Selawik Lowlands of the Kotzebue Sound Subregion between the Baird Mountains to the north and the Waring Mountains to the south. The lowlands are drained by the Kobuk River and its tributaries. Many meandering streams with large sidesloughs and thaw lakes cover the surrounding plains. Large gravel and sand terraces, 100 ft to 200 ft above sea level, are visible from the air.

The river floodplains and gentle slopes that constitute most of the Kiana area are made up surficially of unconsolidated alluvial deposits of clay, silt, gravel, and morainal till from the Pleistocene and recent epochs. Older alluvial and marine sediments have been graywacke, slate, and volcanic rock. Vegetation consists predominantly of scrub and boreal forests. Nearby spruce and poplar forests add to the beauty of this river village.

The land in the Kobuk-Selawik area is underlain by discontinuous permafrost. The Kobuk River usually freezes up in October and breaks up beginning in May. Summer temperatures range from 42°F to 68°F, and the winter range is -16°F to 1°F. The weather is not so extreme as in the more interior locations, and Kiana is not near enough to the coast to experience much maritime weather. Precipitation totals only 16 in. each year (including the rain equivalent of 60 in. of snow).

Power to all homes in Kiana is supplied by the Alaska Village Electric Cooperative using three diesel generators with 35-, 70-, and 100-kW capabilities. Most houses are heated with fuel oil, which is barged in and bought from a local dealer. Water is drawn from wells and stored in a 20,000-gal reservoir. (Some local people, incidentally, talk of a nearby stream that, they say, is "warm" year-round.) Most of Kiana's homes are serviced by a sewer system with an aeration treatment plant. There are also individual septic-tank systems.

Kiana seems an ideal model of technology adapted to rural village customs. The residents support themselves in much the same way as have their forebears for generations. Salmon fishing in the Kobuk and nearby fresh-water lakes is a major activity in summer. Nearly every family has a boat--most equipped with outboard motors--for fishing and river travel. Trapping for fox, lynx, marten, wolverine, weasel, and wolf in the winter is made efficient through widespread use of snowmobiles. The land provides good grazing for the caribou and moose that migrate to the Kiana region in fall and winter. Grizzly and black bears appear in the nearby hills in the fall as they feed prior to hibernation. Many waterfowl inhabit the region.

In addition to this wealth of subsistence resources, Kiana has a strong cash economy. The village boasts two large general stores and a small grocery cooperative. The Kiana mining district has substantial deposits of gold, copper, lead, nickel, and zinc. In the early 1900s, nearly 50,000 oz of placer gold were taken from nearby Klery Creek. No lode mining, however, exists--nor any known petroleum deposits--in the immediate region.

Although Kiana has no critical need for alternative energy sources, its people are presently quite dependent on the barge lines for their fuel transportation and have expressed dissatisfaction at the escalating costs of fuel freight charges.

PRESENT ENERGY CONSIDERATIONS AND REQUIREMENTS FOR KIANA

Climate

Kiana's weather is somewhat harsher than that of Nome. Since there is no climatological recording station at Kiana, data used in this study were obtained from Noorvik, a village about 30 mi from Kiana. Fuel use in Kiana and climatological data from July 1975 through June 1976 were studied. (Complete fuel-use records were available at the elementary school complex and were helpful in determining the monthly fuel-use patterns for the town.) Figure 11 shows fuel use and heating degree days. The design temperature used for Kiana is -35°F. The lowest

Fig. 11--Monthly heating degree days and heating fuel for Kiana, 1975-1976

recorded temperature in Kiana is -54°F , and the yearly average number of heating degree days is 15,471.

Buildings

Kiana has approximately 87 buildings. Of these, about 25 are public buildings or stores; 60, houses; and the remainder, unoccupied or storage buildings. Kiana, at most recent count, has a population of 314 and averages about 5 people per household. Most buildings in Kiana are frame, but four are made of logs. In addition, several trailers are in use at present.

The average house in Kiana is a 20-ft $\times$ 32-ft frame building. Most buildings in this village (Fig. 12) are in good condition and are insulated to about the same degree as houses in Nome. Other nonresidential buildings in town vary in size and are generally slightly larger than the average housing in Nome. The school complexes, one of which is shown in Fig. 13, have a total area of nearly 20,000 sq ft (compared with a total residential building area of about 38,400 sq ft). Thus, it is not surprising that the fuel used to heat Kiana's school is a large proportion of the town's total use of heating fuel.

Present Fuel Use and Cost

Everyone in Kiana, with one exception, uses No.-1 stove oil for space and water heating. Stoves are generally convective/radiative; and in many instances, the oil cook stove is the only source of heating. The fuel oil, costing 51¢/gal at Kotzebue, is barged to Kiana at a cost of 23¢/gal. The consumer at Kiana pays 97.7¢/gal for this fuel at local stores.

One householder in Kiana uses wood for heating fuel. She uses 5 cords of wood per year, which is equivalent to 8.15×10^7 Btu/yr. With a stove efficiency of 0.5, the fuel used to heat her house provides 4.07×10^7 Btu/yr. The remainder of the town used 128,730 gal of No.-1 oil in 1975-1976 at a cost of \$125,769 (plus the "cost" of the firewood--negligible here, but considered important in Huslia, where wood is the primary heating fuel).

Fig. 12--Village of Kiana

Fig. 13--The high school in Kiana

KIANA RESOURCE MODEL

Kiana is located on the Kobuk River, about 30 mi north of the Arctic Circle. The town is underlain by 200 ft to 300 ft of surficial sediments in a region where the permafrost is believed to extend to depths of 800 ft. The relatively shallow sedimentary layer is underlain by crystalline schists of the Brooks Range metamorphic belt, including phyllites, green-schists, quartz-mica schists, and blueschists.

No thermal springs have been verified in the area near Kiana. Since no deep holes have been drilled in the area, and no downhole data are available, we have estimated a thermal gradient of 30°C/km based on knowledge of gradients in other metamorphic terrains. As in Barrow, the deep geologic sections underlying Kiana are essentially monolithic metamorphic rock, with very low porosity/permeability characteristics. Consequently, the expected resource is hot, dry rock that would be exploited by use of an induced fluid system (see Fig. 14).

The thermal load required for Kiana is lower than the load for Barrow. We have modeled a geothermal resource of 100°C (212°F) at a mean depth of 3333 m (10,937 ft). This temperature provides a satisfactory amount of heat for the town for 30 years. In addition, the temperature and thermal power that can be developed by drilling to this depth obviate the need for multiple wellsets. Because well costs dominate system costs, it is very desirable to minimize the total drilling required in Alaskan geothermal facilities.

SYSTEM DESIGN

As for Barrow, the resource utilization model for Kiana is divided into an energy-extraction subsystem and a distribution-piping subsystem. To determine if geothermal energy is competitive with other sources of heating in Kiana, we have developed a preliminary system for extraction and distribution. Because of the geological similarity between the heat resources of Barrow and of Kiana, a single-system model will be used for both towns. Again, system design criteria are 1) safety to inhabitants and to the permafrost region, 2) high system reliability, 3) low initial cost, and 4) low operation and maintenance cost and complexity. The

Fig. 14--Preliminary geothermal-energy extraction subsystem for Kiana

system is described below; and Appendix D presents detailed sizing calculations for Kiana. The calculations presented are typical of the load-sizing calculations performed for both Barrow and Kiana. Note that for the sake of brevity we have included detailed calculations only for Huslia and Kiana. We used the system size and process-state conditions to develop equipment specifications--for which equipment manufacturers provided accurate, though short-term, cost estimates.

The system-sizing considerations made in Appendix D are based on the application of geothermal energy to meet existing load requirements. We do not estimate a trend in population growth in the town, as we feel that moderate growth would affect geothermal- and fossil-fuel use equally. We discuss below alternate applications when the district-heating systems are not fully utilized.

ENERGY-EXTRACTION SUBSYSTEM

Geological assessment of the crystalline schists underlying Kiana indicates virtually no likelihood of encountering a hot aquifer or a zone of hot rock that has any reasonable degree of permeability. We assume that a normal thermal gradient condition ($30^{\circ}\text{C}/\text{km}$) exists at Kiana and that a hot, dry-rock source (100°C) at 10,940 ft can be expected.

The two-hole method of heat extraction considered is based on use of a hydrofracturing process very similar to the system discussed for Barrow. As in Barrow, high-pressure casing is considered necessary because of the relatively high pressure required for hydrofracturing and normal system operation. Wellhead piping connections, valves, heat-exchanger tubes, fittings, and the pump casing are also rated for high-pressure service. Because of the relatively low temperature of the geothermal fluid, piping and valve cost estimates are to be made on the basis of sizing in accordance with applicable ASME and ANSI codes. Estimates allow for system safety instrumentation, alarms, and control logic devices.

We have determined that flow rates generated by operation of the geothermal system described here are within OSHA-specified limits.

DISTRIBUTION-PIPING SUBSYSTEM

Figure 15 shows the candidate water-distribution subsystem to be used for district heating. Kiana is situated in an area of extensive permafrost. Because the actual extent and depth of permafrost are unknown, in this study the town will be treated as if it were situated in a region of continuous permafrost.

Water temperature in the distribution system is not to exceed 180°F. Primary safety criteria are that system pressure shall be maintained within reasonable limits, normal system operation shall have a negligible effect on the permafrost region, and no single piping failure shall cause significant damage to the permafrost region. To meet the safety criteria, we determined that maximum distribution-system design pressure be 100 psig. Further, the distribution-piping subsystem should be adequately insulated and isolated from the permafrost region. In addition, no major piping failure should go undetected, and shut-off capability should be placed at intervals throughout the system.

Because the climate imposes such a high duty-cycle on any heating system in Kiana, high system reliability is defined as high availability to the users, with provisions for quick repair of system failures at any time of year. We determined that the type of piping to be used in the system must have a history of reliable operation in similar applications. To ensure high reliability, the distribution system is divided into a header system with periodic crossties provided to bypass failures. Virtually all residences are designed with service connections in parallel so that individual heaters can be operated independently. We anticipate that at least once in the lifetime of the system the entire secondary loop will be inoperative. Therefore, the drain valves at low points in the piping system--necessary for freeze protection--are included in the cost estimate.

Low initial cost is difficult to attain in Kiana because of the high cost of direct labor, indirect labor, and materials handling (see Appendix C). Because conditions are similar to those at Barrow and Huslia, consideration was given to lightweight piping systems that require minimal skilled labor for assembly and that meet the reliability and safety criteria.

Fig. 15--Preliminary distribution-piping subsystem for Kiana

The candidate selected is the same preinsulated aluminum-jacketed, fiberglass epoxy pipe as recommended for both Barrow and Huslia. For Kiana, the bulk of the piping system is made up of 3-in. pipe sections.

Initially, we considered installation of underground piping. Because of the permafrost condition at Kiana, however, we do not recommend an underground piping system.

Most of the structures in Kiana are built with the floor raised off the ground, supported by framing. Generally, enough subfloor space exists to accommodate a 6-in. or 8-in. outside-diameter pipe. For the purposes of cost optimization, we assume that the district-heating distribution piping runs directly beneath the structures (see Fig. 15). Piping connections made near or under the structures would include tee connections with reducers and cap fittings. Individual user connections to hot and return distribution lines could easily be installed at the above-ground connections. We estimate that the distribution system would be supported by a system of wooden cradles with pipe supports and slide plates. We expect that thrust blocks would be placed and anchored to support points where the piping changes direction.

The piping system could cross narrow streets by means of a simple riser and downcomer separated by a supported, relatively short, straight spool. For wider streets, the geothermal heating lines might be laid underground in a slightly oversized culvert section.

BASE-CASE SYSTEM COSTS

Table 4 displays the base-case costs of the Kiana LGG system. The table below summarizes the full life-cycle costs.

Total capital investment	\$11,185,000
30-yr ownership cost (at 10%)	44,740,000
Average annual ownership cost	1,491,000
Average annual cost	2,350,000

Table 4

KIANA BASE-CASE COSTS
(in \$ thousands)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
1. <u>RESEARCH AND DEVELOPMENT COST (RDC)</u>						
1.1 Survey	4					4
1.2 Site Selection	4					4
1.3 Permits	5					5
TOTAL RDC	13					13
2. <u>PRODUCTION COST (PC)</u>						
2.1 Drilling and Well Preparation						
2.1.1 Material						
2.1.2 Labor	10,000					10,000
2.1.3 Mobilization	92					92
2.1.4 Loss and Repair	100					100
2.1.5 Rig Relocation	50					50
2.2 Wellhead						
2.2.1 Material	135					135
2.2.2 Labor	41					41
2.2.3 Transportation	11					11
2.3 Utilidor	224					224
2.4 Distribution						
2.4.1 Material	160					160
2.4.2 Labor	173					173
2.4.3 Transportation	16					16
TOTAL PC	11,002					11,002

(continued on next page)

Table 4 (continued)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
3. <u>INITIAL DEVELOPMENT COST (IDC)</u>						
3.1 System Start-Up						
3.3.1 Training	8					8
3.3.2 Technical Data	5					5
3.2 Installation--Checkout						
3.2.1 Initial Spares Stockage	18					18
3.3.2 Labor	82					82
3.3 Demobilization	57					57
TOTAL IDC	170					170
4. <u>RECURRING COST (RC)</u>						
4.1 Monitoring, Operation, and Maintenance						
4.1.1 Spares Inventory Replenishment		2	2	2	126	132
4.1.2 Labor		95	101	107	6,336	6,639
TOTAL RC		97	103	109	6,462	6,771
OWNERSHIP COST: RDC	13					13
PC	11,002					11,002
IDC	170					170
RC		97	103	109	6,462	6,771
GRAND TOTAL	11,185	97	103	109	6,462	18,056

BASE-CASE SYSTEM BENEFITS

As stated above, space heating in Kiana consumes approximately 130,000 gal of stove oil. The total retail value of this stove oil--about \$161,000 at the current price of \$0.98 per gal--is pegged as the revenue stream permissible in a pure substitution case. It is immediately apparent that economics rule out building the envisioned geothermal system in Kiana solely for space heating.

Kiana, however, offers an opportunity to examine the net economic and social benefits that might result from using the excess capacity of the geothermal system to support other applications. Kiana has a small population, but it might easily attract a larger work force from the nearby numerous small towns of the Kobuk-Selawik region. In addition, transportation of materials and produce to and from Kiana presents only minor logistic and economic barriers: the airstrip can accommodate C-130 Hercules aircraft, and the Kobuk River permits barging of equipment during the summer.

GEOHERMAL ENERGY AS GROWTH CATALYST: A SPECULATION

The excess capacity of the Kiana system might be used to transform its inhabitants' way of life. The ensuing discussion illustrates the type and nature of services and industry that might be provided. Where possible, we have attempted to size these services, and conclude with rough estimates of the direct and external costs and benefits that might result from an attempt to fully exploit low-temperature geothermal resources in a small Arctic village.

The ensuing speculations, however, should be considered within the following constraints:

- Detailed design of services and exact cost-benefit calculations are well beyond the scope of the present study;
- Like the geothermal system itself, most of the services described are highly capital-intensive, and serve a constituency that possesses neither capital nor the means for its formation. It is doubtful, therefore, that any of the projects could be undertaken without governmental assistance;

- The residents of Kiana have stated no desire to "transform" their town or way of life.

The excess capacity at Kiana could support two revenue-producing activities--greenhouse agriculture and aquaculture--and provide three valuable services: 1) water heating; 2) community laundry, bathing, and swimming facilities; 3) enhanced waste treatment.

Greenhouse Agriculture

Fresh vegetables and other produce are very difficult to obtain in many Alaskan towns. In many parts of the state, severe climate and transportation costs make produce unavailable most of the year. Since demand far exceeds supply, many Alaskans take advantage of the long summer days by using small conventional greenhouses to extend the short growing season. In Kiana, we consider the use of geothermal energy for greenhouse heating to be a very practical way of increasing produce production in the spring and summer seasons when district-heating requirements are low.

To determine if an adequate supply of energy is available, we have developed some preliminary estimates of produce demand in the town, as well as some greenhouse thermal-power estimates.

The lifestyle of Kiana is still very much that of a hunting and gathering culture. Although agriculture and greenhouse culture are somewhat foreign to this way of life, cabbage, root crops, and tubers would be attractive food products to the inhabitants; mushrooms would be a good support crop. Greenhouses with geothermally heated soil beds would allow reasonable production of these vegetables in Kiana.

Greenhouse Energy Requirements

It is very difficult to maintain constant temperature within a greenhouse because of the structure's inherently rapid temperature response to changes in solar radiation. As conduction, convection, and radiation heat flows change, conventional greenhouses must be alternately heated and cooled. In addition, coordinated ventilation/temperature control systems must be utilized to maintain proper humidity levels. Fortunately, Kiana's climate is cool, and greenhouse cooling systems are not required. The

design of the greenhouse heating system must be based on daily minimum temperature, minimum crop-sustaining temperature, and greenhouse size. Ventilation can be controlled by manually operated or automatically modulated dampers.

We have based our heating requirements on 1) a minimum monthly dry-bulb measurement of 0°F; 2) a design wind speed of 15 mph; and 3) providing a four-to-eight-month growing season (see Table 5). So designed, greenhouse systems could be operated seasonally when relatively little district heating is required.

Table 5
MINIMUM MONTHLY DRY-BULB TEMPERATURE^a

Kiana (Noorvik Data)	Mean Daily Min. (°F)	Record Low (°F)
January	-14.7	-54
February	-16.3	-49
March	- 6.3	-43
April	3.1	-30
May	24.4	- 3
June	41.9	2.6
July	47.2	33
August	45.1	22
September	36.4	14
October	21.3	-20
November	4.1	-33
December	-10.4	-52

^a1976 data

Heat-transfer losses from our theoretical greenhouse are calculated based on the assumption that double-paned glass will be used.

We pointed out above that fluctuations in greenhouse temperature during the day respond very quickly to variations in insolation, and that some modulation of air dampers may be required to control greenhouse temperature and humidity. It is obvious that a greenhouse energy balance during daylight hours is a function of conduction, convection, radiation, and infiltration energy-transfer mechanisms. But maximum required heating

load will occur at night, when solar radiation is zero and outside ambient temperature is at a minimum.

Radiation loss from within the greenhouse is negligible. This phenomenon is referred to as the "greenhouse effect." Clear sheet glass will transmit about 90 percent of incident radiation with wavelengths between 0.3 and 3 microns. But virtually all types of glass are opaque to longwave radiation of the type that would be emitted by bodies with temperatures below 250°F within the greenhouse. At night, radiation will occur outside the greenhouse, i.e., the outside surface of glass will radiate to the "black" sky at a fairly constant rate. This radiation will affect the outside-surface temperature, T_{os} , which in turn will affect the conduction gradient through the greenhouse wall. A steady heat-loss model can then be described by a control volume drawn around a section of wall (see figure below), where

$$q_C = h_{os}(T_{os} - T_o)A,$$

$$q_R = \sigma \epsilon (T_{os}^4 - T_{sky}^4)A,$$

$$q_L = U'(T_i - T_{os})A,$$

$$h_{os} = \text{outside-surface convective heat-transfer coefficient} = 6.0 \text{ Btu/hr ft}^2 \text{ } ^\circ\text{R for 15-mph wind,}$$

$$T_{os} = \text{outside-surface temperature,}$$

$$T_o = 460^\circ\text{R for Kiana,}$$

$$\sigma = 0.1714 \times 10^{-8} \text{ Btu/hr ft}^2 \text{ } ^\circ\text{R}^4 \text{ (Stefan Boltzmann constant),}$$

$$T_{sky} = 410^\circ\text{R (effective outer-space temperature),}$$

$$\epsilon = 0.94 \text{ emissivity for glass,}$$

$$U' = \text{overall heat-transfer coefficient, excluding } h_{os}, = \frac{1}{\sum R_i} =$$

$$\frac{1}{\frac{1}{h_i} + \frac{2x_G}{k_G} + \frac{x_{air}}{k_{air}}} \approx 0.60 \frac{\text{Btu}}{\text{hr ft}^2 \text{ } ^\circ\text{R}},$$

$$T_i = 510^\circ\text{R arbitrarily.}$$

Then, at steady state,

$$q_L = q_C + q_R = 0.60(510 - T_{os}) = 6.0(T_{os} - T_o) + 1.6 \times 10^{-9}(T_{os}^4 - 2.826 \times 10^{10}).$$

Rewriting:

$$6T_o + 351.5 = 6.6T_{os} + 1.61 \times 10^{-9}T_{os}^4.$$

Solving implicitly for T_{os} ,

$$T_o = 460^\circ\text{R} \Rightarrow T_{os} = 460.5^\circ\text{R}.$$

Note that T_{os} is very close to outside-air temperature. Heat loss through the greenhouse surfaces, q_L , can then be calculated directly:

$$\begin{aligned} q_L &= U'A(T_i - T_{os}) \\ &= 0.6A(510 - T_{os}) \\ &= 29.7A \frac{\text{Btu}}{\text{hr}}. \end{aligned}$$

To calculate infiltration losses and demonstrate thermal-power capacity, we have chosen an arbitrarily sized greenhouse to be 20 ft $\times$ 20 ft, 10-ft high at top of plate, with a 45° pitched roof. Surface area, A , is then 1566 ft² and volume, V , is 6000 ft³.

Infiltration loss, assuming two exchanges per hour due to air leakage and controlled ventilation, is

$$q_I = 2\rho V C_p (T_i - T_o) ,$$

where for air at 50°F,

$$\rho = 0.078 \frac{\text{lb}}{\text{ft}^3}$$

$$C_p = 0.24 \frac{\text{Btu}}{\text{lb F}}$$

and, therefore,

$$q_I = 11232 \frac{\text{Btu}}{\text{hr}} .$$

Total heat loss from our greenhouse is

$$\begin{aligned} Q &= q_L + q_I \\ &= 57742.2 \frac{\text{Btu}}{\text{hr}} = 1.691 \times 10^{-2} \text{ MW for Kiana.} \end{aligned}$$

Kiana is expected to use an average of 0.89 MW over the life of the facility, but this amount represents only 42 percent of the thermal capacity of the facility (see Appendix B)--which implies that 1.23 MW of excess capacity exists at Kiana. Since each of our "standard" greenhouses consumes 1.7×10^{-2} MW, 72 greenhouses could actually be built. We estimate that this capacity to supply produce far exceeds the demand of the town.

Water Heating

As demonstrated in the resource-life calculations (Appendix B) for Kiana, a two-hole hot, dry-rock system will provide roughly twice the thermal capacity required for district heating. In addition to space heating, service-water heating, warming of water pipes to prevent freezing, and maintaining an emergency water reserve for fire fighting are possible applications. Due to permafrost discontinuity at Kiana,

extensive damage from thawing is less likely than at Barrow, should pipes be run in underground utilidors along with water-distribution and sewer pipes; but problems could still occur. The Public Health Service installed the local water-distribution system here in 1974 and found only occasional permafrost at the 5-ft depths used for burying pipe. Because of uncertainty regarding the safety of the permafrost, we do not recommend applications that would involve buried lines.

Waste Treatment

Kiana has two solid-waste-treatment and two sewage-treatment plants. Aeration and chlorination prior to dumping in the Kobuk River constitute the current environmentally acceptable treatment. Should waste degradation become necessary in the future, or should biodegradation be more economical, geothermal heat could be used because the temperatures in this study are well within the useful temperature range. Enhanced solid-waste-treatment facilities could provide Kiana greenhouses with a resource that is scarce in Arctic regions: rich soil. Composted humus is a routine byproduct of such treatment plants and could be used to renew greenhouse soils.

Laundry and Bathing

A single community "wash house" would be useful in Kiana, where existing facilities are much more limited than in the larger towns. A "bathhouse" might also be acceptable to the local residents, who occasionally travel by snowmobile to hot springs more than 50 mi from Kiana. Temperatures of about 45°C, appropriate for the bathhouse and acceptable for laundry uses, are well within the capacity of the system.

Swimming Pool

A geothermally heated community swimming pool, possibly located at the high school, would provide recreation and promote swimming instruction (badly needed in rural Alaska). This is a low-temperature (30°C) use of geothermal energy, and heat required to obtain this temperature is readily available in the proposed Kiana system. Similar applications have been successfully implemented in the Soviet Union and in Iceland.

Aquaculture

Geothermally facilitated aquaculture, based in the salmon streams of the Kobuk or fish culture in a nearby lake, along with drying and refrigeration facilities, could increase local fishing from subsistence to commercial levels. Temperatures required for aquaculture applications are in the range of 20°C and would be obtainable from the geothermal resource described for Kiana. Since Kiana is in a region of discontinuous permafrost, refrigeration may be more economically accomplished using simple local means such as food-storage cellars. Slow drying of fish, meat, and greenhouse products is possible at temperatures available in the proposed system.

Costs and Benefits of Additional Services

Table 6 specifies a complement of additional services, all served by geothermal energy. The costs identified are as speculative as the services themselves, based on doubling a range of estimates for similar services in the contiguous United States. Where direct economic benefits may be realized, the estimate and underlying rationale are stated.

Most of the accrued benefits are unpredictable. Transforming Kiana in the manner discussed could lead to a considerable population shift to Kiana from neighboring villages. Centralization would bring considerable economic return to the town, and would ease the region's economic distress. The primary benefits of the additional services result from enhancing the quality of the natives' lives. We cannot assign a monetary value to this improvement. Social and moral arguments--for or against--are beyond our competence and charter.

The most compelling argument probably lies in designating Kiana a demonstration site to address the uncertainties discussed. The absolute costs are relatively small, the benefits highly uncertain and potentially great. A small investment in the Kiana demonstration could yield important insights and information, applicable to all areas of the Arctic. Alaskan natives are currently in transition: their traditional culture and economy no longer support them, yet they are some distance from full integration into the American mainstream. A demonstration might identify that the most effective role of abundant energy is easing the classic--and costly--difficulties of transition.

Table 6

COSTS AND BENEFITS OF ADDITIONAL USES

Use	Estimated Cost	Potential Return
<u>Greenhouse Agriculture</u>		
Heating and soil warming for:		
25 greenhouses, 400 ft ² , export produce	\$750,000 to \$1,300,000	\$40,000 to \$60,000 annually (export and local subsistence combined)
5 greenhouses, 400 ft ² , local consumption		
<u>Aquaculture</u>		
Small open-basin fish farm (salmon)	\$8,000 to \$20,000	N/A
Sewage treatment	\$1,000 to \$3,000 (heating only)	Decomposed organic wastes to greenhouses; enhanced treatment efficiency
Community bath house	\$30,000 to \$55,000	External (QOL)
Swimming pool	\$70,000 and up	External (QOL)

VI. NIKOLSKI

THE VILLAGE OF NIKOLSKI

Nikolski, a tiny village of about fifty people, sits on Umnak Island in the Fox Islands group about 800 mi southwest of Anchorage on the Aleutian Chain. The village is situated near Nikolski Bay, between Umnak Lake to the south and Mts. Vsevidof (7050 ft) and Recheshnoi (6510 ft) to the north. The steep, squat mountains and rolling hills are virtually treeless.

The region about Nikolski has high geothermal potential. Twenty-five hot springs are scattered along the Chain between Cold Bay and Attu Island. Mt. Vsevidof is an active volcano, as is Mt. Tulik (4111 ft), farther northeast on Umnak Island. Near Tulik is Mt. Okmok (3519 ft) with the Okmok Caldera (6.5-mi wide) at its center. The Aleutian Islands were volcanically formed and are part of the chain of active volcanoes encircling the Pacific Ocean. In addition to volcanic activity, the Aleutian region has high earthquake potential due to the subduction of the North Pacific Plate under the Continental Plate, as further evidenced by the Aleutian Trench. The islands proper are located on the Continental Shelf, with the Bering abyssal plain to the northwest and the Aleutian Trench to the south.

The people of Nikolski endure a harsh maritime climate. Though the temperatures are mild for Alaska (37° to 50°F in summer, 26° to 39°F in winter), the weather is cloudy, foggy, or rainy much of the time. Annual precipitation is 82 in (34 in. of which is rainfall equivalent of snow-fall); prevailing northwesterly winds average 13.8 kn. These adverse conditions account for a reported 35-percent occurrence of obstructed vision.

The land around Nikolski has little agricultural value other than for grazing. Vegetation varies from moist tundra heath in the lowlands to grassy and alpine hillsides. Though Umnak was formerly the site of an active military installation, there is little development at Nikolski and little local employment. A sheep ranch, started in 1936, provides only a few summer jobs. (A short-lived fox farm operated in Nikolski

during the 1920s,) Local jobs consist of a janitorial position at the school, that of a part-time health aid for the Indian Health Service, and the position of local postmaster. Unlike other Aleut villages, Nikolski has no commercial fishing industry. Local inhabitants participate in a predominantly cash economy, the men leaving each summer to work elsewhere. Jobs in the region include seal processing at St. Paul, warehouse work at Cold Bay, sheep shearing on another part of Umnak or at Unalaska Island, and fish processing at Unalaska village.

Life in Nikolski shows much less urban influence than any of the other sites studied: water is drawn from a nearby pond; sanitary facilities consist of both outhouses and flush toilets with septic tanks; electricity, in 50 percent of the houses, comes from privately operated generators.

Climate

Although Nikolski is the most southerly of the towns investigated in this study, the harshness of the climate due to wind, precipitation, and humidity makes the fuel use for a residence in Nikolski nearly as great as that for a comparable residence in Kiana. Monthly heating degree days in Nikolski are presented in Fig. 16. (No records of monthly fuel use were available in Nikolski, and bulk fuel is delivered to the town semi-annually.) The mean minimum temperature for the coldest month in Nikolski, January, is 26.2°F, and the total annual number of heating degree days is 9865.

Buildings

Most buildings in Nikolski are single-story frame residences. The average-size house is 24 ft × 20 ft and is divided into three or four rooms. There are about 20 houses, with occupancy varying from 1 to 5 people in a house and an average occupancy of 2.5 people per house. Although there is no permafrost problem in Nikolski, most buildings do have a dead-air space below the floor. The two largest buildings in Nikolski are the school (with approximate dimensions of 80 ft × 30 ft) and the two-story Russian Orthodox Church (30 ft × 20 ft). Newer buildings in Nikolski are relatively well-insulated. (One person who had recently built a house described the materials as follows: walls of 3/4-in. plywood, 3-in. fiberglass insulation, and 3/8-in. plywood; ceiling insulated with 3-in. fiberglass; floors of 3/4-in. plywood; subfloors 3/4-in. plywood; 1-ft air space below floor;

Fig. 16--Monthly heating degree days for Nikolski

double- and single-glazed windows.) Older houses are poorly insulated and drafty. (Most of the buildings in Nikolski are "older" buildings.)

The local sheep ranch has several buildings, one of which is a partially heated barn.

Present Fuel Use and Cost

Nearly all space and water heating in Nikolski is accomplished with oil-fueled (No.-1 heating oil) cook stoves. Fuel use by residents averages two drums (53 gal) per month in the winter and 1-1/2 drums per month in the summer months. Approximately 25,000 gal of No-1 fuel oil are used for space and water heating in Nikolski each year. The cost of this fuel in 1976-1977 was 92.5¢/gal, making the annual cost of fuel in Nikolski \$23,125. Thirty-six drums per month, or nearly 23,000 gal/yr are used for heating at the sheep ranch at a cost of approximately \$21,000/yr. All fuel must be shipped into Nikolski on the spring and fall trips of the Northstar III ship through the Bureau of Indian Affairs.

NIKOLSKI RESOURCE MODEL

Nikolski is located on Umnak Island of the Alaskan Chain, on the so-called "Ring of Fire," the chain of volcanoes that forms the backbone of the Aleutian Islands and the Alaskan Peninsula. Evidence exists of thermal hot springs on the island, with reservoir temperatures of 150°C or more at Geyser Bight and Hot Springs Cove. Despite this evidence of thermal springs and of volcanism on the island, the structure of the area underlying the town does not suggest that excessively high (150°C) temperatures would be encountered by drilling. The Nikolski area is underlain by sedimentary rocks that are cut or intercalated with keratophyres and albitized diabase sills. It is logical to deduce that the actual gradient is quite good, and that the Tertiary sandstones, siltstones, and other Tertiary rocks would yield a very good saltwater-bearing aquifer.

Umnak's heat resource could be exploited in two ways. Tapping the known, high-temperature water at, say, Geyser Bight would minimize the risk of encountering an adequate reservoir. The relatively hot water

would have to be piped from Geyser Bight to Nikolski, a distance of eight to ten miles. Although we have not performed a detailed analysis of the economics of such a piping/pumping system, utilization of remote resources is tempting.

The second way of utilizing geothermal energy at Nikolski would be to drill at or near the village site. Although wells have been drilled near Cold Bay and elsewhere on the Alaskan Chain, none has been drilled in the section of rock that underlies Nikolski. Lacking subsurface information, we have chosen a model that appears to be similar to Nikolski, based on lithology, geothermal gradient, and aquifers. Geologic assessment of the Nikolski area indicates that rock structures are very similar to those underlying the Cape Espenberg area of the Seward Peninsula. The Cape Espenberg No.-1 well has been drilled, tested, and is considered to be the closest available representation of an empirical resource model for Nikolski.

Cape Espenberg well No. 1 is 8373-ft deep. The first 1000 ft are fitted with a $10\frac{3}{4}$ -in. I.D. casing. The balance of the hole is fitted with $7\frac{5}{8}$ -in. I.D. casing. In open-hole testing (2.76-in. tubing inserted to a depth of 7914 ft), it was observed that the water level rose to a static level of 7414 ft in 230 min. Bottom-hole temperature was 161°F. The water in the hole was analyzed to be a light brine (~2000 ppm NaCl). Table 7 shows pressure readings recorded during the test.

Table 7

OPEN-HOLE TEST--CAPE ESPENBERG NO.-1 WELL

Recording Depth	8124 ft	8036 ft
Initial hydrostatic	4336 psig (10,002 ft)	4296 psig (9,910 ft)
Initial flow	3160 psig (7,290 ft)	3118 psig (7,193 ft)
Final flow	3541 psig (8,168 ft)	3494 psig (8,060 ft)
Final shut-in	3552 psig (8,194 ft)	3499 psig (8,072 ft)
Final hydrostatic	4226 psig (9,748 ft)	4262 psig (9,827 ft)

Source: Standard Oil of California. Well-completion report and log for Cape Espenberg Well No. 1.

Based on the recorded water-level rise during the test, an average flow rate into the well hole from the aquifer can be calculated. We assume that aquifer capacity is sufficient to drive the level in the 7.62-in.-diameter well and the 2.76-in.-diameter string at the same rate:

$$\text{Volume of well filled with water} = \frac{\pi (10.75)^2}{4} (41) + \frac{\pi (7.62)^2}{4} (7373) = 2361 \text{ ft}^3$$

$$\text{Average flow rate} = \frac{2361 \text{ ft}^3}{230 \text{ min}} = 10.26 \frac{\text{ft}^3}{\text{min}} \Leftrightarrow 76.77 \text{ gpm.}$$

This flow rate is higher than the flow required for district heating at Nikolski. Due to a lack of information on aquifer characteristics, however, a conclusive statement about both long-term bottom-hole pressure and sustained flow rate cannot be made.

Note that final flow pressure is the hydrostatic head of the column of brine ($\rho = 0.437$) in the hole, assuming final flow is zero gpm. Final hydrostatic is bottom-hole pressure against the head of drilling mud used. Since final flow pressure at 8124 ft is approximately 8100 ft of head, some doubt exists that the final fluid level of 7414 ft in the hole was actually recorded under no-flow conditions. For this study, we assume that bottom-hole pressure at Nikolski will not drop to less than the more conservative final flow pressure. The assumption is based on the evidence of fairly high porosity in the aquifer rock structure and on the expected recharge rates. Because of the relatively low flow rate (32 gpm) demanded by Nikolski, we anticipate that diffusion to the borehole in the aquifer would be rapid. With these assumptions, minimum bottom-hole pressure would equal 7414 ft of hydrostatic head. Since the borehole depth is 8373 ft, worst-case operation of the well would require that the geothermal brine be pumped 959 ft to the surface.

Assuming that the brine encountered at Nikolski would have a temperature of 161°F (as at Cape Espenberg No. 1), a wellhead heat exchanger with the following characteristics could be used:

"Hot" Brine Side:

$$T_{IN} = 161^{\circ}\text{F}$$

$$T_{OUT} = 140^{\circ}\text{F}$$

$$\Delta T_{LM} = 13.6^{\circ}\text{F}, \text{ assuming a counterflow configuration.}$$

Circulating Water Side:

$$T_{IN} = 122^{\circ}\text{F}$$

$$T_{OUT} = 151^{\circ}\text{F}$$

The circulating water would then be distributed in Nikolski through a piping system. Figure 17 shows the heat-extraction subsystem.

We first considered direct use of geothermal brine, pumping the fluid into the distribution-piping subsystem. This scheme was rejected because of the periodic maintenance problems that would be incurred throughout the system as dissolved solids were accumulated.

SYSTEM DESIGN

The Nikolski model is very similar to the Huslia model in that both towns would exploit a hydrothermal resource in a region of no permafrost. The major difference between the two sites is that the reservoir at Huslia is artesian, whereas the reservoir at Nikolski must be pumped. The resource utilization model is divided into the energy-extraction subsystem (based on the expected resource discussed above, p. 82 ff.) and the distribution-piping subsystem.

The design criteria that we feel are important at Nikolski are 1) high system reliability, 2) low initial cost, and 3) low O&M and complexity. Since the geothermal resource expected at Nikolski is not a high-pressure resource, the system is inherently safe to the town's inhabitants.

ENERGY-EXTRACTION SUBSYSTEM

Figure 17 represents the preliminary geothermal energy-extraction subsystem. Materials and equipment are rated for light brine service. Piping and valves can be standard schedule, unlike the high-pressure equipment required for the hot, dry-rock applications. The heat exchanger is a plate-type counterflow, low-pressure device with inherently high heat-transfer characteristics. Advantages of plate-type heat exchangers are that they are very good for brine or fouling-fluid service, simple

Fig. 17--Preliminary geothermal-energy extraction subsystem for Nikolski

to disassemble and clean, and can be maintained by relatively unskilled personnel. Pumps and pressure-control valves have been specified for low-pressure service. As in the other towns considered, cost estimates include allowance for block valves, instrumentation alarms, and logic control devices.

The Nikolski heat-extraction subsystem requires the use of a downhole pump to develop the head required for heat-exchanger operation. We believe that it is unreasonable to expect a conventional downhole pump to operate in hot-brine service for extended periods. Consequently, our cost estimate is based on the use of two downhole pumps that can be sequentially operated from a control-panel selector switch. Each pump is controlled by a separate flow controller, on/off/auto station, and discharge-pressure control switch. It is intended that the system can be fully operational with one pump out of service for repairs.

DISTRIBUTION-PIPING SUBSYSTEM

Figure 18 shows the candidate water-distribution subsystem to be used for district heating. Because of the relatively low resource temperature at Nikolski, temperature in the distribution subsystem will not exceed 151°F. As in the Barrow facility, operating pressure should not exceed 100 psig.

The distribution-piping subsystem should be insulated to minimize heat loss between heat exchanger and users. As in Huslia, no major piping failure should go undetected, and shutoff capability should be placed at intervals throughout the system. Because the geothermal resource is required both for town heating and economic self-sufficiency, the system must be highly reliable, with provisions for quick repair of system failures at any time of year. We determined that the type of piping to be used in the system must have a history of reliable operation in similar applications. We assume that virtually all residences have service connections in parallel so that individual heaters can be operated independently. As for the other towns considered, we anticipate that at least once in the lifetime of the system the entire secondary loop will be inoperative. Therefore, the drain valves at low points in the piping system--necessary for freeze protection--are included in the cost estimate.

Fig. 18--Preliminary distribution-piping subsystem for Nikolski

Because of the high cost of direct labor, indirect labor, and materials handling, low initial system cost for Nikolski is difficult to attain (see Appendix C). To minimize initial cost, we considered lightweight piping systems that require minimal skilled labor for assembly and that meet the reliability and safety criteria. The candidate selected for purposes of this study is the same preinsulated, aluminum-jacketed, fiberglass epoxy pipe suggested for the other towns considered. The bulk of the system is made up of 2-in. pipe sections. Each section is a 20-ft spool insulated with 2 in. of polyurethane foam. The pipe spools can be handled easily by two men and assembled by relatively unskilled labor.

Because of the maritime climate on the Alaskan Chain, no permafrost exists at Nikolski; therefore, we have developed our cost estimate on the basis of a buried piping system. For aesthetic reasons, and for protection from accidental mechanical damage, we believe that piping should be buried unless permafrost conditions exist. Individual user connections to the hot and return distribution lines could easily be installed by connecting service lines and short risers to each house. The piping spools could run directly beneath the town streets.

SYSTEM COSTS AND BENEFITS

Table 8 displays the base-case costs of the Nikolski system, and the table below summarizes the full life-cycle costs. As in both Huslia and Kiana, Nikolski's space-heating revenue is miniscule compared with the geothermal system costs. Including the adjacent sheep ranch, annual Nikolski expenditures for space heating are less than \$40,000. As Nikolski might be appropriate for a high-visibility, low-cost demonstration, we have considered implementing additional applications.

Total capital investment	\$14,506,000
30-yr ownership cost (at 10%)	58,024,000
Average annual ownership cost	1,934,000
Average annual cost	2,410,000

Table 8

NIKOLSKI BASE-CASE COSTS
(in \$ thousands)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
1. <u>RESEARCH AND DEVELOPMENT COST (RDC)</u>						
1.1 Survey	4					4
1.2 Site Selection	4					4
1.3 Permits	5					5
TOTAL RDC	13					13
2. <u>PRODUCTION COST (PC)</u>						
2.1 Drilling and Well Preparation						
2.1.1 Material						
2.1.2 Labor	14,000					14,000
2.1.3 Mobilization	90					90
2.1.4 Loss and Repair	14					14
2.1.5 Rig Relocation	50					50
2.2 Wellhead						
2.2.1 Material	59					59
2.2.2 Labor	22					22
2.2.3 Transportation	8					8
2.3 Utilidor	8					8
2.4 Distribution						
2.4.1 Material	35					35
2.4.2 Labor	43					43
2.4.3 Transportation	6					6
TOTAL PC	14,335					14,335

(continued on next page)

Table 8 (continued)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
3. <u>INITIAL DEVELOPMENT COST (IDC)</u>						
3.1 System Start-Up						
3.3.1 Training	8					8
3.3.2 Technical Data	6					6
3.2 Installation--Checkout						
3.2.1 Initial Spares Stockage	6					6
3.3.2 Labor	82					82
3.3 Demobilization	57					57
TOTAL IDC	158					158
4. <u>RECURRING COST (RC)</u>						
4.1 Monitoring, Operation, and Maintenance						
4.1.1 Spares Inventory Replenishment		1	1	1	40	43
4.1.2 Labor		95	101	107	6,336	6,639
TOTAL RC		96	102	108	6,376	6,682
OWNERSHIP COST: RDC	13					13
PC	14,335					14,335
IDC	158					158
RC		96	102	108	6,376	6,682
GRAND TOTAL	14,506	96	102	108	6,376	21,188

Greenhouses

Implementing greenhouse production, even on a small scale, would provide the town of Nikolski with an increased self-sufficiency, both in terms of food production and economic stability. Since Nikolski is a center of Aleut culture, economic stabilization could help ensure the continuation of the culture, which is in danger of disappearing entirely.

Although we consider district heating to be the primary use for energy, we consider the use of geothermal energy for greenhouse heating to be a very practical way of increasing produce production in the spring and summer seasons when district heating requirements are low. To determine if an adequate supply of energy is available, we have developed a preliminary estimate of greenhouse thermal power required.

Because of rapid response to changes in insolation, the temperature inside a greenhouse is difficult to control. As heat flows vary, conventional greenhouses must be heated and cooled. In the town of Nikolski, we have considered the use of a conventional greenhouse fitted with soil and air heaters that utilize water heated from the geothermal resource. Cooling and humidity control can be accomplished by modulation of air dampers because the outside air temperature is low. Based on daily minimum temperature, minimum crop-sustaining temperature, and greenhouse size, we have determined the amount of geothermal energy required to heat a greenhouse at Nikolski. We can then compare the amount of power required to the amount of power available from our resource to determine if heating the greenhouse is reasonable.

We have based our heating requirements on a minimum seasonal dry-bulb measurement (see Table 9) and a design wind speed of 15 mph. We have chosen a minimum outside design temperature of 10°F for Nikolski, to provide a four-to-six-month growing season. The greenhouse system then can be operated seasonally when relatively little district heating is required.

Heat-transfer losses from our theoretical greenhouse are calculated according to the assumption that double-paned glass will be used.

Table 9

MINIMUM DRY-BULB TEMPERATURE AT NIKOLSKI AND COLD BAY^a

Month	Mean Minimum Temperature (°F)	Average Minimum Temperature (°F)	Lowest Temperature (°F)
January	26.2	19.9	1
February	26.8	17.8	-3
March	27.3	16.3	-4
April	27.9	22.5	4
May	33.8	32.0	26
June	37.3	38.8	32
July	41.5	44.7	39
August	43.1	45.4	39
September	41.5	40.7	31
October	36.2	34.5	10
November	31.1	25.2	15
December	28.4	22.9	1

^a1976 data from National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Asheville, North Carolina.

We pointed out above that fluctuations in greenhouse temperature during the day respond very quickly to variations in insolation, and that some modulation of air dampers may be required to control greenhouse temperature and humidity. It is obvious that a greenhouse energy balance during daylight hours is a function of conduction, convection, radiation, and infiltration energy-transfer mechanisms. But maximum required heating load will occur at night, when solar radiation is zero, and outside ambient air temperature is at a minimum.

The heat transfer out of a greenhouse is due to conduction, convection, radiation, and infiltration. Clear sheet glass will transmit about 90 percent of incident radiation with wavelengths between 0.3 and 3 microns. But virtually all types of glass are opaque to longwave radiation of the type that would be emitted by bodies within the greenhouse with temperatures below 250°F. Therefore, radiation loss from within the greenhouse is negligible. This phenomenon is referred to as the "greenhouse effect." Note, however, that at night radiation will occur outside the greenhouse. That is, the outside surface of glass will radiate to the "black" sky at

a fairly constant rate. This radiation will affect the outside-surface temperature, T_{os} , which in turn will affect the conduction gradient through the greenhouse wall. Heat-flux calculations have been performed in a manner exactly the same as the procedure outlined in the discussion of Kiana, with T_o equal to 470°R . Detailed calculations for heat loss at Nikolski have been omitted, but power cost from a 20 ft $\times$ 20 ft greenhouse is estimated to be $47,697 \frac{\text{Btu}}{\text{hr}}$, or 1.397×10^{-2} MW.

Sheep Ranch and Other Animal Husbandry

In addition to space and water heating for the village, space heating of the buildings at the sheep ranch is a major application for moderate-temperature geothermal energy. Small, heated shelters were also suggested by the operators of the sheep ranch as having the potential to increase the survival rate of lambs at birth. The island of Umnak is rich in grazing land with the potential to support many more sheep than are raised here at present.

An anticipated shearing plant would also benefit from this new heat source, and geothermally heated facilities for washing and drying of wool could increase wool production here to significant proportions. A small mill for the production of yarns would require relatively little further development, and knit products would allow a profitable cottage industry to form in Nikolski (and possibly on nearby islands) much as has occurred in Iceland. Any of the various wool products could easily be exported to the Alaskan and world markets from the Aleutian chain by the present modes of transportation: weekly flights to Anchorage or the semi-annual trips of the Northstar III ship.

Aquaculture

Nikolski appears to be an ideal setting for a salmon hatchery. Numbers of salmon in this area are diminishing each year. There is a natural salmon stream leading to a large fresh-water pond at Nikolski, as well as another salmon stream just outside of town, where a hatchery could be located.

Processing

In addition to wool processing, mentioned previously, the capability to process and preserve meat and fish would be greatly enhanced by a large refrigeration facility and, if high-temperature geothermal heat is found to be readily available (from sources further north on the island), a local cannery. Drying of kelp for local fertilizer and for foreign markets is another important potential use of geothermal energy at Nikolski. The nearby bays are rich in beds of kelp which could readily be harvested.

Other Uses

Community bath and wash houses and sewage biodegradation facilities would be appropriate additional uses of geothermal energy at Nikolski.

Although small in population, Nikolski appears to have a dramatic potential for multiple direct heat applications of moderate-temperature geothermal energy. Although little is known of the geology at Nikolski, the island of Umnak has reported geothermal resources (active volcanoes, hot springs, and hot caves). The island is rich in grazing land, has a natural location suited to the development of a salmon hatchery, already has weekly flights linking it with Anchorage and the rest of the world, is centrally located on the Aleutian chain, and is an idyllic spot to live for those who can find employment there without spending months at a time away from home.

The local residents and the Chaluka Native Corporation (the local corporation) as well as the Aleut Corporation are eager to develop the geothermal resources here and to promote a local industry.

EXTENDED SYSTEM COST-BENEFIT DISCUSSION

Arguments for system construction must again be founded on social concern and the need to demonstrate the effect of abundant energy on the transition from a subsistence to cash economy. Nikolski has consistently lost population since such statistics have been recorded. A geothermal-energy demonstration could reasonably be expected to reverse this trend, drawing settlers to Nikolski from remote islands to the east and west. The Aleut people and culture could recrystallize on Umnak, around Nikolski,

the oldest continuous settlement in the western hemisphere. Ummak is equi-distant from Tokyo and Los Angeles, and might serve--in grandiose schemes--as a site for joint U.S.-Japan ventures in agriculture or industry requiring cheap and abundant low-temperature energy. One such application is aluminum production, so highly energy-intensive that the costs of transporting bauxite in and ingots out are more than offset by low energy costs.

VII. NOME

THE TOWN OF NOME

Nome is a legendary gold-rush town situated on the gently rising southern coastal plains of the Seward Peninsula facing the Norton Sound. Although at the time of the Great Gold Rush of 1900, the people of Nome numbered nearly 30,000, today's population is a mere 2,500. No longer a predominantly non-native town, more than half of the local people are Eskimos. Some friction is apparent as the two cultures co-exist in a city whose location, determined by an industry now nearly defunct, offers few resources to support the existing population.

Nome has a predominantly cash economy. Government is the major employer, with jobs in the tourist industry on the increase. Although the Alaska Gold Company of UV Industries, Inc. has recently reactivated two of its gold dredges (shut down since 1962) and is hoping to continue operations, few additional jobs have yet to be provided. At this time, it is still too early to predict the eventual impact of this industry on Nome's economy. Offshore gold dredging has also been considered in this area, but has not yet been developed. Other mineral deposits in the area include tungsten, antimony, and fluorite, but difficulties involved in exporting minerals limit small mining operations. Commercial reindeer herding by natives has not succeeded because of lack of management of the herds. A small reindeer-processing plant in Nome is closed at present.

Nome lacks a deep-water port. The shallow coastal waters (i.e., only 80-ft deep, 30,000-ft offshore) necessitate lightering of cargo with barges approximately one mile from shore. Freight costs are thus increased by about 25 percent. New barge facilities have been studied and proposed, but the economic feasibility of such a project has yet to be proven.

The coast at Nome is currently protected by a rock seawall built by the Army Corps of Engineers in 1951. Prior to that time, coastal storms brought severe damage to the town and heavy beach erosion during the summer months. As recently as 1974, a coastal storm caused major

flooding that reached inland as far as the airport. Other detrimental coastal influences include "ice push" (where huge sheets of ice are pushed inland during storms), prevailing shore drift, and deposition of gravel and silt in the already shallow waters.

Permafrost up to 600-ft deep underlies most of this region and is an important consideration in building construction. Several buildings in downtown Nome show the effects of "frost heave." Breakup usually occurs in the Norton Sound around May 29, and freezeup around November 12. (This past year, however, has been an unusually warm one in Alaska, and many major bodies of water had not completely frozen by late January.) Nome normally experiences maritime weather from June through November, with cool summers (39° to 56°F) and moderate winters (-3°F to 14°F). Precipitation is annually about 16 in. (including the equivalent of 54 in. of snow). Temperature inversions are common; but the open terrain and moderate winds (averaging northerly at 9 kn) generally alleviate any air pollution. Blowing dust (from unpaved streets), however, is a serious summertime problem.

Many people of the Nome area depend on sparse natural resources for a great part of their subsistence. The surrounding terrain is generally moist tundra, low hills, and sand dunes. Plant growth is limited to small shrubs, lichens, mosses, berries, and grasses. The small numbers of grazing animals such as caribou and moose found in the area are important food sources. The Nome and Snake Rivers have an annual salmon migration, and fish (including tomcod, herring, whitefish, smelt, and steelhead trout) forms a major component of the local diet. No commercial fishing is done in the area, though the potential of such an industry has been studied. Walrus and seal are taken near Nome, the skins and ivory fashioned and sculpted by native craftsmen for local sale and export.

Nome, like Barrow, is accessible by air, with regular service provided by Wien and Alaska Airlines. People from nearby villages travel to Nome for shopping and health care. A hospital and clinic is staffed by three doctors and three dentists. Children from outlying villages come to Nome for secondary education.

Most homes in the town are served by Nome Light and Power Utilities, whose five diesel generators (three rated at 60 kW, one at 350 kW, and one at 1233 kW) provide electricity at a cost of 13¢/kWhr. Heating is done with fuel oil. Surface water is taken from springs and wells and stored in a reservoir before distribution. Many houses are served by water mains and sewer lines, but approximately half of the population still have water delivered to their houses and depend on "honey bucket" pickups. A comprehensive city water and sewer plan was developed in 1976 and will probably be constructed when funding becomes available.

PRESENT ENERGY CONSIDERATIONS AND REQUIREMENTS FOR NOME

Climate

The subarctic climate is a major influence on Nome's heating load. The period July 1975 through June 1976 is taken as a typical weather year for purposes of this study. The same period for 1976-1977, for example, does not provide representative data for Alaska, since this was an unusually warm year.

Figure 19 shows monthly heating degree days (NOAA, 1965-1976) and fuel use for Nome. Fuel use is based on monthly fuel deliveries to representative buildings in Nome. (Total annual fuel is discussed below.)

Nome climatological data (NOAA, 1941-1970), including temperature extremes and average wind values, lead us to choose a design temperature of -28°F for this locality.

Buildings

Although many buildings in Nome are poorly insulated and not "tight," most older buildings that were not originally insulated have been improved to varying degrees by their owners, and new buildings are generally well insulated. Windows are double glazed, fitted with storm windows, or covered with flexible plastic during the coldest months. Snow is piled up around the houses in the winter months to provide additional insulation and to make a more effective dead space under the floor. (This practice leads to "frost heaves" in the permafrost, and, as a consequence, houses must be levelled every year.)

Fig. 19--Monthly heating degree days and heating fuel for Nome, 1975-1976

Nome has about 1500 buildings, including garages and sheds. Approximately 85 percent of its 600 heated buildings are single-dwelling residential; 5 percent, multiple dwelling (4-12 units); and 10 percent, churches, government buildings, or stores. Single-dwelling houses may be categorized into three main types: approximately 35 percent, single-story "shacks" with average dimensions of 11 ft x 14 ft; 40 percent, single-story 24-ft x 36-ft houses; 25 percent, two-story 24-ft x 34-ft houses. Most buildings are frame; some, quonset huts and trailers; and many, combinations of two or more building types. Figures 20 and 21 picture examples of typical buildings in Nome.

Most heating systems in Nome are oil-fueled. About 35 percent are space heaters with fans and no ducts or hot-air furnaces with ducts; 25 percent, circulating hot-water heaters; 30 percent, space heaters or cook stoves that heat by convection and radiation. Domestic water is usually heated by the stove used for space heating, though a few houses have electric hot-water heaters. The average house has five to six residents.

Many houses in Nome have a south-facing anteroom with large window areas. These rooms are warmed when the winter sun is above the horizon and provide additional insulation plus some heat to the rest of the house.

Present Fuel Use and Cost

Nearly all of Nome's present geothermally replaceable energy load comprises space and water heating. All bulk fuel is barged into Nome from Standard Oil's Richmond Beach plant near San Francisco. Package products (e.g., oil, grease, fuel in 5-gal cans) are shipped from Seattle. No local natural fuel resource (other than driftwood, which is used in negligible amounts) exists *at this time*. (Though in the past local Eskimos used whale oil, all other fuels have been barged to Nome since the turn of the century.)

Because of the barge and lighterage costs, fuel prices in Nome are high. Lighterage, necessary due to the lack of deep-port facilities, adds approximately 25 percent to the cost of fuel. Nearly all heating in Nome is fueled by No.-1 stove oil and, to a much lesser degree, by No.-2 oil. From July 1975 through June 1976, 2.127×10^6 gal of oil

Fig. 20--Typical Nome houses (photographed in March.1977)

Fig. 21--Store building in Nome (made up of several smaller units of varying construction types)

were used for heating in Nome, with a total cost to users of \$1,212,000. Other fuels--which had a negligible impact on this figure--included propane, white gasoline, kerosene, and driftwood. The volume of oil used for heating is equivalent to $2.98 \times 10^{11} \frac{\text{Btu}}{\text{yr}}$. The actual volume of oil consumed and the heating value are used to develop the design heating load. Calculations and assumptions for load determination are described in Appendix D.

NOME RESOURCE MODEL

The Nome area is underlain by metamorphic rocks of the Nome Group, including interlayered greenschists, quartz-mica and garnet-mica schists, and schistose marbles. The bedrock is generally overlain with sedimentary deposits ranging in thickness from 30 ft to 80 ft. Nome is located in a permafrost region; and although the permafrost may be perturbed due to the warming effects of seawater, it is believed that permafrost extends to a depth of approximately 800 ft.

No known thermal springs exist in Nome, although Pilgrim and Serpentine Hot Springs are located 40 mi and 100 mi, respectively, north of the town. Since no deep holes have been drilled in the Nome area, we have based our assessment of the geothermal gradient on gradients in known basement rocks elsewhere. We assume that the gradient at Nome is approximately 30°C/km (see Appendix A).

We believe that the crystalline schists of the Nome Group have very low fracture porosity/permeability. Because of the permafrost layer, and the limited fracture systems, we believe that the basement rock would not contain water of sufficient capacity to be considered as a usable aquifer. As in Barrow, we believe that the only usable model for Nome is a hot, dry-rock system with induced heat extraction.

By Alaskan standards, Nome is a large town, with a population of about 2500. Because of its size and relatively severe climate, the heating requirements for the town are high. As discussed in Appendix E, drilling in Alaska is extremely expensive. To minimize the number of wells required to provide thermal power for Nome, we have modeled our hot, dry-rock resource as a 250°F hydraulically induced fissure system with forced-fluid heat extraction. Detailed discussion of the heat-utilization systems, resource life, and cost considerations are presented below.

SYSTEM DESIGN

Nome is treated in the same manner as Barrow, with the resource-utilization model being divided into the energy-extraction subsystem and the distribution-piping subsystem. To determine if geothermal energy is competitive with other sources, we have developed a preliminary system for extraction and distribution. The geological similarity between the heat resources of Nome and of Barrow prompted us to treat both towns with the same model. System design criteria are 1) safety to inhabitants and to the permafrost region, 2) high system reliability, 3) low initial cost, and 4) low operation and maintenance cost and complexity. The system is described below. Although Nome is considered a relatively good candidate for geothermal-energy development, we have not included our detailed design-sizing calculations in an appendix. The analysis is, however, similar to the calculations presented for Kiana (Appendix D). We used the system size and process-state conditions to specify equipment, and equipment manufacturers provided accurate cost estimates based on our informal specifications.

The system-sizing considerations are based on the application of geothermal energy to meet existing load requirements for district heating. Population growth and additional capacity for alternate uses have not been considered. Historically, Nome's population has been decreasing, although a self-sufficient energy base might prompt growth. As pointed out above for Kiana, population growth will probably affect both fossil-fuel and geothermal energy use equally. Note that sizing estimates for Nome utilize about 87 percent of the resource modeled. Excessive growth would require an additional well set, which would increase system cost by about 45 percent.

ENERGY-EXTRACTION SUBSYSTEM

Judging from a geological assessment of the Nome rock structure, we conclude that a hot (121°C), dry-rock heat source can be expected at a depth of 13,130 ft. That conclusion assumes that a normal gradient of 30°C/km exists at Nome. We estimate that the expected volume of seawater encroachment due to migration through surface schist fracture

systems is negligible and certainly insufficient to provide the capacity required for consideration as a heat-transfer medium. A qualitative discussion of the hot, dry-rock concept is discussed in the system-design section on Barrow (see Fig. 22).

We estimate that the spudding-in, drilling, and mud- and cement-injection procedures used by oil-well drillers in a permafrost region apply. High-pressure casing is considered necessary because of the relatively high pressure required for hydrofracturing and normal system operation. Wellhead piping connections, valves, heat-exchanger tubes, fittings, and the pump casing are also rated for high-pressure service. Because of the relatively low temperature of the geothermal fluid, piping and valve cost estimates are to be made on the basis of sizing in accordance with applicable ANSI and ASME codes. Estimates allow for system safety instrumentation, alarms, and control logic devices.

As for Barrow and Kiana, we have chosen equipment that ensures that flow rates generated by the operation of the geothermal system described here are within OSHA-specified limits.

DISTRIBUTION-PIPING SUBSYSTEM

Figure 23 shows the candidate water-distribution subsystem to be used for district heating. Nome, like Kiana, is situated in an area of extensive permafrost. Because the actual extent and depth of permafrost are unknown, Nome will be treated in this study as if it were situated in a region of continuous permafrost.

Flow of water through the hot side of the high-pressure heat exchanger is modulated so that water temperature in the distribution subsystem does not exceed 180°F. Primary safety criteria are that 1) system pressure shall be maintained within reasonable limits, 2) normal system operation shall have a negligible effect on the permafrost region, and 3) no single piping failure shall cause significant damage to the permafrost region. To meet the safety criteria, we determined that maximum distribution-subsystem design pressure be 100 psig. As for Barrow and Kiana, the distribution-piping subsystem should be adequately insulated and isolated from the permafrost region. In addition, no major piping failure should go undetected, and shutoff capability should be placed at intervals throughout the system.

Fig. 22--Preliminary geothermal-energy extraction subsystem for Nome

Fig. 23—Preliminary distribution-piping subsystem for Nome

Because the climate imposes such a high duty-cycle on any heating system in Nome, high system reliability is defined as high availability to the users, with provisions for quick repair of system failures during any season. To ensure high reliability, the distribution system is divided into a header system with periodic crossties provided to bypass failures. We assume that residences have service connections in parallel so that individual heaters can be operated independently. We anticipate that at least once in the lifetime of the system the entire secondary loop will be inoperative. Therefore, drain valves at low points in the piping system--necessary for freeze protection--are included in the cost estimate.

To meet the criterion of low initial cost, we considered lightweight piping systems that require minimal skilled labor for assembly and that meet the reliability and safety criteria. The candidate selected for the purposes of this study is a preinsulated, aluminum-jacketed, fiberglass epoxy pipe that has been used extensively in Alaskan and Antarctic services. The bulk of the piping system is made up of 6-in. and 2-in. pipe sections. Each section is a 20-ft spool insulated with 2 in. of polyurethane foam, identical in design to the pipe described for Barrow (Sec. III).

Initially, we considered installation of underground piping. Installation of such systems in permafrost or cyclically freezing soil is a major problem, however, both in terms of man-hours required and of eventual damage to the utilidor or piping system. Burying a piping system that would distribute water at temperatures up to 180°F almost certainly implies the use of utilidors, utiliducts, and a forced-air utilidor cooling system to maintain the integrity of the permafrost. Failures in the underground piping system would likely go undetected for an extended period. Consequently, because of the relatively high temperature of the water, a high probability exists that extensive local melting of the permafrost would occur.

The resultant subsidence phenomenon could cause extensive damage to the district heating system, as well as possible collapse of ground and structural foundations in the immediate area. We estimate that the cost of installing a utilidor system would be in the neighborhood of

\$2900 per house (CH₂M Hill, 1976). Because of the likelihood of damage from undetected failures, and because of the high cost of installation, we do not recommend an underground piping system for Nome.

Most of the structures in Nome are built to withstand frost heave, with the floor raised off the ground, supported by framing. Generally, enough subfloor space exists to accommodate a 6-in. or 8-in. outside diameter pipe. For the purposes of cost optimization, the district-heating distribution piping is considered to run directly beneath the structures (see Fig. 23). Piping connections made near or under the structures would include tees, reducers, and cap fittings. Individual user connections to the hot and return distribution lines could be easily installed above-ground. We estimate that the distribution subsystem would be supported by a system of wooden cradles with pipe supports and slide plates. We have conducted our cost estimates on the basis of using thrust blocks, placed and anchored to support dummy stub connections where the piping changes direction.

The piping system could cross narrow streets by means of a simple riser and downcomer separated by a supported, relatively short, straight spool. For wider streets, the geothermal heating lines might be laid underground in a slightly oversized culvert section.

BASE-CASE SYSTEM COSTS

Table 10 displays the detailed costs of the Nome system. The table below summarizes the life-cycle costs.

Total capital investment	\$ 32,063,000
30-yr ownership cost (at 10%)	128,252,000
Average annual ownership cost	4,275,000
Average annual cost	5,313,000

BASE-CASE SYSTEM BENEFITS

Figure 24 compares 30-yr annual costs for the Nome system with alternative conventional-energy costs. It is apparent that the Nome system becomes cost-effective only if the price of conventional fuel (stove oil) rises rapidly, or if additional uses are made which have an

Table 10

NOME BASE-CASE COSTS
(in \$ thousands)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
1. <u>RESEARCH AND DEVELOPMENT COST (RDC)</u>						
1.1 Survey	8					8
1.2 Site Selection	8					8
1.3 Permits	5					5
TOTAL RDC	21					21
2. <u>PRODUCTION COST (PC)</u>						
2.1 Drilling and Well Preparation						
2.1.1 Material	15,000	12,349				27,349
2.1.2 Labor						
2.1.3 Mobilization	90					90
2.1.4 Loss and Repair	150	123				273
2.1.5 Rig Relocation	100	53				153
2.2 Wellhead						
2.2.1 Material	300	318				618
2.2.2 Labor	60	64				124
2.2.3 Transportation	39	40				79
2.3 Utilidor	800	502				1,302
2.4 Distribution						
2.4.1 Material	500	356				856
2.4.2 Labor	500	385				885
2.4.3 Transportation	50	34				84
TOTAL PC	17,499	14,224				31,723

(continued on next page)

Table 10 (continued)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
3. <u>INITIAL DEVELOPMENT COST (IDC)</u>						
3.1 System Start-Up						
3.3.1 Training	8	8				16
3.3.2 Technical Data	6					6
3.2 Installation--Checkout						
3.2.1 Initial Spares Stockage	95					95
3.3.2 Labor	82	43				125
3.3 Demobilization			77			77
TOTAL IDC	191	51	77			319
4. <u>RECURRING COST (RC)</u>						
4.1 Monitoring, Operation, and Maintenance						
4.1.1 Spares Inventory Replenishment		10	11	12	710	743
4.1.2 Labor		139	201	213	12,600	13,153
TOTAL RC		149	212	225		13,896
OWNERSHIP COST: RDC	21					21
PC	17,499	14,224				31,723
IDC	191	51	77			319
RC		149	212	225	13,153	13,739
GRAND TOTAL	17,711	14,424	289	225	13,153	45,802

Fig. 24--Increase in oil price for space heating compared with the cost of a geothermal system

economic or social benefit. The remainder of this subsection discusses possible added uses.

Greenhouse Agriculture

Because of the severe climate in Nome, produce is virtually unavailable most of the year. Since demand far exceeds supply, we consider the use of geothermal energy for greenhouse heating to be a very practical way of increasing produce production in the spring and summer seasons when district heating requirements are low.

To determine if an adequate supply of energy is available, we have developed some preliminary estimates of thermal power required to support a geothermally heated greenhouse.

Greenhouse Power Estimate

It is very difficult to maintain constant temperature within a greenhouse because of the structure's inherently rapid temperature response to changes in solar radiation. As conduction, convection, and radiation heat flows change, conventional greenhouses must be alternately heated and cooled. In addition, coordinated ventilation/temperature control systems must be utilized to maintain proper humidity levels. Greenhouse cooling systems are not required in Nome because temperatures can be controlled by operation of air dampers to regulate the influx of cool air. The design of the greenhouse heating system must be based on daily minimum temperature, minimum crop-sustaining temperature, and greenhouse size. Humidity can be controlled by operation of the manual or automatically modulated dampers.

We have based our heating requirements on a minimum seasonal dry-bulb temperature (see Table 11) and a design wind speed of 15 mph. We have chosen a minimum temperature of 19°F for Nome, to provide a six-month growing season. These greenhouse systems then can be operated seasonally when relatively little district heating is required.

Heat-transfer losses from our theoretical greenhouse are calculated according to the assumption that double-paned glass will be used.

We pointed out above that fluctuations in greenhouse temperature during the day respond very quickly to variations in insolation, and that some modulation of air dampers may be required to control greenhouse

temperature and humidity. It is obvious that a greenhouse energy balance during daylight hours is a function of conduction, convection, radiation, and infiltration energy-transfer mechanisms. But maximum required heating load will occur at night, when solar radiation is zero, and outside ambient air temperature is at a minimum. Based on an analysis identical to that of Kiana, an expected heat loss has been developed. The calculations for Nome have been omitted for the sake of brevity; but with an outside temperature of 479°R, we have determined that a 20-ft × 20-ft greenhouse requires 38,722 Btu/hr, or 1.134×10^{-2} MW for proper operation. Based on the system proposed for Nome, we conclude that excess geothermal capacity (9.72 MW × 0.13) is 1.26 MW, which is sufficient to heat over 100 greenhouses. This capacity is far in excess of that required by the town of Nome.

Table 11

MINIMUM DRY-BULB TEMPERATURES AT NOME^a

Month	Average Minimum Temperature	Lowest Temperature
January	- 8.7	-27
February	-25.9	-39
March	- 6.6	-31
April	- 1.0	-20
May	25.6	19
June	36.2	27
July	41.4	31
August	44.7	36
September	38.6	29
October	24.2	7
November	9.0	-15
December	1.1	-22

^a1976 data from National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Asheville, North Carolina.

Aquaculture

Nome is not sufficiently near any fresh-water sources to permit realistic consideration of aquaculture.

Waste Treatment

Geothermal heat could be useful in speeding biodegradation in Nome's sewage-treatment system. Ideally, geothermally supported greenhouses could utilize the composted material and sludge that are typical byproducts of solid-waste processing.

Bath Houses and Swimming Facilities

The excess potential of the Nome system, approximately 8 MW during the summer months, is sufficient to support numerous community facilities of this type.

COST-BENEFIT DISCUSSION

Nome combines several features that make it the most attractive site studied for a high-visibility demonstration of geothermal potential. Although the geothermal system is not clearly superior, it is cost-competitive during later stages of system life. Adding other services and applications should further enhance the total benefits of the geothermal system. Nome is sufficiently populous to support these additional uses and to provide a labor base should industrial uses prove economically feasible.

VIII. WRANGELL

THE TOWN OF WRANGELL

Wrangell (and Southeast Alaska in general) differs strikingly in appearance from the rest of the state. Wrangell nestles against heavily forested foothills at the northwest end of Wrangell Island, facing the Zimovia and Stikine Straits and other islands of the Alexander Archipelago. Fog and low clouds, typical of maritime climate, lend Wrangell a misty aura during much of the year.

Because of varied topography, weather conditions around Wrangell are quite localized and can change rapidly. The temperatures vary little and are generally cool (summer, 47° to 65°F; winter, 24° to 37°F; extremes, -10° to 92°F), but permafrost is rare. High humidity, frequent cloud cover, and much precipitation (over 100 in. a year) make this a rain-forest region. Winds are moderate to strong, averaging easterly at 9 kn, with extremes SSE at 42 kn. Channeling effects created by islands and mountains maintain low velocity winds from September through May, becoming stronger from May to August. Inversions do occur and, depending on the wind and the location of surrounding mountains, pollution from house heating, cars, utility plants, and the lumber and pulp mills does become a problem. Part of the processing previously handled by the pulp mill has been discontinued because of objections from environmentalists, but local people are divided in their environmental stands.

The latitude (54°31'N) sees less change between summer and winter daylight hours than elsewhere in Alaska, the longest day being 17-1/2 hr, and the shortest, 7 hr. The lingering cloud cover and shadows from neighboring mountains and foothills prevent much of the possible solar radiation from reaching the ground.

Very moist and cool ground temperatures slow decomposition in Southeast Alaska, and the subsequent lack of aeration and of nitrogen fixation results in very acid, infertile soil. People are able to maintain small home gardens; but there is no large-scale agriculture or domestic grazing land. Erosion where plant growth has been disturbed (e.g., by logging or road building) can lead to slides. The most important forests in this

region are Sitka Spruce and Western Hemlock. The local climate allows some of these trees to grow as large as 14 ft in diameter. Also, wet tundra, muskeg, and some alpine tundra are found near Wrangell.

Wrangell has elementary and secondary schools, and vocational training facilities, as well as a hospital and clinic with two doctors and a dentist. There are radio, television, and telephone communications. For a population of about 3000 people, approximately 600 jobs are available. Government and transportation are the major employers outside of the lumber and fishing industries. The rugged coast of this region is icefree all year. The marine environment is rich in nutrients, with water temperatures from 42.5° to 45.0°F in winter and 55.0° to 57.0°F in summer. Domestic fishing is mainly for salmon, herring, and halibut. The harvest of pink salmon has declined in the last 15 years while other harvests have remained stable. Foreign commercial fishing previously was legal outside of a 12-mi limit from the Alaska coast; but since March 1, 1977, a 200-mi limit permits only limited takes by foreign fisheries. The potential of aquaculture, mariculture, and hatcheries is being researched by the Alaska Aquaculture Foundation in Wrangell. Although no facilities of this sort now exist near Wrangell, the group hopes to obtain funding for such projects in the near future.

The present gross land structure in this region was formed during the Quaternary period by glacial and volcanic activity. Southeast Alaska is generally in a period of glacial retreat at this time. Wrangell is situated on the circum-Pacific seismic belt and has a high potential earthquake risk. No mining is done on Wrangell Island, but mineral discoveries in "Southeast" include garnet, fluorite, limestone, gold, zinc, lead, copper, silver, palladium, uranium, iron, antimony, molybdenum, beryllium, thorium, chromium, titanium, and nickel. Wrangell has no known petroleum fields but is not far from the Gulf of Alaska Tertiary Petroleum Province. Most known coal beds in this region lie near Juneau. Several thermal springs are close to Wrangell, along the Stikine River.

Electricity is provided Wrangell by a 2675-kW diesel generator. Future power is a major concern to the populace. Although electric rates are lower than in Nome and Barrow, the cost is still higher than consumers desire, and available electricity is now quite limited. Fresh surface

water in reservoirs supplies most of the town's daily 1,400,000-gal consumption. Producing wells in Wrangell are usually bedrock wells, though some have yielded water from unconsolidated layers. City-provided sewage disposal serves over half of the town.

Wrangell is accessible year-round by the ferry (Alaska Marine Highway System) that runs between Seattle and Skagway. Alaska Airlines provides daily (except weekend) jet service. Local charters and air-taxis provide transportation among the islands. Changeable weather conditions often prevent Alaska Airlines from stopping in Wrangell, and light aircraft are usually float planes or amphibians (wheels and floats), since they are often forced down far from an airstrip. Freight is brought in by air or barge.

Climate

The climate of Wrangell is relatively mild compared with that of the other towns in this study. A coastal city, Wrangell has a very high precipitation rate, with an average annual precipitation of 82.4 in. Temperatures range within thirty degrees year-round. The minimum recorded temperature (in January) is 24.5°F, and the mean low temperature is 29.7°F. Annual heating degree days total only 8503; monthly degree days are depicted in Fig. 25.

Buildings

Most buildings in Wrangell are very well insulated and "tight." Relatively good access to suppliers and materials provides Wrangell residents and builders with most modern-day materials at reasonable prices. Averaging 1000 sq ft, most houses are frame structures with sheetrock inner walls and plywood and shiplap outer walls. Fiberglass insulation is used, and windows are thermopane or are fitted with storm windows for winter. Wrangell has approximately 800 residential buildings and 200 commercial buildings (including a hospital, two hotel/motel facilities, two lumber mills, one cannery, one theatre, a senior citizens center, a legion hall, ten churches, a public library, two financial institutions, and a museum).

Fig. 25--Monthly heating degree days for Wrangell

WRANGELL RESOURCE MODEL

The Wrangell area is underlain by metamorphic rocks of the Wrangell-Revillagigedo Belt, including phyllites, metawackes, and garnet-bearing quartz-mica schists. The bedrock is generally overlain with fine-grained marine deposits ranging in thickness from zero to thirty feet. Wrangell is located in a region of no permafrost.

No known thermal springs exist in Wrangell, although Bailey and Bell Island Hot Springs are located about 50 mi to the southeast and Chief Shakes Hot Springs about 25-mi northeast of town. Since no deep holes have been drilled in the Wrangell area, we have based our assessment of the geothermal gradient on gradients in other metamorphic terranes of the Barrovian type. We assume that the gradient at Wrangell is approximately 30°C/km (see Appendix A).

The metamorphic rocks underlying Wrangell have very low fracture porosity/permeability. Because of the limited fracture systems, and monolithic nature of the basement rock, we believe no likelihood exists of encountering a useable aquifer at depth. As in Barrow, we believe that the only useable model for Wrangell is a hot, dry-rock system with induced heat extraction.

Wrangell is a large town with a population of about 2500. But because it is located in "Southeast," an area of rather mild maritime climate by Alaskan standards, the heating requirements for the town are moderate. As discussed in Appendix E, drilling in Alaska is extremely expensive. To minimize the number of wells required to provide the thermal power for Wrangell, we have modeled our hot, dry-rock resource as a 250°F hydraulically induced fissure system with forced-fluid heat extraction. Detailed discussion of the heat-utilization systems, resource life, and cost considerations are presented below.

SYSTEM DESIGN

We have developed a model that represents a workable implementation scheme for the town of Wrangell, performing our analysis as a preliminary engineering exercise and not as a parametric study of system costs. As in our other investigations, we began our technical investigation of Wrangell by determining the thermal power required for district heating. Based on

the specific geothermal resource that we have considered, a preliminary resource utilization model has been developed to site-specific design criteria, in accordance with good engineering practice. We then performed sizing calculations and developed preliminary process specifications for the materials and equipment required for a district heating system in Wrangell. With the help of many vendors, we obtained cost quotations and estimates based on our specifications. Our system design criteria are 1) safety to inhabitants and to the permafrost region, 2) high system reliability, 3) low initial cost, and 4) low O&M and complexity.

The resource utilization model is divided into the energy-extraction subsystem and the distribution-piping subsystem. Fig. 26 represents the energy-extraction subsystem; Fig. 27, a preliminary piping distribution subsystem.

ENERGY-EXTRACTION SUBSYSTEM

Figure 26 shows the preliminary geothermal-energy extraction subsystem. In developing the system, we consider it critical that system safety considerations be given high priority. We assume that the spudding-in, drilling, and mud- and cement-injection procedures are identical to the procedures used by oil-well drillers in a nonpermafrost region. We consider high-pressure casing necessary because of the relatively high pressure required for hydrofracting and normal system operation. Valve and pipe ratings and end connections are in accordance with ANSI and ASME specifications for water service at 1500 psig. The system includes a shell-and-tube counterflow heat exchanger. We determined that a shell-and-tube heat exchanger with a high-pressure rating on the tubes and tubesheets was required for a hot, dry-rock resource application. Fittings and pump casings in the extraction system are also rated for high-pressure service. Cost estimates include allowance for system safety valving and instrumentation, alarms, and control logic devices. We have sized equipment so that flow rates generated by operation of the geothermal system will result in noise levels well within OSHA-specified limits.

Fig. 26--Preliminary geothermal-energy extraction subsystem for Wrangell

Fig. 27--Preliminary distribution-piping subsystem for Wrangell

DISTRIBUTION-PIPING SUBSYSTEM

Figure 27 shows the candidate water-distribution system to be used for district heating.

Water temperature in the distribution system is not to exceed 180°F. Primary safety criteria are that system pressure be maintained within reasonable limits and that no single piping failure go undetected. To meet the safety criteria, we determined that maximum distribution-subsystem design pressure should not exceed 100 psig. In addition, shutoff capability should be placed at intervals throughout the system.

High system reliability is defined as high availability to the users, with provisions for quick repair of system failures at any time of year. We determined that the type of piping to be used in the system must have a history of reliable operation in similar applications. To ensure high reliability, the distribution subsystem is divided into a header system with periodic crossties provided to bypass failures. As in the models for the other towns investigated, all residences are considered to have service connections in parallel so that individual heaters can be operated independently. We anticipate that at least once in the lifetime of the system the entire secondary loop will be inoperative. Therefore, drain valves at low points in the piping system--necessary for freeze protection--are included in the cost estimate.

Low initial cost is a difficult objective to attain in Alaska. To minimize labor and equipment required, we considered lightweight piping systems that require minimal skilled labor for assembly and that meet the reliability and safety criteria. The candidate selected for the purposes of this study is the preinsulated, aluminum-jacketed, fiberglass epoxy pipe described in above discussions of other towns. The bulk of the piping system is made up of 6-in. pipe sections. Each section is a 20-ft spool insulated with 2 in. of polyurethane foam. The pipe spools can be handled easily by two men and assembled by relatively unskilled labor.

We consider installation of underground piping practical because Wrangell is not located in a permafrost region.

We expect that user connections could be made to the supply and return lines with short risers and service connection lines. The piping could be buried directly beneath the streets as in conventional piping installations.

PRESENT FUEL USE AND COSTS

Our research indicates that space heating in Wrangell consumed 2,022,000 gal of stove oil in 1976. This consumption translates to a total space-heating cost of \$978,600 at then-present rates of \$0.484/gal and \$0.474/gal of No.-1 and No.-2 stove oil, respectively.

BASE-CASE SYSTEM COSTS

Table 12 details the costs of the Wrangell geothermal system. Total life-cycle costs are as follows:

Total capital investment	\$16,067,000
30-yr ownership cost (at 10%)	64,268,000
Average annual ownership cost	2,142,000
Average annual cost	2,674,000

BASE-CASE SYSTEM BENEFITS

Figure 28 displays space-heating fuel expenditures for Wrangell, assuming three alternative rates of price inflation. The Wrangell base-case geothermal system is clearly cost-effective at higher inflation rates. Numerous other uses of geothermal energy may prove attractive in Wrangell, as discussed below.

Industrial Processing

Wrangell's currently operating cannery and lumber mills could be prime customers for geothermally provided heat. We were unable to obtain figures for the heating-fuel use at these operations; but further study of the economies of such implementation are advisable should additional geological evidence be favorable to drilling for the geothermal resource at Wrangell.

Aquaculture

Hatcheries to increase the number of salmon returning to the Stikine River are needed at Wrangell and would be a suitable application for low-temperature geothermal energy.

Table 12

WRANGELL BASE-CASE COSTS
(in \$ thousands)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
1. <u>RESEARCH AND DEVELOPMENT COST (RDC)</u>						
1.1 Survey	4					4
1.2 Site Selection	4					4
1.3 Permits	5					5
TOTAL RDC	13					13
2. <u>PRODUCTION COST (PC)</u>						
2.1 Drilling and Well Preparation						
2.1.1 Material	13,350					13,350
2.1.2 Labor						
2.1.3 Mobilization	92					92
2.1.4 Loss and Repair	134					134
2.1.5 Rig Relocation	50					50
2.2 Wellhead						
2.2.1 Material	470					470
2.2.2 Labor	70					70
2.2.3 Transportation	30					30
2.3 Utilidor	40					40
2.4 Distribution						
2.4.1 Material	844					844
2.4.2 Labor	755					755
2.4.3 Transportation	43					43
TOTAL PC	15,878					15,878

(continued on next page)

Table 12 (continued)

COST CATEGORY	YEAR					
	1	2	3	4	5-30	Total
3. INITIAL DEVELOPMENT COST (IDC)						
3.1 System Start-Up						
3.3.1 Training	8					8
3.3.2 Technical Data	5					5
3.2 Installation--Checkout						
3.2.1 Initial Spares Stockage	79					79
3.3.2 Labor	82					82
3.3 Demobilization	52					52
TOTAL IDC	226					226
4. RECURRING COST (RC)						
4.1 Monitoring, Operation, and Maintenance						
4.1.1 Spares Inventory Replenishment		8	9	9	532	558
4.1.2 Labor		95	101	107	6,336	6,639
TOTAL RC		103	110	116	6,868	7,191
OWNERSHIP COST:						
RDC	13					
PC	15,828					
IDC	226					
RC		103	110	116	6,868	7,191
GRAND TOTAL	16,067	103	110	116	6,868	23,264

Fig. 28--Increase in oil price for space heating in Wrangell compared with the cost of a geothermal system

Swimming and Recreational Facilities

Wrangell is currently attempting to raise funds for a community swimming pool. Residents of the community express a great need for recreational facilities and tourist attractions. A geothermally heated spa could be a possible tourist attraction for this town.

Agriculture

Greenhouses and soil improvement, facilitated by geothermal heat, would be welcomed by the residents of Wrangell, though such uses are not as significant here as are the above applications.

DISCUSSION OF COSTS AND BENEFITS

Of the six sites studied, Wrangell is the most appropriate for a demonstration if cost-effectiveness is the sole criterion for decision-making. Unfortunately, Wrangell does not offer the opportunities for an "Arctic" demonstration afforded by the other towns, nor does it appear to need the low-cost energy as much as other sites.

The Wrangell case may be particularly illuminating in considering a "lower-48" demonstration. Our estimates of geothermal-system costs apply Alaska drilling rates to the Wrangell system; that it emerges cost-competitive in spite of this handicap leads one to speculate that northerly "lower-48" communities may find local-gradient geothermal resources most attractive for space heating. Towns and small cities in the coterminous United States will not be subject to exorbitant drilling costs typical of Alaska, yet many have more severe climates than Wrangell.

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Appendix A

THE GEOLOGIC SETTING AND GEOTHERMAL POTENTIAL OF
SIX ALASKAN TOWNS AND VILLAGES

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INTRODUCTION

This report has benefited from hundreds of references on bedrock and surficial geology, in addition to site-specific knowledge of the author in all areas other than Huslia. It has been handicapped by a paucity of subsurface geothermal data at Nome, Kiana, Wrangell and Nikolski. Only a few key references have been cited, as compilation of all sources would have demanded additional time and expense.

Where subsurface geothermal data were not available, reasonable gradients were selected for models, based on data from localities in similar geologic settings. In the case of metamorphic terranes, an average gradient of 30°C was used, based on measurements taken in similar metamorphic terranes on a world-wide scale.

Popular opinion would suggest that heat flow and geothermal gradients should be high along the "Ring of Fire", coincident with the chain of volcanoes forming the backbone of the Aleutian Archipelago and the Alaska Peninsula. However, downhole thermal measurements taken in test wells along the volcanic line have shown that there is a large variance in gradients at various localities, ranging from very low to moderately high (e.g. $16 - 44^{\circ}\text{C}/\text{km}$). Naturally, test wells avoid the flanks of obvious volcanoes, and we assume that we could increase our "batting average" if we were to deliberately drill volcanic targets of very young age. The point I wish to make is that no guarantees of high geothermal gradients accompany the drilling of test holes at large step-out distances between active or inactive volcanoes along the Alaskan segment of the circum-Pacific volcanic belt.

I have suggested that the Cape Espenberg model be used for Nikolski, as the subsurface geology appears to be quite similar

to that which we might expect to encounter in a test well drilled from a site within Nikolski village. There is, of course, no guarantee that the geothermal gradient is the same at the two localities. However, the gradient measured in the Cape Espenberg test well is not excessively high or low, and should serve as a conservative model for evaluation of the concept. This model is not suggested for drilling experiments to the north, near Geyser Bight and Okmok Caldera.

WRANGELL

Geologic Setting

Bedrock: The Wrangell area is underlain by metamorphic rocks of the Wrangell-Revillagigedo belt, including phyllites, meta-wackes and garnet bearing quartz-mica schists. The schist terrane is intruded by small bodies of quartz diorite, which tend to parallel the layering and schistosity of the enclosing schists (Iemke, 1974).

Surficial deposits: Bedrock is overlain by fine-grained marine deposits (clays, silts and sands), and beach deposits (sands and gravels), overlain by muskeg. The thickness of the surficial deposits ranges from zero to 30 feet. There is no permafrost.

Bedrock structure: The metamorphic rocks are sub-isoclinally folded, with axial planes which dip to the northeast (see Fig. 1A, below).

Fig. 1A--Idealized sub-isoclinal structure in the Wrangell area.

Geothermal Data

Thermal springs: Although there are no thermal springs in the Wrangell area, Bailey and Bell Island Hot Springs are located approximately 50 miles to the southeast, and Chief Shakes Hot Spring is located about 25 miles northeast of Wrangell.

Heat flow and geothermal gradients: No deep holes have been drilled in the Wrangell area, and no downhole geothermal data are available. Based on measured geothermal gradients in other metamorphic terranes of the Barrovian type, we estimate that the geothermal gradient will be around $30^{\circ}\text{C}/\text{km}$.

Geothermal Targets And Drilling Parameters

Targets: None of the rock units in the Wrangell-Revillagigedo schists can be expected to offer inter-granular porosity/permeability potential. Potential targets will be confined to fracture porosity in the more competent units such as meta-wackes and quartzites. Possible seawater encroachment offers interesting potential and possible drilling problems. The drill site would be located relatively close to the beachline, and the hole would be spudded in about 50 feet above sea level if it is located within the town of Wrangell.

Drilling parameters: The rig would be set up on a muskeg covered site, but the cover is relatively thin, and the underlying sands and gravels are competent. With the exception of the initial 10-30 feet of unconsolidated sediments, the hole will be drilled through metamorphic rocks of the Wrangell-Revillagigedo terrane. Drilling problems will include slower drilling rates, down-dip drifting of the bit and possible seawater encroachment. To obtain 100°C temperatures, we anticipate a 10,800 foot hole. The section which would be cut by the hole is diagrammatically shown in Fig. 2A.

Logistics: The drill rig and associated equipment would be transported to Wrangell by ship, and off-loaded to trucks which could transport them to the site. Site preparations would be routine. Crews could be accommodated in the town of Wrangell.

Fig. 2A-- Generalized sub-surface geologic section of the Wrangell area, Alaska.

Geothermal Models

Based on an assumed geothermal gradient of approximately $30^{\circ}\text{C}/\text{km}$ in the underlying metamorphic terrane, and the

accompanying lack of porous aquifers, we propose a hot-dry rock model. Possible fracture porosity in the more competent rock units could promote fracture communication between paired holes in induced systems.

NIKOLSKI

Geologic Setting

Bedrock: The Nikolski area is underlain by Tertiary sedimentary rocks including bedded siltstones, sandstones, and subordinate tuffs (Figs. 3A and 4A). A mile to the north, the Tertiary sediments are intruded by a mafic intrusive complex which underlies "High Hills," which is topped by the "White Alice" station (Fig. 5A). Approximately 1/2 mile south of the village, fine-grained granodiorite is exposed in the sea cliffs on the west side of the island. The sediments have been baked near the contacts with the intrusives. Steeply dipping to vertical basalt dikes also cut the sediments. Such dikes are well exposed along the road from the village to the White Alice Station.

According to Byers (1959), the sediments are also cut by and/or intercalated with keratophyres and albitized diabase sills. The Tertiary section composes the basement of the island, and to the northeast these rocks are unconformably overlain by the younger volcanic piles of flows and pyroclastics associated with Recheschnoi, Vsevidof and Okmok volcanoes.

Surficial deposits: These deposits range in age from late Pleistocene to recent, including till, glacial outwash, beach deposits, dune sand, talus and alluvium. The village of Nikolski is located on a thin blanket (20-40 feet) of beach sand and gravel which in turn rests on the flat surface of the Nikolski plain which is an old wave-cut surface on bedrock. The sands and gravels are water bearing, and the village water system obtains water from shallow wells driven to a depth of 20 to 30 feet.

Fig. 3A--Diagrammatic Composite section; Nikolski, Geyser Bight and Hot Springs Cove areas, Umnak Island, Alaska.

Note: Drilling rate will be relatively fast in tuffs and argillites, and slow in diabase, keratophyre and quartz diorite.

Fig. 4A--Gently dipping Tertiary siltstones and tuffs exposed in a road cut between Nikolski and the White Alice site on High Hill.

Fig. 5A--High Hill and the White Alice site as viewed from Nikolski. High Hill is underlain by a mafic intrusive complex which cuts the Tertiary sedimentary section.

Bedrock structure: Layered rocks in the complex have a north-westerly strike, and dips have been reported from horizontal to vertical . Dips at the head of Driftwood Bay suggest a southeasterly plunging anticline. Near Nikolski, however, the dips are nearly horizontal.

Geothermal Data

Thermal springs: Thermal springs are located at Geyser Bight, Hot Springs Cove, Okmok Caldera and in the small valley that drains eastward across the narrowest part of Umnak Island. Sinter deposits and geothermometry indicate that sub-surface reservoir temperatures may be above 150°C for some of the Geyser Bight and Hot Springs Cove springs, and between 90° and 150°C for some of the springs in Okmok Caldera.

Heat flow and geothermal gradients: No deep holes have been drilled on Umnak Island, and no downhole geothermal data are available. The 1945 eruption of Okmok volcano and the 1883, 1906-1910 and 1926-1927 eruptions of nearby Bogoslof volcano indicate that magma has reached the upper levels of the volcanic conduit systems in very recent time. Rhyolite domes of post-glacial age, at the head of Russian Bay, also suggest that silicic volcanism has occurred in this area in the last few thousand years.

Sass and Monroe (1970) calculated heat flow values from geothermal measurements taken in four deep drill holes on Amchitka Island, and obtained an equilibrium heat flow of 1.3 HFU. Gradients measured in the holes ranged from 20° to $35^{\circ}\text{C}/\text{km}$, and increased with depth. This increase was apparently due to water circulation in the upper parts of the holes. The deeper of the four drill holes bottomed out at 1158 meters, with a maximum temperature of about 40°C . Although Amchitka Island is about 500 miles to the southwest of Umnak, these data are the best we have at present.

Geothermal Targets And Drilling Parameters

Targets: The sinter-depositing thermal springs in Geyser Bight and Hot Springs Cove are good indicators of sub-surface hot water systems with temperatures above 150°C (White and Williams, 1976). The proximity of Holocene (< 10,000 years) rhyolite domes is also encouraging. The geologic map (Byers, 1959) indicates that following a relatively thin layer of surficial deposits, a drill hole would penetrate the older basement rocks. The proposed target would be a geothermal anomaly associated with a sub-surface magma reservoir or cooling pluton related to the rhyolite domes. Due to the lack of heat flow and gradient measurements, there is no reliable way to estimate the depth of such a target..... but 2 km is selected as a reasonable depth.

The basement rocks are somewhat altered on the north end of the island, as they have been zeolitized and partially replaced by carbonate and silica. Based on lithologic descriptions, intergranular porosity and permeability will be marginal in these rocks. The most likely target would be the possible intersection of porous sandstone or tuffaceous aquifers near the subsurface extension of the silicious domes or in an area of high heat flow adjacent to the thermal springs. However, it is more likely that the aquifers, if found, will be due to fracture porosity in volcanics or argillites.

Drilling at Nikolski would offer more risk than at Geyser Bight or Hot Springs Cove, as there are no hot springs or silicic domes near Nikolski village. Seawater intrusion is a possible complication at both sites. However, we can assume that the drill would penetrate Tertiary sandstones, siltstones, tuffaceous sediments and rare basaltic (diabasic) dikes and sills.

Although we have no measured heat flow or thermal gradient data on Umnak Island, we think it is logical to deduce that the gradient is perturbed near the silicic domes and hot springs,

and that the actual gradient may be around $40^{\circ}\text{C}/\text{km}$. Although the subsurface gradient may be less at Nikolski, based on surface evidence....we will also hypothesize that the quartz dioritic intrusives are very young ($< 10,000,000$ years), and that the gradient is also somewhat perturbed near Nikolski.

If we assume that a hot water pipeline from Geyser Bight to Nikolski would be uneconomic, then we must drill near the Nikolski village site. Because of the lack of subsurface information at Nikolski, we have chosen a model which may be geologically similar to Nikolski, based on lithology, geothermal gradient and aquifers. This model is based on data from the Cape Espenberg #1 well, drilled west of Kotzebue, Alaska.

Logistics: The drill rig and associated equipment would be transported to Umnak Island by ship, and lightered ashore. Landings may be difficult. Camp facilities will have to be constructed for crews.

Geothermal Models

The Espenberg model: Under the provisions of a development agreement with the NANA Regional Corporation, the Standard Oil Company of California drilled two wells in the Kotzebue area during the winter of 1974-1975 (Cape Espenberg #1; Nimiuk Pt. #1). Both of the wells were "dry holes", as no indications of gas or oil were detected in either well. Both wells are of unusual interest, however, as they have provided new information on the subsurface geology of the area, including the presence of a rather thick section of coal-bearing Tertiary rocks which contain salt water-bearing aquifers and a geothermal gradient which is higher than that in many sedimentary sections.

The Espenberg well reached a total depth of 8373 feet, with a bottom hole temperature of 161°F (72°C). Crystalline basement rocks were intersected at approximately 8100 feet, including marbles, calc-schists and phyllites. The schists appear to have been hornfelsed by intrusives. The crystalline basement is overlain by a basal sequence of conglomerate and sandstones, which is succeeded by tuffaceous volcanics interbedded with sandstones and siltstones. The tuffs leave the section at about 5500 feet, and coal-bearing sandstones, conglomerates and siltstones make up the rest of the section. Both conglomerates and coal beds decrease up section in the drill hole. The measured geothermal gradient is 28°C/km.

Tests were conducted on four zones in the Espenberg well. Three were either unsuccessful or dry tests. Formation test #2, conducted on a zone near the bottom of the well at 7914-8128 feet, resulted in no oil or gas, but a 7414-foot rise of salt water mixed with sand and mud, which occupied the hole in three hours and fifty minutes. This zone is apparently an excellent saltwater aquifer.

A subsurface section for the Cape Espenberg #1 well is shown in Fig. 6A; a deduced section for Nikolski is diagrammed in Fig. 3A, p. A-9.

GENERALIZED
GEOLOGIC SECTION
CAPE ESPENBERG #1 WELL

Fig. 6A

NOME

Geologic Setting

Bedrock: The Nome area is underlain by metamorphic rocks of the Nome Group, including inter-layered greenschists, quartz-mica and garnet-mica schists and schistose marbles.

Surficial deposits: Bedrock is overlain by glacial and marine sedimentary deposits ranging in thickness from 30 to 80 feet. The sediments are mantled by tundra vegetation. North of the present beachline, the sediments are perennially frozen below the mobile layer. Permafrost is believed to extend down to depth of 800 feet in the sub-surface.

Bedrock structure: The crystalline schists of the Nome Group are complexly folded, with fold styles ranging from sub-isoclinal to isoclinal (see Fig. 7A, below).

Fig. 7A--Sub-isoclinal and isoclinal fold styles.

Geothermal Data

Thermal springs: Although there are no thermal springs in the Nome area, Pilgrim and Serpentine hot springs are located 40 and 100 miles north of Nome, respectively.

Heat flow and geothermal gradients: No deep holes have been drilled in the Nome area, and no downhole geothermal data are available. Based on known geothermal gradients in basement rocks elsewhere, however, we will assume that the geothermal gradient is approximately 30°C/km.

Geothermal Targets And Drilling Parameters

Targets: None of the rock units in the Nome Group can be expected to offer inter-granular porosity/permeability potential. Rather, fracture porosity in the more competent units such as marbles and quartzites constitutes the only known reservoir potential. Considering the overlying permafrost zone, however, there is no guarantee that such fracture systems if found, will contain water at the desired depth. Possible seawater encroachment offers interesting potential, and possible drilling problems. The drill site would be located relatively close to the beachline, and the hole would be spudded in at about 50 feet above sea level. The warming effect of seawater perturbs the permafrost zone in coastal areas of Alaska, and it is possible that this effect might allow seawater to enter fracture systems in the underlying bedrock adjacent to the coastline.

Drilling parameters: The rig would be set up on a tundra site, and the usual drilling pad and permafrost techniques would apply. With the exception of the first 30-80 feet of unconsolidated sediment, the hole will be drilled through metamorphic rocks of the Nome Group. Drilling problems will include the slower drilling rates encountered in crystalline rocks, down-dip drifting of the bit and possible seawater encroachment. To obtain 100°C temperatures, we anticipate a 10,800 foot hole. The section which would be cut by the drill is diagrammatically shown in Fig. 8A.

Fig. 8A--Diagrammatic subsurface geologic section of the Nome area, Alaska.

Logistics: The drill rig and associated equipment would be shipped to Nome via barge and lightered into the Port of Nome. The usual site preparations for drilling and spudding into permafrost would be required. Crews could be accommodated in the City of Nome.

Geothermal Models

We have no deep hole data in the Nome area, so we suggest a working geothermal gradient of $30^{\circ}\text{C}/\text{km}$a reasonable gradient for regional metamorphic terranes. The Nome

Group is too highly recrystallized for remnant porosity in the metasediments, although fracture porosity may exist at depth in some of the more massive metaigenous rock units in the section.

The model assumes hot-dry rock conditions, and no in-situ fluids (an induced system).

HUSLIA

Geologic Setting

Bedrock: The Huslia area is underlain by a thick section of Cretaceous marine and non-marine sedimentary rocks, including greywackes, mudstones, sandstones, shales and conglomerates. The non-marine sandstones and conglomerates are frequently associated with low grade coal seams. These rocks are widely distributed in the sub-surface of the lower Yukon and Kobuk-Koyukuk basins. Huslia is located near the contact between these rocks (Nulato Formation) and a sequence of Late Cretaceous-Early Tertiary felsic volcanic rocks which overlie the Nulato Formation. The volcanics crop out to the south in a limited area bounded by the large bend in the Koyukuk River (Patton, 1973).

Surficial deposits: Bedrock is overlain by 50-100 feet of alluvial silts and sands deposited by the Koyukuk River, plus a shallow blanket of wind-deposited silt. The surface is mantled by tundra vegetation.

Bedrock structure: Fold axes have northeasterly trends, and fold styles range from open-upright to asymmetrical. The folds tend to be tightly appressed, and frequently bounded by small faults derived from shearing off of the lower limbs. Evidence from the Nulato #1 dry hole drilled by Benedum & Associates approximately 80 miles southwest of Huslia, suggested repetition of the section from thrust-faulting.

Geothermal Data

Thermal springs: Thermal springs are located near Tunalkten Lake, 12 miles northeast of Hughes; and near Denikto Ridge on the north side of Hot Springs Creek, five miles from the

Koyukuk River ($65^{\circ}55'N/155^{\circ}00'W$). No data are available for these springs. However, we do know that Tunalkten springs issue from greywacke bedrock.

Heat flow and geothermal gradients: The Nulato #1 drill hole bottomed out at 12,015 feet. The bottom hole temperature was $154^{\circ}F$ ($86^{\circ}C$), and the gradient was $18.6^{\circ}C/km$. A hole drilled at Huslia would penetrate similar rocks, and these data are applicable to target assessment.

Geothermal Targets And Drilling Parameters

Targets: Although the Nulato #1 hole was drilled near an oil seep, no oil or gas was found in commercial quantities. The greywackes which dominated the section had very low porosities (e.g. 7% porosity), and few reservoir rocks were cut by the hole. Many fractures were filled by calcite, which reduced the probability of obtaining fracture porosity. However, some sands were intersected by the hole, and one could hope to encounter a reasonably thick and porous sand zone as a reservoir. Various studies indicate that similar Cretaceous rocks compose subsurface sections up to at least 20,000 feet throughout the region; so regardless of drilling site location, one could expect to penetrate similar rocks in this part of the basin. In this case, we could expect to drill to 12,000 feet to obtain $80^{\circ}C$, with a rather low probability of obtaining a good reservoir.

Drilling parameters: The rig would be set up on a tundra site, and the usual drilling pad and permafrost techniques would apply. The Nulato #1 crew encountered hole alignment problems, and complained that the drilling rates were unusually slow for sediments, regardless of bit design. The section which would be cut by the hole is shown in Fig. 9A.

Logistics: The rig and associated equipment would be shipped by barge up the Yukon, and on up the Koyukuk River to Huslia. The usual site preparation for drilling and spudding in to permafrost terrane would be required. A camp would have to be constructed for the crews, some distance from the village.

Fig. 9A--Diagrammatic sub-surface geologic section of the Huslia area, Alaska.

Geothermal Models

It is reasonable to assume that the geothermal gradient under Huslia would be similar to that measured in the Nulato #1 test well, as geologic mapping indicates that the two localities are underlain by the same formational rock units. The relatively low geothermal gradient ($18-20^{\circ}\text{C}/\text{km}$) would require deep drill holes to obtain minimum working temperatures for both natural and induced hot water systems. Optimistically, we could hope to penetrate a deep aquifer with fair porosity and permeability, which contained a typical connate brine under hydrostatic pressure calculated for such depths and accompanying temperatures. These calculations should be based on an average rock density of 2.4. It is tempting to speculate on the possibility of geopressured reservoirs, but no gas shows were detected in the Nulato #1 test well. The possibility should not be completely rejected, however, as the Nulato #1 well was drilled in the vicinity of an oil seep.

We are left with two choices; (1) a model which rejects possible hot water aquifers at reasonable depths and temperatures, and consequent use of the hot-dry rock model, or (2) the presence of a good brine reservoir with the same depth/temperature parameters defined by the Nulato test well. An additional gas drive component would be very helpful, but we cannot defend this variation in the model based on current information.

KIANA

Geologic Setting

Bedrock: The Kiana area is underlain by crystalline schists of the Brooks Range metamorphic belt, including phyllites, greenschists, quartz-mica schists and blueschists.

Surficial deposits: Bedrock is overlain by alluvial silts, sands and gravels. The surface is mantled by tundra vegetation. Permafrost is believed to extend to depths of 800 to 1200 feet in the sub-surface.

Bedrock structure: The metamorphic rocks are isoclinally to sub-isoclinally folded. The trend is northeasterly, and axial planes of folds dip to the southeast.

Geothermal Data

Thermal springs: No thermal springs have been reported in the area.

Heat flow and geothermal gradients: No deep holes have been drilled in the area, and no downhole geothermal data are available. Based on geothermal gradients in other metamorphic terranes, we estimate that the geothermal gradient will be around 30°C/km.

Geothermal Targets And Drilling Parameters

Targets: None of the rock units in the schist terrane can be expected to have good porosity-permeability values.

Potential targets will be confined to fracture porosity in the more competent units such as greenstones and quartzites.

Drilling parameters: The rig would be set up on a tundra site, and the usual drilling pad and permafrost techniques would apply. Kiana is underlain by a considerable thickness of surficial sediments (perhaps 200-300 feet). Following penetration of these sediments, the entire hole will be in crystalline schists. Drilling problems will include the slower drilling rates encountered in crystalline rocks, drifting of the bit and the usual permafrost complications. A geologic section is shown as Fig. 10A.

Fig. 10A--Diagrammatic subsurface geologic section of the Kiana area, Alaska.

Logistics: The drill rig and associated equipment would be transported by barge up the Kobuk River via Kotzebue Sound. The usual site preparations for drilling and spudding into permafrost terrane would be required. Crews could be accommodated in the village, by arrangements with the Blankenship Company.

Geothermal Models

To obtain higher temperatures, for example 70 to 100°C, we anticipate drilling to 7,500-10,800 feet. At these depths, we can expect hot-dry rock conditions in the subsurface schist terrane. However, fracture porosity in some of the more competent units, such as greenstones, might still prevail at greater depth....which would aid in developing fracture communication between two holes in an induced system.

BARROW

Geologic Setting

Bedrock: The Barrow area is underlain by sand, gravel and clay of the Gubik Formation (60 feet), followed by the Grandstand Formation which includes massive sandstone beds with clay shale partings (250 feet); the Topagoruk Formation containing clay shales and fine-grained sandstones (1,780 feet); the Oumalik Formation containing claystones, siltstones and shales (725 feet); and a pre-Mesozoic basement of dense black argillite (Collins, 1961) (Robinson, 1964). This section was penetrated by the South Barrow Test Well #1 (see Fig. 11A).

Fig. 11A--Composite geologic section, Barrow area, Alaska.

Surficial deposits: The Gubik Formation, of Pleistocene age, is cemented by interstitial ice. The surface is mantled by tundra vegetation. The tundra is underlain by silt, sand and gravel which may be remnant beach deposits or lag concentrates from deflation of the Gubik Formation.

Bedrock structure: The test holes were drilled on the so called "Barrow High" which was first detected by seismic and gravity surveys. Dips range from gentle to steep in the test holes. The top of the argillite basement was penetrated at 3,385 feet.

Geothermal Data

Thermal springs: There are no thermal springs in the area.

Heat flow and geothermal gradients: Downhole temperature measurements in the South Barrow #1 well, give a gradient of $26^{\circ}\text{C}/\text{km}$. Heat flow values calculated by Lachenbruch and Sass for this and other drill holes on the North Slope have been low; ranging between 1.2 and 1.8 HFU.

Geothermal Targets And Drilling Parameters

Targets: Porosity-permeability values were not very encouraging, as determined for cores taken from the South Barrow drill holes with the exception of thin sandstone beds which gave faint shows of oil between 3,045 and 3,165 feet. South Barrow #4 produced gas from both the Jurassic and the argillite. Apparently, the gas was in fracture porosity in the argillite. Considering the required temperatures and measured gradients, the best target would be a highly fractured argillite reservoir at approximately 10,000 feet.

Drilling parameters: The rig would be set up on a tundra site, and the usual permafrost techniques would apply. Permafrost extends to approximately 700 feet in the subsurface. Salt water was encountered in most of the South Barrow drill holes, and it is likely that both brines and seawater encroachment are involved. Drilling rates would be reasonably fast, above the argillite.

Logistics: The drill rig and associated equipment could be obtained from one of the various operators engaged in drilling in the Prudhoe or Pet. 4 fields. Accommodations for crews are available in the village of Barrow.

Geothermal Models

Barrow is underlain by the so called "Barrow High", a structural high which brings the basement up to relatively shallow depths under the Barrow area. In this case, basement is the argillite which was penetrated by the deeper Barrow test holes. Argillite was penetrated at approximately 3385' in the South Barrow #1 test well, where the bottom hole temperature was 85°F (30°C). This hole was located 1 mile southwest of Barrow village, and about 1500 feet south of the coastline. Although there were faint shows of oil in sandstone beds between 3045 and 3165 feet, formation tests recovered no oil or gas. Gas has been produced for local use from several wells in this area. Brine has been associated with gas blows in at least two test wells. The water chemistry indicates that the waters are probably connate brines rather than sea water.

The more reliable downhole gradient measurements obtained from the test holes indicates that the average geothermal gradient is about 26°C/km under the Barrow area.

Therefore, drilling would have to proceed to about 9000' (2.7 km) to obtain temperatures near 70°C. At that depth, the hole would bottom in the argillite basement terrane. Earlier laboratory tests have shown that the argillite has very poor intergranular porosity and permeability at much shallower depths than 9000 or more feet. Too, fracture porosity can be expected to decrease with increasing depth; a condition which does not favor the presence of connate or ground water in suitable quantities for a natural system. Under these constraints, the hot-dry rock model appears to be more realistic.

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Appendix B

HOT, DRY-ROCK RESOURCE LIFE

These calculations describing resource thermal capacity are based on an annual fixed load for each town. Since loads will vary on a seasonal basis, we expect that real rock temperature will fluctuate slightly from our expression for $r(t)$. The periodicity of $T_{(x,o,t)}$ will probably drop heat extraction efficiency because irreversibilities in the system will increase; and resource life will therefore decrease. Based on temperatures required at Barrow, Kiana, Nome, and Wrangell, resource life calculations have been made for site-specific initial rock temperatures, T_{ROCK} .

The procedure used to treat resource life is based on the analysis developed by Bodvarsson (*Geothermics*, September 1974). The values of thermal conductivity, density, and heat capacity of the various rock groups considered vary somewhat. However, the variations in the physical constants are slight and will have a small effect on life. We have chosen values for density, conductivity, and specific heat of the metamorphic rocks which are constant for all four sites and are approximately in the middle of the range of site-specific values.

The amount of power which can be extracted from a hot, dry-rock source is a strong function of flowrate and, to a lesser degree, ΔT . Because of local load requirements and local thermal gradient, flowrate and ΔT are highly site-specific. Care should be taken in extrapolating resource life for these sites to some other, or generalized, site.

Because of the economics of drilling in Alaska, we have selected values of ΔT at the wellhead which minimize the total number of wells required for each site. The obvious penalty which we pay for minimizing wells is that the wells must be deeper to intercept the gradient at a satisfactory temperature. Initial wellhead temperature at Barrow, Nome, and Wrangell is 250°F. Initial wellhead temperature at Kiana is 200°F. Consequently, a drop in wellhead ΔT at Kiana to 90 percent of its initial value can be sustained over the life of the facility without degraded performance. A drop in wellhead ΔT to 70 percent of its initial value can be sustained at the other three sites.

We should point out a notation convention which is valid for this appendix only:

$$T_o \equiv T_{\text{ROCK, INITIAL}} - T_{\text{REINJECT, INITIAL}}$$

and

$$T_{(x,o,t)} \equiv T_{\text{ROCK FACE AT TIME } t} - T_{\text{REINJECT AT TIME } t},$$

so that our expressions for T are really descriptions of a temperature difference. Then,

$$r(t) = \frac{T_{(x,o,t)}}{T_o} = \text{erf} \left[\frac{\beta \sqrt{t}}{Q} \right]$$

is a non-dimensional description of rock-face temperature as a function of time and flow rate, where

$$\beta = \frac{k}{\sigma \sqrt{a}}$$

$$Q = \frac{qt}{x} = \text{Total mass of water per ft}^2 \text{ evaluated over the operating time of the facility.}$$

$$\sigma = 1.0 \frac{\text{Btu}}{\text{Lbm}^\circ\text{F}} = \text{heat capacity for water.}$$

Typical properties of the rock groups we consider are:

$$k = 1.69 \frac{\text{Btu}}{\text{hr ft}^\circ\text{F}} \quad (7 \text{ millicalories/cm}^\circ\text{C sec})$$

$$\rho = 166.73 \frac{\text{Lbm}}{\text{ft}^3} \quad (2.67 \text{ grams/cm}^3)$$

$$c = 0.225 \frac{\text{Btu}}{\text{Lbm}^\circ\text{F}} \quad (0.225 \frac{\text{Cal}}{\text{Gram}^\circ\text{C}})$$

$$a = \frac{k}{\rho c} = 0.0450 \frac{\text{ft}^2}{\text{hr}} \quad (0.0116 \frac{\text{cm}^2}{\text{sec}}) .$$

Substituting

$$\beta = 7.967 \frac{\text{Lbm}}{\text{ft}^2 [\text{hr}]^{1/2}} .$$

In the cases of Barrow, Nome, and Wrangell, if ΔT drops 30 percent, the equipment which we have modeled will operate satisfactorily.

$$T_{\text{ROCK, INITIAL}} = 250^\circ\text{F}$$

$$T_{\text{REINJECT, INITIAL}} = 140^\circ\text{F} \Rightarrow T_o = 250^\circ - 140^\circ = 110^\circ .$$

In the case of Kiana, ΔT is allowed to drop 10 percent.

$$T_{\text{ROCK, INITIAL}} = 200^\circ\text{F}$$

$$T_{\text{REINJECT, INITIAL}} = 140^\circ\text{F} \Rightarrow T_o = 200^\circ - 140^\circ = 60^\circ .$$

Note that although initial rock temperature varies from site to site, in all cases reinjection temperature is maintained at 140°F over the life of the facility. 140°F is selected for heat-exchanger-performance purposes; i.e., circulating water in the distribution system is not allowed to drop below 122°F (50°C), because we consider temperatures below 50°C to be of marginal utility for district heating. We have no data that indicate a somewhat lower reinject temperature would cause system operation problems.

For Barrow, Nome, and Wrangell,

$$r(\text{LIFETIME}) = \frac{T_{(x,o,\text{LIFETIME})}}{T_o} = 0.7 \Rightarrow T_{(x,o,\text{LIFETIME})} = 77^\circ\text{F} .$$

For Kiana,

$$r(\text{LIFETIME}) = \frac{T_{(x,o,\text{LIFETIME})}}{T_o} = 0.9 \Rightarrow T_{(x,o,\text{LIFETIME})} = 54^\circ\text{F} .$$

The steady-state (seasonally adjusted) load for each site is estimated as follows:

Site	Max Load (MW)	$\times \frac{\text{Annual Heating Degree Days}}{(12)(\text{Maximum Monthly HDD})}$	= Average Load (MW)
Barrow	21.0	$\frac{20265}{(12)(2486)}$	14.26
Kiana	1.4	$\frac{17500}{(12)(2300)}$	0.89
Nome	16.4	$\frac{14325}{(12)(2015)}$	9.72
Wrangell	8.0	$\frac{8503}{(12)(1142)}$	4.96

For Barrow, Nome, and Wrangell, the average ΔT over 30 yr is

$$T_{AV} \frac{110 + 77}{2} = 93.5^{\circ}\text{F} .$$

For Kiana,

$$T_{AV} \frac{60 + 54}{2} = 57^{\circ}\text{F} .$$

$$\sigma = 1.0 \frac{\text{Btu}}{\text{Lbm}^{\circ}\text{F}} .$$

Since

$$14.26 \text{ MW} = 4.87 \times 10^7 \frac{\text{Btu}}{\text{hr}} ,$$

$$9.72 \text{ MW} = 3.32 \times 10^7 \frac{\text{Btu}}{\text{hr}} ,$$

$$4.96 \text{ MW} = 1.69 \times 10^7 \frac{\text{Btu}}{\text{hr}} ,$$

$$0.89 \text{ MW} = 3.04 \times 10^6 \frac{\text{Btu}}{\text{hr}} .$$

Our initial equation for $r(t)$ is an expression in terms of operating time and the integral of flow per unit surface area of fissure with respect to time. We arbitrarily choose an operating lifetime of 30 yr for our system. Our expression then determines a unique Q_{MAX} . Choosing a lifetime thus limits the total flow which can be passed over the fissure surface.

For Barrow, Nome, and Wrangell,

$$0.7 = \text{erf} \left[\frac{7.967\sqrt{262980}}{Q_{MAX}} \right], \quad \text{where } t = 30 \text{ yr} = 262980 \text{ hr}$$

$$= \text{erf} \left[\frac{4085.6}{Q_{MAX}} \right] \Rightarrow Q_{MAX} = 5.574 \times 10^3 \frac{\text{Lbm}}{\text{ft}^2}.$$

For Kiana,

$$0.9 = \text{erf} \left[\frac{7.967\sqrt{262980}}{Q_{MAX}} \right] \Rightarrow Q_{MAX} = 3.504 \times 10^3 \frac{\text{Lbm}}{\text{ft}^2}.$$

Assuming that well entrance and exit effects are negligible and that flow is evenly distributed through the fracture, Q_{MAX} is a useful parameter. For a fissure of half surface A' , flow will be distributed over some effective fraction of the area, say, λ , which is a parameter based on crack geometry, inlet and outlet flow geometry, and the resultant horizontal and vertical components of fluid velocity which determine the flow profile through the fissure. $\lambda A'$ then represents an effective crack area which we will call A . For the purposes of this study, we select a value of A which is equal to $9.6211 \times 10^6 \text{ ft}^2$. This area corresponds to a single circular crack 3500 ft in diameter with flow distributed evenly over its entire surface. In reality, the crack geometry which would yield this effective area may be two or more smaller parallel crack surfaces propagated from a common slant-drilled hole, each communicating with a second slant-drilled hole. Assuming one crack of surface A per wellset (one injection well and one extraction well), we can then determine the number of wellsets required for each site.

The mass flow rate into the hydrofractured region is

$$\begin{aligned}\dot{m} &= \frac{\text{Load}}{\sigma_T A_V} \\ &= \frac{4.87 \times 10^7}{93.5} = 5.21 \times 10^5 \frac{\text{Lbm}}{\text{hr}} \quad \text{for Barrow,} \\ &= \frac{3.04 \times 10^6}{57} = 5.33 \times 10^4 \frac{\text{Lbm}}{\text{hr}} \quad \text{for Kiana,} \\ &= \frac{3.32 \times 10^7}{93.5} = 3.55 \times 10^5 \frac{\text{Lbm}}{\text{hr}} \quad \text{for Nome,} \\ &= \frac{1.69 \times 10^7}{93.5} = 1.81 \times 10^5 \frac{\text{Lbm}}{\text{hr}} \quad \text{for Wrangell.}\end{aligned}$$

Over 30 yr, the accumulated flow is

$$\begin{aligned}1.37 \times 10^{11} \text{ Lbm for Barrow,} \\ 1.40 \times 10^{10} \text{ Lbm for Kiana,} \\ 9.34 \times 10^{10} \text{ Lbm for Nome,} \\ 4.76 \times 10^{10} \text{ Lbm for Wrangell.}\end{aligned}$$

If crack area is $9.6211 \times 10^6 \text{ ft}^2$, then

$$Q_{\text{REQ'D}} = \frac{1.37 \times 10^{11} \text{ Lbm}}{9.62 \times 10^6 \text{ ft}^2} = 1.42 \times 10^4 \frac{\text{Lbm}}{\text{ft}^2} \text{ for Barrow;}$$

similarly,

$$\begin{aligned}Q_{\text{REQ'D}} &= 1.46 \times 10^3 \frac{\text{Lbm}}{\text{ft}^2} \text{ for Kiana,} \\ &= 9.71 \times 10^3 \frac{\text{Lbm}}{\text{ft}^2} \text{ for Nome,} \\ &= 4.95 \times 10^3 \frac{\text{Lbm}}{\text{ft}^2} \text{ for Wrangell.}\end{aligned}$$

The Q_{MAX} available from one set of wells is:

$$5.574 \times 10^3 \frac{\text{Lbm}}{\text{ft}^2} \text{ for Barrow, Nome, and Wrangell}$$

and

$$3.504 \times 10^3 \frac{\text{Lbm}}{\text{ft}^2} \text{ for Kiana.}$$

$\Psi \equiv \frac{Q_{REQ'D}}{Q_{MAX}}$ is then the number of wellsets required for each site;

for Barrow $\Psi_B = 2.55 \Rightarrow 3 \text{ wellsets,}$

Kiana $\Psi_K = 0.42 \Rightarrow 1 \text{ wellset,}$

Nome $\Psi_N = 1.74 \Rightarrow 2 \text{ wellsets,}$

Wrangell $\Psi_W = 0.89 \Rightarrow 1 \text{ wellset.}$

Appendix C
CONSTRUCTION COSTS

BASE-CASE COST ESTIMATES

Base-case costs are developed in four categories: research and development (RDC), production (PC), initial development (IDC), and recurring (RC). The first three categories comprise all capital costs, while recurring costs include only those operations and maintenance activities performed after a system (or portion thereof) is producing revenue.

Research and Development Cost (RDC)

Costs in this category typically include the time required for administrative personnel to apply for drilling permits and for a drilling specialist and geologist to select drilling sites in or near the town. All base labor rates in this category are estimated at \$200/day.

Production Cost (PC)

Drilling and Well Preparation--calculated as follows:

$$\frac{\text{Calculated Well Depth}}{\text{Estimated Drilling Distance/Day}} \times \text{Estimated Daily Cost (\$50,000)}$$

All three figures are composite estimates based on interviews with Alaska drilling firms, the Alaska State Geological Society, and relevant well logs.

Mobilization, Rig Relocation--composite estimates from the sources listed above.

Loss and Repair--1 percent of estimated drilling costs.

Wellhead, Utilidor, and Distribution System--calculated from the bills of labor and materials detailed earlier.

Initial Development Cost (IDC)

System Start-Up--training costs are based on an operations and maintenance crew of three men per well pair. Crew members are costed

at \$10/hr, supervisors at \$15/hr. Technical data is expected to comprise 250 pages of material, at a preparation cost of \$20/page.

Installation-Checkout--Initial spares stockage is estimated at 3 percent of combined wellhead and distribution system material cost. Labor includes all crew costs (devoted to on-the-job training and checkout) subsequent to training and prior to on-line operation.

Demobilization--the cost of shipping the well rig back to its point of origin. Compiled from estimates from the sources referenced under Drilling and Well Preparation.

Recurring Cost (RC)

Spares Inventory Replenishment is estimated as 10 percent of initial spares stockage, per year. Labor is based on the crew composition and costs discussed under System Start-Up above.

* * *

Costs subsequent to the initial year are assumed to inflate at a 6-percent annual rate.

BASE-CASE FINANCIAL SUMMARY

The summary table data are calculated as follows:

Total Capital Investment--RDC + PC + IDC

30-Yr Ownership Cost--Interest Rate (10%) × System Lifetime ×
Total Capital Investment

Average Annual Ownership Cost-- $\frac{30\text{-Yr Ownership Cost}}{30}$

Average Annual Cost--Based on setting, revenues equal to costs:

$\frac{(30\text{-Yr Ownership Cost} + RC) \cdot (Royalties - 10\%) \cdot (Taxes - 2.25\%)}{30}$

Installation Costs:	Barrow	Huslia	Kiana	Nikolski	Nome	Wrangell
Direct Materials	\$2,009,400	\$262,008	\$294,088	\$ 94,036	\$1,579,140	\$1,312,786
Direct Labor	1,003,295	197,918	213,158	65,295	964,012	825,235
Utilidor or Trench Piping Installation	1,520,120	23,100	224,640	8,000	1,274,700	40,000
Freight	<u>187,478</u>	<u>25,636</u>	<u>26,163</u>	<u>13,717</u>	<u>158,652</u>	<u>72,521</u>
Total	\$4,720,293	\$508,662	\$758,049	\$181,048	\$3,976,504	\$2,250,542

CONSTRUCTION COST ESTIMATE					Invitation No.		Date		Sht. <u>1</u> of <u> </u>		
PROJECT Barrow Geothermal Installation					☐ CODE A ☐ CODE C		Drawing No.				
LOCATION Barrow, Alaska					☐ CODE B ☐ CODE D		Estimator		Checker		
DISTRIBUTION SYSTEM EQUIPMENT	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs	Rate	Cost	Mat'l & Labor	Wt Lbs Unit	Total Wt lbs
8" dia. fiberglass/epoxy spools, 20 ft length, 2" polyurethane insulation	1,150	ea.	\$343	\$394,450	4.66	5,359				100	115,000
8" sleeves including jacket and foam	1,150	ea.	9.75	11,210	0.23	265				5	5,750
2" dia. fiberglass/epoxy spools, 20 ft lengths, 2" nominal polyurethane insulation	3,120	ea.	125	390,000	2.04	6,365				40	124,800
2" sleeves including jacket and foam	3,120	ea.	8.50	26,520	0.10	312				5	15,600
90° ell, F/E, 2"x2" with 2" nominal polyurethane insulation	178	ea.	34.00	6,050	2.26	402				4	712
45° ell F/E, 2"x2" with 2" nominal polyurethane insulation	8	ea.	34.00	270	2.22	18				4	32
Tee connection, F/E, 2"x2"x2" with 2" polyurethane insulation	1,000	ea.	60.00	60,000	3.42	3,420				6	6,000
Tee connection, F/E, 8"x8"x8" with 2" polyurethane insulation	16	ea.	280.00	4,480	11.15	178				15	240
Tee connection, F/E, 8"x8"x2" with 2" polyurethane insulation	16	ea.	320.80	5,130	11.15	178				17	272
Reducer, F/E, 2"x1" with 2" polyurethane insulation	450	ea.	40.80	18,360	.85	383				2	900

CONSTRUCTION COST ESTIMATE					Invitation No.		Date		Smt. <u>2</u> of <u> </u>		
PROJECT Barrow Geothermal Installation					☐ CODE A ☐ CODE C		Drawing No.				
LOCATION Barrow, Alaska					☐ CODE B ☐ CODE D		Estimator		Checker		
	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs	Rate	Cost	Mat'l & Labor	Wt. lb	Total Wt lbs
Reducer, F/E, 8"x2" with 2" polyurethane insulation	16	ea.	\$300.00	\$4,800	5.31	85				5 lb	80
Butterfly valves 2" 125# full lug, rubber lined, al/br disc. manual operators	64	ea.	63	4,032	1.70	109				8	512
Drain valves 1", bronze gate, handwheel operator	64	ea.	14	896	.50	32				2.3	147
Flanges - 125# full bolt pattern - 2" (FF)	128	ea.	34	4,352	0.80	102				4	512
Flanges - 125# full bolt pattern - 8"	16	ea.	129	2,064	3.10	50				7.8	125
WELLHEAD EQUIPMENT											
6" nominal carbon steel pipe, A106-B, schedule 80. Ends prepared for butt weld connection	300	ft	\$7.75	\$ 2,325	0.56	168				29 ^{1b} / _{ft}	8,700
6" 90° ell, schedule 80, butt weld end prepared	28	ea	41.16	1,152	12.26	343				32	896
6" 1500# flange, raised face, weld neck, schedule 80 bore	48	ea	288	13,824	8.50	408				164	7,872
6" 900# manually operated gate valve, BW end connections	12	ea	3,677	44,124	16.00	192				655	7,860
4" pressure control valve pneumatic operator w/positioner	3	ea	9,000	27,000	24.00	72				700	2,100

Smt. 3 of

Estimator

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Checker

	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No.	Units	Unit Price	Cost	Hrs	Total Hrs	Rate	Cost	Mat'l & Labor	Wt	Total Wt
					Unit					Unit	
Instrumentation, control panel, instrument air compressor	3	ea	\$7,000	\$21,000	35.00	105				500 lb	1,500
Electrical switchgear, relay rack, & misc. wiring	1	Lot	12,000	12,000	60.00	60				400	400
Centrifugal brine reinjection pump	3	ea	680	2,040	12.00	36				250	750
Wellset pressurizing pump	3	ea	1,895	5,685	35.00	105				267	801
Heat exchanger--shell & tube	9	ea	75,000	675,000	240.00	2,160				30,000	270,000
Weatherproof insulated box housing	6	ea	14,300	85,800	20.00	120				5,000	30,000
Circulating water pump- distribution system	1	ea	4,163	4,163	20.00	20				1,263	1,263
			\$1,826,727			21,047					602,824
Add Loss 10%			182,673					@47.67		@	0.311
			\$2,009,400					\$1,003,295			\$187,478
								BASIC SYSTEM TOTAL	\$3,200,173		
Surface Utilidor-containing 8" & 2" insulated distribution piping	42,700	LF @	\$35.60					\$1,520,120			
								TOTAL	\$4,720,293		

CONSTRUCTION COST ESTIMATE

Invitation No.

Date

Sht. 1 of

PROJECT Huslia Geothermal Installation

☐ CODE A

☐ CODE C

Drawing No.

LOCATION Huslia, Alaska

☐ CODE B

☐ CODE D

Estimator

Checker

DISTRIBUTION SYSTEM EQUIPMENT	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs.	Rate	Cost	Mat'l & Labor	Wt Unit	Total Wt
3" dia fiberglass/epoxy spools 20 ft length, 2" polyurethane insulation	1050	ea	\$153	\$160,650	2.24	2,352				46 $\frac{1b}{ft}$	48,300
sleeves-3" including jacket and foam	1050	ea	9.75	10,238	0.11	116				5	5,250
tee connections, f/e, 3"x3"x3" with 2" polyurethane insulation	65	ea	82	5,330	4.56	296				6.9	448
reducer-3"x1" f/e, with 2" polyurethane insulation	50	ea	98.40	4,920	1.56	78				2.3	115
45° lateral connection fittings, 3"x3"x3"	12	ea	82	984	2.32	28				6.9	83
butterfly valves-3" 125# full lug rubber lined al/br disc, manual operator	20	ea	89.70	1,794	2.35	47				15	300
drain valve-1" bronze gate, handwheel operator	21	ea	14	294	0.50	11				2.3	48
flanges-125# ft, full bolt pattern - 3"	40	ea	34	1,360	1.15	46				4	160
WELLHEAD EQUIPMENT											
6" nominal carbon steel pipe, A106-B, standard schedule, Ends prepared for std butt weld connection	100	ft	7.75	775	0.56	56				29	2,900
6" 90° ell, standard schedule, flanged connection	10	ea	41.16	412	12.26	123				32	320

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CONSTRUCTION COST ESTIMATE						Invitation No.		Date		Sht. 3 of ____	
PROJECT Huslia Geothermal Installation						☐ CODE A ☐ CODE C		Drawing No.			
LOCATION Huslia, Alaska						☐ CODE B ☐ CODE D		Estimator		Checker	
	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs.	Rate	Cost	Mat'l & Labor	Wt Unit	Total Wt
Carried Forward				\$238,189		3,389					\$69,286
			Loss Add 10%	23,819		@	58.40			@	0.37
				<u>\$262,008</u>				<u>\$197,918</u>			<u>\$25,636</u>
							BASIC SYSTEM TOTAL		<u>\$485,562</u>		
Excavate trench for two 3" insulated pipes 2'-0" to 3'-0" deep	10,500					@ 220 ft		\$23,100			
							TOTAL		<u>\$508,662</u>		

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CONSTRUCTION COST ESTIMATE

PROJECT					Kiana Geothermal Installation		Invitation No.		Date		Sm. 2 of	
LOCATION					Kiana, Alaska		☐ CODE A ☐ CODE C ☐ CODE B ☐ CODE D		Drawing No.		Estimator	
CHECKER												

WELLHEAD EQUIPMENT	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT		
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs	Rate	Cost	Mat'l & Labor	Wt Unit	Total Wt	
6" nominal carbon steel pipe, A106-B, schedule 80. Ends prepared for butt weld connection	100	ft	\$7.75	\$ 775	0.56	56					29 ¹ / _{ft}	2,900
6" 90° ell, schedule 80, butt weld end prepared	10	ea	41.16	412	12.26	123					32	320
6" 1500# flange, raised face, weld neck, schedule 80 bore	16	ea	288	4,608	8.50	136					164	2,624
6" 900# manually operated gate valve, BW end connections	4	ea	3,677	14,708	16.00	64					655	2,620
4" pressure control valve pneumatic operator/positioner	1	ea	9,000	9,000	24.00	24					700	700
Instrumentation, control panel, instrument air compressor	1	ea	12,000	12,000	60.00	60					500	500
Electrical switchgear, relay rack & misc. wiring	1	lot	9,000	9,000	45.00	45					300	300
Centrifugal wellhead brine reinjection pump	1	ea	680	680	12.00	12					250	250
Wellset pressurizing pump	1	ea	1,895	1,895	35.00	35					267	267
Heat exchanger--shell & tube	1	ea	39,780	39,780	160.00	160					14,040	14,040
Weatherproof insulated box housing--8' x 20'	1	ea	14,300	14,300	20.00	20					5,000	5,000

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CONSTRUCTION COST ESTIMATE

Invitation No.

Date

SM. 2 of

PROJECT Nikolski Geothermal Installation

☐ CODE A

☐ CODE C

Drawing No.

LOCATION Nikolski, Alaska

☐ CODE B

☐ CODE D

Estimator

Checker

WELLHEAD EQUIPMENT	QUANTITY		MATERIAL		LABOR				TOTAL Mat'l & Labor	FREIGHT		
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs	Rate	Cost		Wt Unit	Total Wt	
6" nominal carbon steel pipe, A106-B, std. schedule. End prepared for butt weld connection	100	ft	\$7.75	\$ 775	0.56	56				29 lb Ft		2,900
6" 90° ell standard schedule	10	ea	41.16	412	12.26	123				32		320
6" 125# flange, raised face, weld neck standard schedule	16	ea	288	4,608	2.25	36				164		2,624
6" 150# manually operated gate valve. Flanged end connections	4	ea	263	1,052	3.25	13				197		788
4" temperature control valve, diaphragm operator	1	ea	2,200	2,200	12.00	12				400		400
Instrumentation, control panel, instrument air compressor	1	ea	8,000	8,000	40.00	40				400		400
Electrical switchgear, relay rack, misc. wiring	1	lot	9,000	9,000	45.00	45				300		300
Centrifugal wellhead brine reinjection pump	1	ea	500	500	8.00	8				500		500
Downhole booster pump	2	ea	1,500	3,000	10.00	20				200		400
Heat exchanger-plate type	1	ea	6,000	6,000	24.00	24				450		450
Circulating water pump-distribution system	1	ea	330	330	7.00	7				75		75

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CONSTRUCTION COST ESTIMATE					Invitation No.		Date		Sht. <u>1</u> of <u> </u>		
PROJECT Nome Geothermal Installation					☐ CODE A ☐ CODE C		Drawing No.				
LOCATION Nome, Alaska					☐ CODE B ☐ CODE D		Estimator		Checker		
DISTRIBUTION SYSTEM EQUIPMENT	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs	Rate	Cost	Mat'l & Labor	Wt Unit	Total Wt
6" dia. fiberglass/epoxy spools, 20 ft. length, 2" polyurethane insulation	1,000	ea.	\$241	\$241,000	4.42	4,420				78 lb	78,000
Sleeves - 6" including jacket and foam	1,000	ea.	8.50	8,500	0.22	220				5	5,000
2" dia. fiberglass/epoxy spools, 20 ft. length, 2" polyurethane insulation	3,200	ea.	125	400,000	2.04	6,528				40	128,000
Sleeves - 2" including jacket and foam	3,200	ea.	8.50	27,200	0.10	320				5	16,000
90° ells, F/E 6" x 6" with 2" polyurethane insulation	30	ea.	129.00	3,870	5.26	158				7.8	234
90° ells, F/E 2" x 2" with 2" polyurethane insulation	120	ea.	34.00	4080	2.26	271				4	480
45° ells, F/E 2" x 2" with 2" polyurethane insula- tion	12	ea.	34.00	408	2.22	27				4	48
Tee connections, F/E, 2"x2"x2" with 2" polyurethane insula- tion	1,300	ea.	60.00	78,000	3.42	4,446				6	7,800
Reducer, F/E, 2" x 1" with 2" polyurethane insulation	1,200	ea.	40.80	48,960	.85	1,020				2	2,400
Butterfly valves 6", 125 [#] full lug, rubber lined, al/br disc manual operators	12	ea.	199.20	2,390	4.10	49				48	576

CONSTRUCTION COST ESTIMATE						Invitation No.		Date		Sht. 2 of _____	
PROJECT Nome Geothermal Installation						☐ CODE A ☐ CODE C		Drawing No.			
LOCATION Nome, Alaska						☐ CODE B ☐ CODE D		Estimator		Checker	
	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs	Rate	Cost	Mat'l & Labor	Wt Unit	Total Wt
Butterfly valves 2", 125# full lug, rubber lined, al/br disc manual operators	128	ea.	\$63	\$8,064	1.70	218				81b	1,024
Drain valves 1", bronze gate, handwheel operator	128	ea.	14	1,792	0.50	64				2.3	294
Flanges 125# full bolt pattern 6" (FF)	24	ea.	129	3,096	2.25	54				7.8	187
Flanges 125# full bolt pattern 2" (FF)	256	ea.	34	8,704	0.80	205				4	1,024
WELLHEAD EQUIPMENT											
6" nominal carbon steel pipe, A106-B, schedule 80. Ends prepared for butt weld connection	200	ft	7.75	1,550	0.56	112				29 ^{1b} _{ft}	5,800
6" 90° ell, schedule 80, butt weld end prep	20	ea	41.16	823	12.26	245				32	640
6" 1500# flange, raised face, weld neck, schedule 80 bore	32	ea	288	9,216	8.50	272				164	5,248
6" 900# manually operated gate valve, BW end connections	8	ea	3,677	29,416	16.00	128				655	5,240
4" pressure control valve pneumatic operator with positioner	2	ea	9,000	18,000	24.00	48				700	1,400
Instrumentation, control panel, instrument air compressor	2	ea	7,000	14,000	35.00	70				250	500

CONSTRUCTION COST ESTIMATE						Invitation No.		Date		Shw. 3 of _____	
PROJECT Nome Geothermal Installation				☐ CODE A ☐ CODE C		Drawing No.					
LOCATION Nome, Alaska				☐ CODE B ☐ CODE D		Estimator				Checker	
	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs.	Rate	Cost	Mater & Labor	Wt Unit	Total Wt
Electrical switchgear, relay rack, & misc. wiring	1	Lot	\$10,000	\$10,000	50.00	50				350lb	350
Centrifugal wellhead brine reinjection pump	2	ea	680	1,360	12.00	24				250	500
Heat exchanger--shell & tube	6	ea	75,000	450,000	240.00	1,440				30,000	180,000
Wellset pressurizing pump	2	ea	1,895	3,790	35.00	70				267	534
Weatherproof insulated box housing	4	ea	14,300	57,200	20.00	80				5,000	20,000
Circulating water pump-distribution system	1	ea	4,163	4,163	20.00	20				1,263	1,263
				\$1,435,582		20,559					462,543
		Add Loss 10%		143,558		@ \$46.89				@	0.343
				\$1,579,140				\$964,012			158,652
							BASIC SYSTEM TOTAL	\$2,701,804			
Surface utilidor--containing 6" or 2" insulated pipe	42,000	LF				@ 30.35	\$1,274,700				
							TOTAL	\$3,976,504			

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CONSTRUCTION COST ESTIMATE					Invitation No.		Date		Sm. 1 of		
PROJECT Wrangell Geothermal Installation					☐ CODE A ☐ CODE C		Drawing No.				
LOCATION Wrangell, Alaska					☐ CODE B ☐ CODE D		Estimator		Checker		
DISTRIBUTION SYSTEM EQUIPMENT	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs.	Rate	Cost	Mat'l & Labor	Wt lbs Unit	Total Wt lbs
6" dia. fiberglass/epoxy spools, 20 ft length, 2" polyurethane insulation	2,000	ea.	\$241	\$482,000	4.42	8,840				78 lb	156,000
6" sleeves including jacket and foam	2,000	ea.	8.50	17,000	0.22	440				5	10,000
90° ells, F/E, 6"x6" with 2" polyurethane insulation	2	ea.	129.00	258	5.26	11				7.8	16
45° ells, F/E, 6"x6" with 2" polyurethane insulation	18	ea.	129.00	2,322	7.20	130				7.8	140
Tee connections, F/E, 6"x6"x6" with 2" polyurethane insulation	790	ea.	192.00	151,680	7.50	5,925				12	9,480
Reducers, F/E, 6"x1" with 2" polyurethane insulation	760	ea.	230.40	175,104	4.00	3,040				4	3,040
Butterfly valves-6" 125# full lug, rubber lines, s/s disc, manual operator	30	ea.	199.20	5,976	4.10	123				48	1,440
Drain valves-1", bronze gate, handwheel operator	64	ea.	14	896	0.50	32				2.3	147
Flanges, 125# full bolt pattern 6" (FF)	60	ea.	129	7,740	2.25	135				7.8	468
45° lateral connection fitting 6"x6"x6"	10	ea.	129	1,290	5.20	52				7.8	78

CONSTRUCTION COST ESTIMATE					Invitation No.		Date		Sht. <u>2</u> of <u> </u>			
PROJECT Wrangell Geothermal Installation					☐ CODE A ☐ CODE C		Drawing No.					
LOCATION Wrangell, Alaska					☐ CODE B ☐ CODE D		Estimator			Checker		
WELLHEAD EQUIPMENT	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT		
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs	Rate	Cost	Mat'l & Labor	Wt Unit	Total Wt	
6" nominal carbon steel pipe, A106-B, schedule 80. Ends prepared for butt weld connection	200	ft	\$7.75	\$ 1,550	0.56	112					29 ¹ / ₂ lb/ft	5,800
6" 90° ell, schedule 80, butt weld end prepared	20	ea	41.16	823	12.26	245					32	640
6" 1500# flange, raised face, weld neck, schedule 80 bore	32	ea	288	9,216	8.50	272					164	5,248
6" 900# manually operated gate valve, BW end connections	8	ea	3,677	29,416	16.00	128					655	5,240
4" pressure control valve, diaphragm operator with positioner	2	ea	9,000	18,000	24.00	48					700	1,400
Instrumentation, control panel, instrument air compressor	2	ea	7,000	14,000	35.00	70					500	1,000
Electrical switchgear, relay rack, & misc. wiring	1	Lot	12,000	12,000	60.00	60					400	400
Centrifugal brine reinjection pump	2	ea	680	1,360	12.00	24					250	500
Wellset pressurizing pump	2	ea	1,895	3,790	35.00	70					267	534
Heat exchanger---shell & tube	3	ea	66,500	199,500	200.00	600					26,600	79,800

CONSTRUCTION COST ESTIMATE						Invitation No.		Date		Sm. 3 of _____	
PROJECT Wrangell Geothermal Installation						☐ CODE A ☐ CODE C		Drawing No.			
LOCATION Wrangell, Alaska						☐ CODE B ☐ CODE D		Estimator		Checker	
	QUANTITY		MATERIAL		LABOR				TOTAL	FREIGHT	
	No. Units	Unit	Unit Price	Cost	Hrs Unit	Total Hrs.	Rate	Cost	Matl & Labor	Wt Unit	Total Wt
Weatherproof insulated box housing	4	ea	14,300	\$57,200	20.00	80				5,000	lb 20,000
Circulating water pump-distribution system	1	ea	2,321	2,321	20.00	20				800	800
				<u>\$1,193,442</u>		<u>20,457</u>					<u>302,171</u>
		Add Loss 10%		<u>119,344</u>		@	40.34				@ 0.24
				<u>\$1,312,786</u>				\$825,235			72,521
							BASIC SYSTEM TOTAL		<u>\$2,210,542</u>		
Excavate trench for 6" for 2" insulated pipes, 2'-0" to 3'-0" deep	20,000					@ 2.00/ft			40,000		
							TOTAL		<u>\$2,250,542</u>		

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Barrow

	<u>Foreman</u>	<u>Plumber</u>	<u>Apprentice or Laborer</u>
Rate:	<u>21.23</u>	<u>19.77</u>	<u>14.83</u>
70 hrs	1,486.10	1,383.90	1,038.10
Subsistence \$50 × 7	<u>350.00</u>	<u>350.00</u>	<u>350.00</u>
	1,836.10	1,733.90	1,388.10
	<u>÷ 50</u>	<u>÷ 50</u>	<u>÷ 50</u>
	36.72	34.68	27.76
	<u>× 1</u>	<u>× 2</u>	<u>× 1</u>
	36.72	69.36	27.76

Average Rate \$33.45

(Allow 6-wk tour) = 6 × 50 or 300 hr

Flight: 218.06

Travel Time: 8 hr × 2 = 16

Contingency = 2

18 hr @ 18.90 = 340.20

\$558.26

÷ 300 \$ 1.86

\$35.31

Add Contractors insurances, bonds, taxes, etc.

35% \$12.36

Hourly Rate \$47.67

Huslia

	<u>Foreman</u>	<u>Plumber</u>	<u>Apprentice or Laborer</u>
Rate:	<u>21.23</u>	<u>19.77</u>	<u>14.83</u>
70 hr	1,486.10	1,383.90	1,038.10
Subsistence \$50 × 7	<u>350.00</u>	<u>350.00</u>	<u>350.00</u>
	1,836.10	1,733.90	1,388.10
	<u>÷ 50</u>	<u>÷ 50</u>	<u>÷ 50</u>
	36.72	34.68	27.76
	None	<u>× 2</u>	<u>× 1</u>
		69.36	27.76

Average Rate \$32.37

(Allow 4-wk tour) 200 hr

Flight:	171.14	
Travel time 8 hr × 3 = 24 hr @ 18.90	453.60	
Waiting time 8 hr		
(3 men) 6 days = 48 hr @ 32.37	<u>1,553.76</u>	
	2,178.50	
	<u>÷ 200</u>	<u>\$10.89</u>
		\$43.26
<u>Add</u> contractors insurance, bonds, taxes, etc. 35%		<u>\$15.14</u>
	Hourly Rate	<u>\$58.40</u>

Kiana

	<u>Foreman</u>	<u>Plumber</u>	<u>Apprentice or Laborer</u>
Rate:	<u>21.23</u>	<u>19.77</u>	<u>14.83</u>
70 hr	1,486.10	1,383.90	1,038.10
Subsistence \$50 × 7	<u>350.00</u>	<u>350.00</u>	<u>350.00</u>
	1,836.10	1,733.90	1,388.10
	<u>÷ 50</u>	<u>÷ 50</u>	<u>÷ 50</u>
	36.72	34.68	27.76
	None	<u>2</u>	<u>1</u>
		69.36	27.76

Average Rate \$32.37

(Allow 4-wk tour) 200 hr

Flight:	234.72
Travel time 8 hr × 3 = 24 hr @ 18.90	453.60
Waiting time 8 hr	
(3 men) 3 days = 24 @ 33.37	<u>800.88</u>
	1,489.20
	<u>÷ 200</u> \$ 7.45
	\$39.82
<u>Add</u> contractors insurance, bonds, taxes, etc. 35%	<u>\$13.94</u>
	Hourly Rate <u>\$53.76</u>

Nikolski

	<u>Plumber</u>	<u>Apprentice or Laborer</u>
Rate:	<u>19.23</u>	<u>14.42</u>
102 hr	1,961.46	1,470.84
Subsistence \$50 x 7	<u>350.00</u>	<u>350.00</u>
	2,311.46	1,820.84
	<u>÷ 60</u>	<u>÷ 60</u>
	38.52	30.35

Average Rate \$34.44

(Allow 7-wk tour) 420 hr

Flight	427.72
Travel Time 8 hr x 3 = 24 @ 18.90	453.60
Waiting Time 8 hr x 6 = 48 @ 34.44	<u>1,653.12</u>
	2,534.44
	<u>÷ 420</u>

\$ 6.03

\$40.47

Add contractors insurance, bonds, taxes, etc. 35%

\$14.17

Hourly Rate \$54.64

Nome

	<u>Foreman</u>	<u>Plumber</u>	<u>Apprentice or Laborer</u>
Rate:	<u>21.23</u>	<u>19.77</u>	<u>14.83</u>
70 hr	1,486.10	1,383.90	1,038.10
Subsistence \$50 × 7	<u>350.00</u>	<u>350.00</u>	<u>350.00</u>
	1,836.10	1,733.90	1,388.10
	<u>÷ 50</u>	<u>÷ 50</u>	<u>÷ 50</u>
	36.72	34.68	27.76
	<u>× ½</u>	<u>× 2</u>	<u>× 1</u>
	18.36	69.36	27.76

Average Rate \$32.99

(Allow 6-wk tour) 300 hr

Flight

182.02

Travel Time 8 hr × 2 = 16

Contingency = 2

18 hr @ 18.90 =

340.20

522.22

÷ 300 \$ 1.74

\$34.73

Add contractors insurance, bonds, etc. 35%

\$12.16

Hourly Rate

\$46.89

Wrangell

	<u>Foreman</u>	<u>Plumber</u>	<u>Apprentice or Laborer</u>
Rate:	<u>20.69</u>	<u>19.23</u>	<u>14.42</u>
52 hr	1,075.88	999.96	749.84
Subsistence 40 x 7	<u>280.00</u>	<u>280.00</u>	<u>280.00</u>
	1,355.88	1,279.96	1,029.84
	<u>÷ 44</u>	<u>÷ 44</u>	<u>÷ 44</u>
	30.82	29.09	23.41
	<u>x 1</u>	<u>x 2</u>	<u>x 1</u>
	30.82	58.18	23.41
			Average Rate \$28.10

(Allow 6-wk tour) 300 hr

Flight

203.50

Travel Time 8 hr x 2 = 16

Contingency = 2

18 hr @ 18.40 =

331.20

534.70

÷ 300 \$ 1.78

\$29.88

Add contractors insurance, bonds, etc. 35%

\$10.46

Hourly Rate \$40.34

Basic Plumber's Rate

	<u>North of 63° Latitude</u>	<u>South of 63° Latitude</u>
	Barrow	Wrangell
	Nome	Nikolski
	Kiana	
	Huslia	
Basic Rate	\$17.42	\$16.90
Health & Welfare	.60	.73
Pension	1.30	1.40
I.A.P.F.	-	.05
App. Tr.	<u>.45</u>	<u>.15</u>
Total	\$19.77	\$19.23

Foreman + \$1.46/hr

Apprentice 75% of journeyman rate

Working Conditions

North of 63° Latitude (Barrow, Nome, Kiana, & Huslia)

Normal current working week

6 days at 10 hr = 60 hr

Overtime paid = 10 hr

Total 70 hr paid

Production Hours: 50 hr

South of 63° Latitude (Wrangell; Southeast Alaska)

6 days at 8 hr = 48 hr

Overtime paid = 4 hr

Total 52 hr paid

Production Hours: 44 hr

Nikolski (Aleutian Chain)

7 days at 12 hr = 84 hr

Overtime paid = 28 hr

Total 102 hr paid

Production Hours: 60 hr

Size of Crew

<u>Barrow</u>	1 Foreman
	2 Plumbers
	1 Apprentice or Laborer
<u>Nome</u>	1 Foreman (part time)
	2 Plumbers
	1 Apprentice or Laborer
<u>Kiana</u>	2 Plumbers
	1 Apprentice or Laborer
<u>Huslia</u>	2 Plumbers
	1 Apprentice or Laborer
<u>Wrangell</u>	1 Foreman
	2 Plumbers
	1 Apprentice or Laborer
<u>Nikolski</u>	1 Plumber
	1 Apprentice or Laborer

Air Fares

Anchorage to: _____

Point Barrow Daily \$218.00 return

Nome Daily \$182.02 return

Kiana Via Kotzebue
Daily \$234.72 return (overnight outward)

Huslia Via Galena
Monday
& \$171.14 return (overnight outward)
Thursday

Nikolski Thursday Only \$427.72 return

Wrangell Daily \$203.50 return via Juneau
From Seattle Daily \$194.16 return via Juneau

Transportation

Barrow

Barge: 0.111/lb trans.

Handling: 0.200

0.311

Nome

Barge: 0.143/lb trans.

Handling: 0.200

0.343

Kiana

Barge: 0.167/lb trans.

Handling: 0.200

0.367

Huslia

Barge: 0.170/lb trans.

Handling: 0.200

0.370

Nikolski

Barge: -

Flight: 0.322/lb trans.

Handling: 0.250

0.572

Wrangell

Barge: 0.09/lb trans.

Handling: 0.15

0.24

Appendix D

LOAD-SIZING CALCULATIONS FOR HUSLIA AND KIANA

The load-size calculations presented below are for the town of Huslia. These calculations are very similar to the calculations for Nikolski and Wrangell, the only variations being in the materials used for construction, ΔT , the number and size of structures to be heated, and fuel used.

Huslia

Two methods are used to size the thermal load for Huslia.

Method 1. The town of Huslia comprises thirty houses and one store. Each building uses approximately seven cords of wood per year for heating and cooking. For purposes of this study, we assume that virtually all the wood burned is used to heat the houses. The heating value used for wood is 16,300,000 Btu/cord. Stove efficiency is assumed to be 0.50.

Because of Huslia's small size (pop. 159), climatologic data have not been recorded. The location nearest Huslia for which data are available is Hughes, Alaska, about 60 mi northeast of Huslia. For the years 1942 through 1967, mean daily minimum temperature for the month of December is -19.1°F . For purposes of this study, we assume an outside design temperature of -20°F . Data for Hughes indicate that 15,233 heating degree days can be expected in an average year. Average heating degree days for December are 2344. Since it is expected that seasonal use of firewood is directly proportional to the fraction of annual heating degree days, fuel consumption in Huslia is estimated to be

$$\left[\frac{2344}{15233}\right] \left[\frac{7 \text{ cords}}{\text{structure}}\right] [31 \text{ structures}] = 33.4 \text{ cords used during December in a typical year.}$$

The design heat loss due to all heat-transfer mechanisms is H_L . An indoor temperature of 75°F at Huslia is assumed. Then, using the ASHRAE Modified Degree Day Procedure for sizing load (1976 ASHRAE Systems, p. 43.8),

$$H_L = \frac{E \Delta T \eta V}{D(24) C_D C_F},$$

where

$$E = 33.4 \text{ cords,}$$

$$\Delta T = 75 - (-20) = 95^\circ\text{F, the difference between indoor and outdoor design temperature,}$$

$$\eta = 0.5,$$

$$V = 1.63 \times 10^7 \frac{\text{Btu}}{\text{cord}},$$

$$D = 2344 \text{ heating degree days,}$$

$$C_D = 0.57, \text{ an interim heat loss correction factor,}$$

$$C_F = 1.36, \text{ a partial load correction factor assuming that existing wood-burning equipment is not oversized at all.}$$

Substituting:

$$H_L = 5.93 \times 10^5 \frac{\text{Btu}}{\text{hr}}$$

$$\left(5.93 \times 10^5 \frac{\text{Btu}}{\text{hr}}\right) \left(\frac{1 \text{ hr}}{60 \text{ min}}\right) \left(\frac{17.57 \text{ watts}}{\frac{\text{Btu}}{\text{min}}}\right) \left(\frac{1 \text{ MW}}{10^6 \text{ watts}}\right) = 0.174 \text{ MW}_{\text{THERMAL}}$$

Method 2. The second technique used to size the load for Huslia is the ASHRAE heating load general procedure (1972 ASHRAE Handbook of Fundamentals, Chap. 21). The standard ASHRAE house has been modified to reflect construction of the average Huslia house. Huslia has 30 residences. Each is a single-story log structure with a pitched roof. The houses average about 20 ft x 20 ft and are generally built on pilings leaving a dead air space between the floor and the ground. We assume that 7 percent of the exterior wall surface is occupied by windows. The one store in Huslia--a two-story building, 30 ft x 28 ft--is constructed the same as the houses.

Walls: For the houses, each wall is 20 ft x 10 ft = 200 ft²; of the total, 14 ft² is window area; 186 ft² is log wall. For the store, each wall is approximately 29 ft x 20 ft = 580 ft², of which 40.6 ft² is window and 539.4 ft² is log wall. The log portion of the walls is modeled as follows:

T_o = outside temperature
= -20°F for Huslia

T_i = inside temperature
= 75°F

The following table lists the thermal resistances for the homogeneous log wall:

Location	Resistance
1. Outside surface (15-mph wind assumed)	0.17
2. 6-in.-thick, squared log wall	7.85
3. Inside surface (still air)	<u>0.68</u>
	Total Resistance
	8.70

Then, $U_{\text{WALL}} = \frac{1}{R} = 0.1149 \frac{\text{Btu}}{\text{hr ft}^2 \text{ } ^\circ\text{F}}$.

Windows: From ASHRAE, double-paned windows have

$$U_{\text{WINDOW}} = 0.58 \frac{\text{Btu}}{\text{hr ft}^2 \text{ } ^\circ\text{F}}.$$

Pitched Roofs (45° pitch assumed): Area of each house roof = 566 ft²;
area of store roof = 1188 ft².

$$T_o = -20^\circ\text{F}$$

$$T_i = 85^\circ\text{F (assumed)}$$

For the purpose of this heat-transfer estimate, insulation on the ceiling and the laminated roof are combined into one series of thermal resistances (see table below).

Location	Resistance
1. Outside surface (15-mph wind assumed)	0.17
2. Asphalt shingle roofing	0.44
3. Building paper	0.06
4. Plywood deck, 5/8-in.	0.80
5. R-9 insulation	9.00
6. Gypsum wallboard, 1/2-in.	0.45
7. Inside surface (still air)	<u>0.62</u>
	Total Resistance 11.54

Then, $U_{\text{ROOF}} = \frac{1}{R} = 0.0866$.

Frame Flooring: House floor area = 400 ft^2 ; store floor area = 840 ft^2 .

$$T_1 = 75^\circ\text{F}$$

$$T_o = -20^\circ\text{F}$$

The following table lists resistances for the floor:

Location	Resistance
1. Top surface (still air)	0.61
2. Linoleum	0.05
3. Plywood, 5/8-in.	0.78
4. Air space	0.85
5. Wood subfloor, 3/4-in.	0.94
6. Bottom surface (still air)	<u>0.61</u>
	Total Resistance 3.84

Then, $U_{\text{FLOOR}} = \frac{1}{R} = 0.260$. Adjusting for framing (2" x 8" @ 16" o.c.),

$$U_{\text{FLOOR}} \times 0.94 = 0.260 \times 0.94 = 0.245 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$$

Doors: The "average" house in Huslia is assumed to have two 30-in. x 80-in. doors totalling 33.33 ft^2 , with $U_{\text{DOOR}} = 0.49$.

The heat loss from the town of Huslia due to conduction and convection is then

$$Q' = \sum_{i=1}^5 q_i = \sum_{i=1}^5 A_i U_i \Delta T_i$$

The following table summarizes values for A_i , U_i , ΔT_i for the store and houses in Huslia:

i	Heat-Transfer Surface	$A_i (\text{ft}^2)$	$U_i \frac{\text{Btu}}{\text{hr ft}^2 \text{ } ^\circ\text{F}}$	$\Delta T_i (^\circ\text{F})$
1	Walls	24477.6	0.115	95
2	Windows	1842.4	0.580	95
3	Pitched roofs	18168.0	0.087	105
4	Frame flooring	12840.0	0.260	95
5	Doors	1033.3	0.490	95

Then, $Q' = 900,146.8 \frac{\text{Btu}}{\text{hr}}$.

Heat Loss Due to Infiltration in Huslia. We assume that the average Huslia house has an infiltration factor of 1.8. If each house is 20 ft $\times$ 20 ft $\times$ 10 ft (ignoring the attic), and the store is 28 ft $\times$ 30 ft $\times$ 20 ft (also ignoring the attic), then heat loss due to infiltration is

$$Q'' = (1.8) [(30)(4000) + (1)(16800)] = 246240 \frac{\text{Btu}}{\text{hr}}.$$

Total heat loss Q , calculated by Method 2, is

$$Q = Q' + Q'' = 1.146 \times 10^6 \frac{\text{Btu}}{\text{hr}} = 1.91 \times 10^4 \frac{\text{Btu}}{\text{min}}.$$

Converting to megawatts,

$$Q = \frac{(1.91 \times 10^4)(17.57)}{10^6} = 0.336 \text{ MW}_{\text{THERMAL}}.$$

Although the town is located in a region of general permafrost, the ground in Huslia is free of permafrost because of the proximity of the Koyukuk River. It is practical to consider burying the distribution piping at Huslia. We assume that the buried pipe's outside-surface temperature is maintained at a constant 33°F. The piping heat loss can then be represented as follows:

where

$$\begin{aligned}
 T_1 &= 150^\circ\text{F} & D_2 &= 3'' & k_{2,3} &= 0.217 \frac{\text{Btu}}{\text{hr ft}^\circ\text{F}} \\
 T_4 &= 33^\circ\text{F} & D_3 &= 3.25'' & k_{3,4} &= 0.0133 \frac{\text{Btu}}{\text{hr ft}^2^\circ\text{F}} \\
 & & D_4 &= 7'' & &
 \end{aligned}$$

Water temperature is estimated to be 150°F. Because of the relatively long length of piping used in Huslia, average temperature will be somewhat less, and heat loss will be lower than the value calculated here.

For water at 150°F, the average properties are:

$$\begin{aligned}\rho &= 61.20 \frac{\text{Lbm}}{\text{ft}^3} & k &= 0.381 \frac{\text{Btu}}{\text{hr ft}^\circ\text{F}} \\ \mu &= 1.04 \frac{\text{Lbm}}{\text{ft hr}} & N_{PR} &= 2.72\end{aligned}$$

Nikolski requires a flow rate of 60 gpm, through each of two 3-in. lines $\Rightarrow V = 1.30 \text{ ft/sec}$. Therefore,

$$\begin{aligned}N_{Re_D} &= \frac{VD\rho}{\mu} = \frac{(1.30)(3600)(\frac{1}{4})(61.20)}{1.04} \\ &= 6.885 \times 10^4.\end{aligned}$$

Therefore, the water flow is turbulent, with the water being cooled;
 $n = 0.3$.

From McAdams,

$$\begin{aligned}N_{NU_D} &= 0.028(N_{Re_D})^{0.8}(N_{PR})^{0.3} \\ &= 0.023[6.885 \times 10^4]^{0.8}[2.72]^{0.3} = 230.37; \\ h_{1,2} &= \frac{N_{NU_D} k}{D} = \frac{(2.3037 \times 10^2)(0.381)}{0.25} = 3.51 \times 10^2 = h_{1,2}.\end{aligned}$$

The overall heat-transfer coefficient is then

$$U_4 = \frac{1}{\frac{r_4}{r_2 h_{1,2}} + \frac{r_4 \ln(\frac{r_3}{r_2})}{k_{2,3}} + \frac{r_4 \ln(\frac{r_4}{r_3})}{k_{3,4}}} = \frac{1}{6.65 \times 10^{-3} + 1.076 \times 10^{-1} + 16.83} = 0.059 .$$

Heat lost from the pipe is then

$$\frac{q}{L} = (\frac{A_4}{L}) U_4 (t_1 - t_5) = 12.65 \frac{\text{Btu}}{\text{hr ft}} .$$

Since total length of distribution piping in Huslia is expected to be 21,000 ft, total heat loss due to conduction and convection is

$$(12.65)(21000) = 2.657 \times 10^5 \frac{\text{Btu}}{\text{hr}} = 4.428 \times 10^3 \frac{\text{Btu}}{\text{min}} = 0.078 \text{ MW}.$$

The following table summarizes the heat losses for Huslia:

Item	Loss (MW)	
Huslia buildings - Method 1	0.17	
Huslia buildings - Method 2	0.34	
Piping distribution	<u>0.08</u>	<u>0.08</u>
Total Geothermal Power Required	0.25	0.42

For system sizing and cost-estimating purposes, we use a design load of 1.0 MW.

Kiana

The load-sizing calculations for Kiana are very similar to the load sizing calculations for other towns located in a permafrost region. Therefore, the methods outlined here are close to the exercises for Barrow and Nome, which are not presented.

Two methods are used to determine the thermal load for Kiana.

Method 1

In January 1976, we estimate that the Public Health Service consumed a total of 1100 gal of No.-1 oil to operate the water and sewer facilities in Kiana. For the purposes of this study, we assume that PHS process efficiency is 0.80:

$$H_{L_1} = \frac{(0.80) \left(\frac{1100 \text{ gal}}{31 \text{ days}} \right) \left(\frac{1.4 \times 10^5 \text{ Btu}}{\text{gal}} \right) \left(\frac{1 \text{ day}}{24 \text{ hr}} \right) \left(\frac{1 \text{ hr}}{60 \text{ min}} \right) \left(\frac{17.57 \text{ watt}}{\text{Btu/min}} \right)}{10^6 \frac{\text{watt}}{\text{megawatt}}}$$

$$H_{L_1} = 4.85 \times 10^{-2} \text{ MW}$$

The balance of No.-1 oil used in Kiana in January 1976 for space heating is 12,900 gal, E. The design heat loss from all heat-transfer mechanisms $\equiv H_{L_2}$. The temperature differential for Kiana is the difference between an indoor temperature of 75° and an assumed outdoor design temperature of -35°F. The efficiency η of the average heater in Kiana is assumed to be 0.60. From historical data, there were 2300 degree days.

From Chap. 43 of the *ASHRAE Systems Handbook*,

$$H_{L_2} = \frac{E \Delta t \eta (V)}{D(24) C_D C_F}$$

where

$$C_D = 0.71 \quad ,$$

$$C_F = 1.36 \quad ,$$

$$V = 1.40 \times 10^5 \text{ Btu/gal} \quad .$$

Substituting into the above equation,

$$H_{L_2} = \frac{(1.29 \times 10^4)(110)(0.60)(1.40 \times 10^5)}{(2300)(24)(0.71)(1.36)} = 2.236 \times 10^6 \frac{\text{Btu}}{\text{hr}}$$

$$\left(2.236 \times 10^6 \frac{\text{Btu}}{\text{hr}}\right) \left(\frac{1 \text{ hr}}{60 \text{ min}}\right) \left(\frac{17.57 \text{ watt}}{\text{Btu/min}}\right) \left(\frac{1 \text{ MW}}{10^6 \text{ watt}}\right) = 0.655 \text{ MW} \quad .$$

H_L is then equal to

$$H_{L_1} + H_{L_2} = 0.0485 + 0.655 = 0.7035 \text{ MW}_{\text{THERMAL}} \quad .$$

Method 2

The second technique used to size the load for Kiana is the ASHRAE heating load general procedure outlined in Chap. 21 of the 1972 *ASHRAE Handbook of Fundamentals*. The standard ASHRAE house has been modified to reflect estimated construction of the average Kiana house.

We estimate that 60 residences, each having a floor area of approximately 20 ft x 32 ft, are to be heated by means of geothermal energy. In addition, a 14,900 ft² multi-room school is to be heated, as well as an additional 30,000 ft² made up of the high school and miscellaneous buildings. For the purposes of this study, we divide the total square footage of the buildings in Kiana into a number of "standard" Kiana buildings, each having an area of 640 ft². The total number of equivalent standard buildings is

$$\frac{(20 \times 32)60 + 14900 + 30000}{640} = 130 \text{ buildings .}$$

From firsthand inspection, we concluded that the "average" building in Kiana is a single-story frame structure with a raised floor and subfloor. Virtually every structure has a pitched roof. For the purposes of this study, we assume that 7 percent of the exterior wall surface of the "average" building is occupied by windows; and that all ceilings are 10 ft above the floor. For computational convenience, the "average" Kiana building will be modeled as having four exterior walls, each of which is 25 ft, 3.6 in. long. Properties of the "average" Kiana building are described below.

Walls. Each wall is 25 ft, 3.6 in. x 10 ft = 253 ft². Of the total, 7 percent is window area or 17.71 ft²; the balance of the wall area, 235.29 ft², is modeled as follows:

T_o = outside
temp
= (-35°F) for Kiana

T_i = inside
temp = 75°F

The resistances for the laminated wall are listed below.

Location	Resistance
1. Outside surface (15-mph wind assumed)	0.17
2. Wood siding, 1/2-in. x 8-in. lapped (average)	0.81
3. Plywood sheeting, 1/2-in.	0.64
4. R-9 insulation	9.00
5. Gypsum wallboard, 1/2-in.	0.45
6. Inside surface (still air)	<u>0.68</u>
Total Resistance	11.75

$$\text{Then, } U_{\text{wall}} = \frac{1}{R} = 0.0851 \frac{\text{Btu}}{\text{hr ft}^2 \text{ } ^\circ\text{F}}$$

Windows. From *ASHRAE* (Chap. 20, Table 8) for a double-paned window:

$$U_{\text{window}} = 0.58 \frac{\text{Btu}}{\text{hr ft}^2 \text{ } ^\circ\text{F}}$$

Pitched Roofs. (45° pitch assumed):

$$\text{Area of roof} = 905.22 \text{ ft}^2$$

$$T_o = -35^\circ\text{F}$$

For the purposes of this heat-transfer estimate, we combine the insulation on the ceiling and the laminated roof into one series of thermal resistances that are treated at the roof. We assume an attic temperature of 85°F. The resistances for the laminated pitched roofs are:

Location	Resistance
1. Outside surface (15-mph wind assumed)	0.17
2. Asphalt shingle roofing	0.44
3. Building paper	0.06
4. Plywood deck, 1/2-in.	0.64
5. R-9 insulation	9.00
6. Gypsum wallboard, 1/2-in.	0.45
7. Inside surface (still air)	<u>0.62</u>
Total Resistance	11.38

$$\text{Then, } U_{\text{roof}} = \frac{1}{R} = 0.0879.$$

Frame Flooring. 640 ft², flat area:

$$T_1 = 75^\circ\text{F}$$

$$T_0 = -35^\circ\text{F}$$

The resistances for the laminated floors are then,

Location	Resistance
1. Top surface (still air)	0.61
2. Linoleum	0.05
3. Plywood, 5/8-in.	0.78
4. R-9 insulation	9.00
5. Wood subfloor, 3/4-in.	0.94
6. Bottom surface (still air)	<u>0.61</u>
Total Resistance	11.99

Then, $U_{\text{floor}} = \frac{1}{R} = 0.0834$.

Doors. We assume that the "average" building has two 30-in. x 80-in. doors totalling 33.33 ft², with a $U_{\text{DOOR}} = 0.49$ (see *ASHRAE Fundamentals*, Chap. 20, Table 9).

The heat loss for the average Kiana building is

$$Q' = \sum_{i=1}^5 q_i = \sum_{i=1}^5 A_i U_i \Delta T_i$$

The values for A_i , U_i , and ΔT_i are summarized below.

i	Heat-Transfer Surface	$A_i (\text{ft}^2)$	$U_i \frac{\text{Btu}}{\text{hr ft}^2 \text{ } ^\circ\text{F}}$	$\Delta T_i (^\circ\text{F})$
1	Walls	941.16	0.0851	$75 - (-35) = 110$
2	Windows	70.84	0.58	$75 - (-35) = 110$
3	Pitched roofs	905.22	0.0879	$85 - (-35) = 120$
4	Frame flooring	640.00	0.0834	$75 - (-35) = 110$
5	Doors	33.33	0.49	$75 - (-35) = 110$

Then, $Q' = 30,545.90 \frac{\text{Btu}}{\text{hr}}$.

Heat Loss from Infiltration. We estimate that the average building in Kiana is fairly new and probably of slightly better construction than the houses in Nome. An infiltration factor of 0.90 is chosen because of the construction. The volume in the average Kiana building = 6400 ft^3 , excluding the attic. The heat loss from infiltration is, from *ASHRAE Fundamentals*, Chap. 20, Table 7:

$$(0.90)(6400) = 5760 \frac{\text{Btu}}{\text{hr}} = Q'' .$$

The total heat loss, Q , equals

$$Q' + Q'' = 30545.90 + 5760 = 36305.90 \frac{\text{Btu}}{\text{hr}} .$$

For 130 equivalent buildings, heat loss is

$$(130) \left(36305.90 \frac{\text{Btu}}{\text{hr}} \right) \left(\frac{\text{hr}}{60 \text{ min}} \right) = 78662.78 \frac{\text{Btu}}{\text{min}}$$

$$= \frac{(78662.78)(17.57)}{10^6} = 1.382 \text{ MW}_{\text{THERMAL}}$$

Heat Loss in Kiana Distribution Piping

$$\begin{array}{lll} D_2 = 3" & t_1 = 180^\circ\text{F} & k_{2,3} = 0.217 \frac{\text{Btu}}{\text{hr ft}^\circ\text{F}} \\ D_4 = 7" & T_5 = -35^\circ\text{F} & k_{3,4} = 0.0133 \frac{\text{Btu}}{\text{hr ft}^\circ\text{F}} \end{array}$$

For water at $t = 180^\circ\text{F}$,

$$\rho = 60.57 \frac{\text{Lbm}}{\text{ft}^3} \quad k = 0.389 \frac{\text{Btu}}{\text{hr ft}^\circ\text{F}}$$

$$\mu = 0.84 \frac{\text{Lbm}}{\text{ft hr}} \quad N_{\text{PR}} = 2.16,$$

flowing 85 gpm through each of two 3" headers $\Rightarrow V = 3.69 \frac{\text{ft}}{\text{sec}}$

$$\therefore N_{\text{Re}_D} = \frac{VD\rho}{\mu} = \frac{3.69(\frac{1}{4})60.57(3600)}{0.84} = 2.39 \times 10^5.$$

Therefore, the flow is turbulent with the water being cooled, $\Rightarrow n = 0.3$.

From McAdams,

$$\begin{aligned}
 N_{NU_D} &= 0.023(N_{Re_D})^{0.8}(N_{PR})^{0.3} \\
 &= 0.023[2.39 \times 10^5]^{0.8}[2.16]^{0.3} = 5.83 \times 10^2.
 \end{aligned}$$

Then

$$\begin{aligned}
 h_{1,2} &= \frac{N_{NU_D} k}{D} = \frac{(5.82 \times 10^2)(3.89 \times 10^{-1})}{2.5 \times 10^{-1}} = 9.06 \times 10^2 \\
 &= h_{1,2}.
 \end{aligned}$$

It is assumed that the outside film coefficient, $h_{4,5}$, is 1.0 Btu/hr ft²°F (assuming still air near the pipe). The overall heat transfer coefficient is then

$$\begin{aligned}
 U_4 &= \frac{1}{\frac{r_4}{r_2 h_{1,2}} + \frac{r_4 \ln \left(\frac{r_3}{r_2} \right)}{k_{2,3}} + \frac{r_4 \ln \left(\frac{r_4}{r_3} \right)}{k_{3,4}} + \frac{1}{h_{4,5}}} \\
 &= \frac{1}{2.58 \times 10^{-3} + 1.07 \times 10^{-1} + 16.83 + 1.0} = 5.574 \times 10^{-2}.
 \end{aligned}$$

The dominant terms in U are the resistance due to the insulation and the outside film coefficient.

The overall heat transfer equation and surface heat flux can be equated to yield:

$$h_{4,5}(t_4 - t_5) = U_4(t_1 - t_5) \quad .$$

Solving for t_4 :

$$t_4 = \frac{5.57 \times 10^{-2}(180 - (-35)) + 1.0(-35)}{1}$$

$$t_4 = 0.23^\circ\text{F} \quad \Delta t = 35.23^\circ\text{F}$$

$$t_m = -17.38^\circ\text{F}$$

For air at -35°F :

$$\rho = 0.09344 \frac{\text{Lbm}}{\text{ft}^3}$$

$$k = 0.01220 \frac{\text{Btu}}{\text{hr ft}^\circ\text{F}}$$

$$\mu = 0.03694 \frac{\text{Lbm}}{\text{ft hr}}$$

$$N_{PR} = 0.727$$

$$\beta = \frac{1}{425^\circ\text{R}}$$

Then, computing the Grashof number

$$N_{GR_D} = \frac{D^3 \rho^2 g \beta \Delta t}{\mu^2}$$

$$= \frac{(0.583)^3 (0.09344)^2 (32.2) (3600)^2 (35.23)}{(0.03694)^2 425}$$

$$= 4.386 \times 10^7$$

$$(N_{GR_D})(N_{PR}) = (4.386 \times 10^7)(0.727) = 3.189 \times 10^7 .$$

For a horizontal cylinder:

$$N_{NU_D} = 0.525(N_{GR_D} N_{PR})^{0.25}$$

$$= 39.45$$

$$\Rightarrow h_{4,5} = \frac{39.45(0.0122)}{0.583} = 0.826 .$$

The computed value of $h_{4,5}$ agrees with the assumed value within 17.4 percent, and is slightly overestimated. Therefore, the value of U_4 is adequate and will be used to determine overall heat loss.

$$\frac{q}{L} = \left(\frac{A_4}{L} \right) U_4 (t_1 - t_5)$$

$$= 21.96 \frac{\text{Btu}}{\text{hr ft}} .$$

Since total pipe length in Kiana is estimated to be 14,400 ft, total heat loss from piping due to conduction and convection is

$$(21.96)(14400) = 3.16 \times 10^5 \frac{\text{Btu}}{\text{hr}} = 5.27 \times 10^3 \frac{\text{Btu}}{\text{min}} ,$$

$$\frac{\left(5.27 \times 10^3 \frac{\text{Btu}}{\text{min}} \right) \left(17.57 \frac{\text{watt}}{\text{Btu}} \right)}{10^6 \text{ watt}} \text{ MW} = 0.093 \text{ MW} .$$

Heat losses for Kiana are summarized below.

Item	Loss (MW)	
Kiana buildings - Method 1	0.7035	
Kiana buildings - Method 2		1.38
Piping distribution in Kiana	<u>0.093</u>	<u>0.093</u>
Total Geothermal Power Required	0.796	1.473

For system sizing and cost estimating purposes, we use a design load of 1.4 MW.

Load calculations for the six towns are calculated below.

Town	MW Power	Hot Side $\Delta T(^{\circ}F)$	Hot Side Flow Rate	Cold Side $\Delta T(^{\circ}F)$	Cold Side Flow Rate
Barrow	21.0	250-140	6.52×10^5 Lbm/hr	180-122	1.24×10^6 Lbm/hr
Huslia	1.0	150-140	3.40×10^5 Lbm/hr	148-120	1.22×10^5 Lbm/hr
Kiana	1.4	200-140	1.33×10^3 Lbm/hr	180-122	8.24×10^4 Lbm/hr
Nikolski	0.24	161-140	3.90×10^4 Lbm/hr	151-122	2.83×10^4 Lbm/hr
Nome	16.4	250-140	5.09×10^5 Lbm/hr	180-122	1.61×10^4 Lbm/hr
Wrangell	8.0	250-140	2.48×10^5 Lbm/hr	180-122	4.71×10^5 Lbm/hr

Appendix E

ALASKA DRILLING COSTS

Information obtained to date indicates that amortized well costs will dominate the total annual cost of normal-gradient geothermal systems to a much greater extent in Alaska than in the contiguous United States. A discussion of these costs, with a breakdown of incident costs, follows.

COST RANGE OF PETROLEUM WELLS IN ALASKA

Cost figures were obtained from the petroleum industry and from private drilling contractors in Alaska as part of independent studies by Dr. Robert Forbes and the authors of this report. Sources of information are cited where permissible; but several of our sources requested to remain unnamed because their information is proprietary. This approach provides a broader information base and a means for checking the validity of the numbers. Well costs obtained independently by Dr. Forbes and the authors are in accord and up to 10 times the cost of petroleum wells in the "lower 48." The drilling costs outlined herein are based on remoteness of site, Alaska labor and materials differentials, and geological information.

Drilling deep holes in Alaska is very expensive; in fact, disproportionately expensive, when compared to the Alaska cost differential for other services. For example, a 10,000-ft well recently drilled at Beaver Creek on the Kenai Peninsula cost \$8,000,000. And that project is a good example of the lower end of the cost continuum, as Kenai Peninsula logistics are relatively simple compared with more remote sites. A 14,000-ft hole drilled at Cathedral River on the Alaska

Peninsula cost \$10,000,000; and more recently, a dry hole drilled at an offshore site in the Gulf of Alaska cost \$15,000,000. One of our sources suggests \$1,000,000/1,000 ft of drill hole as a working estimate. In Alaska, as elsewhere, cost is seen to increase with depth of drilling. Figure 1E shows well cost as a function of depth for some recent petroleum wells.

COST BREAKDOWN

Daily Rates

Daily operating costs are quite high in Alaska. At current rates, it costs about \$40,000 to \$60,000/day to operate a large drill rig after it is on site. This figure is a daily rate that *does not include* the following:

1. Mobilization and demobilization;
2. Site preparation, including roads, airstrips, and campsite;
3. Casing;
4. Logging and testing (wire-line services);
5. Fuel;
6. Standby or yard time on the drill rig, after it is committed and before it is moved to the site.

The daily rate will vary depending on the remoteness of the site, number of people in the camp, and whether the hole progresses at a normal rate without complications (jammed drill strings, etc.) requiring delays and the services of specialty crews that must be brought in to the site. Daily rates comprise drilling contractor's fees for

Fig. 1E--Well cost as a function of depth for recently drilled petroleum well in Alaska

rig time, bits and drilling materials, personnel and crews, and transportation of workers to Anchorage or another home base for one-week-on/one-week-off work periods (with 12-hr daily shifts).

Based on rock types and formations at the six sites, we estimate that drilling times will range from 80 to 100 days if no major difficulties are encountered. Estimates of the minimum number of days of drilling at each site, along with site-specific mobilization and demobilization costs, will allow us to approximate the drilling costs for each location in the final report.

Mobilization and Demobilization

The cost of drilling in Alaska varies greatly with the location of the well. Mobilization costs include transportation of rigs and other drilling equipment, steel casings, cement, drilling fluids, fuel, and materials for support facilities. (Demobilization, costing about 70 percent of mobilization for petroleum drilling operations, includes mandatory cleaning up and revegetation of the site, where necessary, in addition to removing rigs, etc.) Such costs, which are much greater than in the lower 48 states, are a contributing factor to the high cost of drilling in Alaska.

To drill a well at a remote Alaskan location, it is necessary to barge or fly in equipment. All six study sites are accessible by barge (usually originating in Seattle or California). Barge rates for shipping drilling equipment are substantially lower than air transport, but often far less convenient. Shipping to those locations lacking deep-sea ports, for example, involves additional lighterage fees.

Rig time is less costly while in transit than when in operation, but cost of downtime must be considered for the time that equipment is on the barges. Scheduling must be done well in advance of the anticipated drilling season and is limited to the short summer, during which the major rivers are navigable (for Huslia and Kiana), and when the ice pack is open (Nome and Barrow). Conversely, land transportation of construction and drilling equipment where no roads exist is best accomplished during winter months (when the tundra is frozen).

Air transportation is usually accomplished with Hercules cargo aircraft having a 45,000-lb capacity. These aircraft require a 5000-ft airstrip for landing and take-off under full load. All six sites, except Huslia, have acceptable airstrips. (The airstrip at Huslia, only 3000-ft long, would need lengthening to make it suitable for "Heracs.")

Since drill sites for this study are assumed to be chosen on the bases of nearness to the center of population, geological considerations, land use and availability, accessibility via roads, and proximity to the airstrip or dock, road-building costs are not a major mobilization consideration.

Although the direct cost of air mobilization averages \$1,000,000 for the six study sites and direct barge costs are only half this figure, the additional difficulties of barging make air transportation less expensive and the mode of choice for Nome, Barrow, Kiana, and Nikolski. Wrangell has good port facilities and is easily accessible by barge from Seattle. Huslia's airstrip could be improved without great cost should barging logistics prove difficult.

J. H. McKeever, Amoco Production Company, Anchorage, has supplied the following rough cost estimates for a project involving an 8,000- to 10,000-ft hole to be drilled on the Seward Peninsula, including the various phases of work that might be required at a remote site:

Drilling	\$1,500,000
Standby	500,000
Mobilization and Demobilization	
Barge	2,000,000
Air (Hercules)	1,500,000
Dirt Work	
Winter	1,500,000
All weather	3,000,000
Airstrip (Hercules) if necessary	1,500,000
Casing	500,000
Logging and Testing	500,000
Fuel	1,000,000

Mr. McKeever also notes that daily costs had risen to \$65,000 in 1977 on one Amoco well in Alaska.

If two holes are drilled at one site, the total cost will of course be reduced about 25 percent by the simplified logistics of the second hole; but there will be costs associated with moving the rig to the second site, and the \$40,000-\$60,000/day rate will still apply.

Note that the above cost estimates do not include the wellhead and downhole hardware that would be required in a completed geothermal well. One of our sources has cited \$1,000,000 as the cost of casing and wellhead hardware for a 10,000-ft hole. Two sources agreed that drill rigs could not be brought into Nome and evacuated for less than \$1,000,000.

Availability of Drill Rigs

Drilling rigs must be of the sort that can be broken down to fit into a "Herc" or onto a barge. About three or four suitable drill rigs are available in Alaska for contract drilling. One is in Fairbanks; the others, in Kenai. Drill rigs have to be requisitioned a long time in advance; and once the rig is committed, the user pays about \$1000/day standby time. This fee is also charged during transit time to the site. Alternative possibilities include moving drill rigs down from Barrow or north from California. One means of decreasing the cost of drilling is to engage a rig that is already in the area and thus cut mobilization costs.

The relative cost of drilling geothermal wells in the six Alaskan towns and villages will of course be related to accessibility and geotechnical requirements. Logistically, the sites with nearby airports and/or port facilities will be the least expensive. For example, rigs could be flown directly from Kenai to Nome, Barrow, and Kiana; but would probably be barged to Huslia. The decision on barging versus airlift for Nikolski would have to be based on comparative cost estimates. For Wrangell, it would probably be less expensive to transport a rig via barge from California than to relocate an Alaskan rig.

The Nome Model

We assume that a well can be drilled a short distance from the Nome airport and that the drill rig will be flown in by Hercules aircraft from Kenai. The crews may be housed and fed in Nome, obviating the construction of a large camp. Two 10,000-ft holes are to be drilled and cased, one-quarter mile apart, with the usual logging and testing services. Estimated costs are as follows:

Airlift of rig from Kenai to Nome, and mobilization on site No. 1	\$ 500,000
60 days drilling time @ \$40,000/day	2,400,000
Casing	500,000
Logging and testing	500,000
Fuel	500,000
Moving of rig to site No. 2	500,000
60 days drilling time @ \$40,000/day	2,400,000
Casing	500,000
Logging and testing	500,000
Demobilization of rig and transport back to Kenai	<u>500,000</u>
Total cost for two holes	\$9,310,000
Subtotal for one hole	\$5,400,000

This cost model utilizes minimum incident costs and is a very conservative estimate when compared with the actual well costs discussed above. \$5,400,000 may be considered the bottom-line cost for a 10,000-ft well at Nome.

Relative Costs at Other Sites

At Wrangell, costs would be 20-percent less than those at Nome; and more at Huslia, Barrow, and Kiana. Nikolski costs would probably be about the same as those at Nome.

Holes drilled in soft sedimentary rather than harder metamorphic rocks would proceed at more rapid drilling rates, and (without complications) would require less rig time. For example, two years ago the Nimiuk Point No.-1 well near Kotzebue was drilled to 6311 ft and abandoned in 53 days. However, most holes in harder rocks will require more time. Therefore, the 60-day estimate used in the above cost breakdown is quite optimistic.

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